ME 8491 -ENGINEERING MATERIALS AND METALLURGY

UNIT- III

FERROUS AND NON-FERROUS METALS

Effect of alloying additions on steel- α and β stabilisers– stainless and tool steels – HSLA, Maraging steels – Cast Iron - Grey, white, malleable, spheroidal – alloy cast irons, Copper and copper alloys – Brass, Bronze and Cupronickel – Aluminium and Al-Cu – precipitation strengthening treatment – Bearing alloys, Mg-alloys, Ni-based super alloys and Titanium alloys.

TWO MARKS:

1. Compare the marten site that is formed in maraging steels with the martensite that is formed in carbon steels.[may/june2006]

The composition of maraging steel develops martensite upon cooling (usually by air quenching) form the austenitizing temperature. The martensite formed in these steels, unlike the martensite of other carbon steels, is ductile and tough. The ductility and toughness of this martensite result from its very low carbon content.

2. What is the main strengthening mechanism in high strength aluminium alloys?[may/june2006]

Precipitation strengthening treatment, also known as age hardening, is the main strength mechanism in high strength aluminium alloys.

3. What are the effect of chromium and molybdenum in low alloy steels? [Nov/dec2006] [May/June2013]

The effects of chromium in low alloy steels are to:
* increase corrosion and oxidation resistance.
*increase hardenability.
* increase high temperature strength.
* resist abrasion and wear.
The effects of molybdenum in low alloy steels are to:
*improve high temperature creep resistance.
*increase hardenability.
* stabilize carbides.

4. What is the purpose of magnesium treatment in producing S.G iron? [Nov/dec2006]

The spheroidal cast iron is produced by adding magnesium to molten cast iron. The magnesium converts the graphite of cast iron from flake from into spheroidal or nodular form. The presence of spheroidal graphite improves the ductility strength, fracture toughness, and other mechanical properties.

5. Distinguish between grey cast irons and spheoridal graphite cast irons in terms of microstructures and mechanical properties. [May/june2007]

Grey cast iron: the microstructure of grey cast iron consists of graphite flakes, as shown in fig 3.5,section 3.17.2 chapter 3 in our text book.

*grey cast iron possesses excellent compressive strengths. it also has good torsional and shear strengths, and good corrosion resistance.

Spheroidal graphite cast iron:

The sg cast iron has excellent ductility, tensile and yield strengths than grey and malleable cast irons. It has good toughness, good fatigue and impact strength.

6. What is the composition of 18/4/1 type high speed steel?[may/june2007]

The 18/4/1 high speed steel contains 18% tungsten,4% chromium, and 1% vanadium.

7. List different types of tools steels. [Nov/dec2007]

1. Cold work tool steels 2.shock resisting tool steels
3. Hot work tool steels 4.high speed tool steels
5. Plastic mould tool steels 6.special purpose tool steels

8. Mention any two aluminium base alloys and their applications. [Nov/dec2007]

1. Duralumin:a)used for aircraft and automobile industries.
b) For making electric cables, in surgical and orthopaedic implements.
2) y-alloy: used for making pistons of engines, cylinder heads, gear boxes, propeller blades, etc.

9. How does silicon addition influence the properties of steel? [Apr/may2008]

The effects of silicon addition in steels are:
*silicon acts as a general purpose deoxidiser.
*silicon improves electrical and magnetic properties.
*silicon improves oxidation resistance.
*silicon strengthens low alloy steels.

10. Write short notes on the types of stainless steels. [May/june2009]

1. Austenite stainless steels: they have the austenite structure retained at room temperature.
2. Ferrite stainless steels: they have ferritic in structure at all temperatures upto their melting points.
3. Martensitic stainless steels.

11. With composition, property and application explain? [May/june2009]

a) Tin bronze b) naval brass

Alloy name	Composition(wt%)	Properties	Typical applications
1.tin bronze (bell bronze)	78 cu,22 sn	*hard and brittle *possesses resonance	*for making bells, coins, medals, etc.
2.naval brass	59 cu,40 zn,1 sn	*can be forged and extruded *corrosion resistant	*for marine and engineering structural uses.

12) Name the alloying elements in high speed steel.

Tungsten, chromium, and vanadium.

13) State the applications of tool steel.

a) The tool steels are used in the following applications. General tool and die applications in which resistance to distortion or cracking is needed.
b) Die work, including blanking, drawing thread rolling as well as gases, rolls for following sheet metal, etc.
c) Pneumatic tools, hand chisels, cold cutters, punches, heavy duty shear blades.
d)general purpose steel for tools operating at high cutting speeds, such as drills,reamers,broaches,milling cutters,hobs,saws,etc.
e) Tools for hot forging machines, hot trimming tools, hot blanking and extrusion dies, etc.

14) What are the effects of adding sic in steels?

a) Acts as a general purpose deoxidizer.
b) Improves electrical and magnetic properties.
c) Improves oxidation resistance.
d) Strengthens low alloy steels.
e) Increases hardenability of steels carrying non-graphitizing elements.

15) Differentiate brass from bronze.

*BRASS is an alloy of copper and zinc.

*BRONZE is an alloy of copper and tin.

16) What will be the effects, if the following elements alloyed with steels?

a) Phosphorous; b) sulphur.
*phosphorus is usually added with sulphur to improve machinability in low alloy steels.phosphorus, in small amounts, aids strength and corrosion resistance.
*when sulphur is added in small amounts with steel, it improves machinability but does not cause hot shortness.

17) Write down the composition and any one application of the following alloys: (April / May 2010)

a)duralumin; b)brass
a)DURALUMIN: composition 94 Al, Cu,0.5 Mg,0.5 Mn,0.5 si,0.5 fe.
Properties: it is an wrought alloy; possesses maximum strength after age hardening; high strength-to weight ratio.
b) BRASS: brass is an alloy of copper and zinc.
Properties: they are stronger; they have lower thermal and electrical conductivity; they can be cast into moulds.

18) What is inoculation?

Inoculation is nothing but grain refinement when a metal casting freezes, impurities in the melt and walls of the mould in which solidification occurs serve as heterogeneous nucleation sites. Sometimes we intentionally introduce nucleating particles into the liquid. Such practices are called grain refinement or inoculation.

19) What is precipitation hardening?

Precipitation hardening, also known as age hardening, is the method of improving the physical properties of some of the non-ferrous alloys by solid state reaction.

20) Name the typical properties and applications of high-strength low-alloy steels.

*the primary purpose of HSLA steels is weight reduction through increased strength.

*these HSLA steels are widely used as structural or constructional alloy steels.

21) Specify the % of carbon content in (a) gray CI and (b) white CI.

a) Grey CI-carbon 2.5 to 4%

b) White CI-carbon 1.8 to 3%

22) Name some of the common uses of brass alloy.

Typical applications include imitation jewellery; decorative work; making coins,madals,fuse caps; for press-work; cold forming; radiator cores; for extruding rods and tubes; etc.

23) How do you enhance the mechanical strength of aluminium?

By alloying aluminium with one or more alloying elements such as Cu,Mg,Mn,Si and Ni.

24) What is the structure difference between white cast iron and grey cast iron?

*white cast iron derives its name from the fact that its fracture surface has a white or silvery appearance.

*the microstructure of grey cast iron consists of graphite flakers, which resemble a number of potato crisps glued together at a single location.

25) Name any two precipitation hardenable alloys.

1. aluminium-copper alloy

2. copper-beryllium alloy

26) Write the effect of "Cr" as alloying element on steel. [may/june2013]

a) Cr increases corrosion and oxidation resistance.
b) It increases hardenability.
c) It increases high-temperature strength.
d) It resists abrasion and wear.

27) Give the composition of the following non-ferrous alloys.

a) Gunmetal; b) Babbit metal.
a)composition of gunmetal: 88% Cu,10% Sn,2% Zn,2% Ni.
b) Composition of baddit metal: 82% Sn,10% Sb,Cu 4%,Pb 4%.

28) What is the alloying nickel and chromium in steels? Effect of alloying nickel:

*increases hardenability.
*improves resistance to fatigue.
Effect of alloying chromium:
*increases corrosion and oxidation resistance.
*increases hardenability.
*increases high-temperature strength.

29) Differentiate between precipitation hardening and dispersion strengthening.

*precipitation hardening is the most important method of improving the physical properties of some of the non-ferrous alloys by solid state reaction.

*dispersion strengthening is the reduction of plastic deformation of a solid by the presence of a uniform dispersion of another substance which inhibits the motion of plastic dislocations.

30) Discuss about the grey cast iron.

Typical composition of grey cast iron is given below:
Carbon – 2.5 to 4%
Silicon – 1 to 3%
Manganese – 0.4 to 1%
Phosphorus -0.15 to 1%
Sulphur -0.02 to 0.15%

31) What is bearing alloys?

Bearing alloys are the materials used for making bearings. The widely used bearing materials are white metals, copper-base alloys, aluminium-base alloys, etc.

32) What are bronze? List some uses of bronze. [may/june2013]

BRONZE is an alloy of copper and tin.
Uses:
For making bells, coins, medals, etc.

16 MARKS

1. Discuss the Characteristics of copper and also mention its alloys their properties and uses. **(Nov/Dec 2006, 2007) (Nov/Dec 2010) (May/June 2013)**

Copper alloys:

- ❖ Copper may be alloyed with a number of elements to provide a range of useful alloys.
- ❖ The copper alloys possess a number of unique superior characteristics: high thermal and electrical conductivity, high corrosion resistance, high ductility and formability, and interesting colour for architectural uses.

The important copper alloys are:

1. Brasses(copper-zinc alloys)
2. Bronzes (copper-tin-zinc-alloys)
3. Gun-metals(copper-tin-alloys),and

4. Cupro- nickels(copper-nickel alloys)

- Other alloying of beryllium or chromium to copper gives high-strength alloys.
- A small addition of cadmium gives a significant increase in strength with little loss of electrical conductivity.
- An addition of tellurium to copper gives an alloy with very good machinability.

1. Brasses:

- Brass is an alloy of copper and zinc. Sometimes, small amounts of other metals such as tin, lead, aluminium, and manganese may be added.
- Up to 36% zinc, brass is a single phase solid solution identified as the α phase and these alloys are called α brasses.
- α brasses are relatively soft, ductile, and easily cold worked.
- Brasses having more than 36% zinc have a two phase-α and β phases-at room temperature. These brasses are harder and stronger than the α brasses.

Characteristics of brasses:

- Brasses are stronger than copper.
- Brasses have lower thermal and electrical conductivity than copper.
- They can be cast into moulds, drawn into wires, rolled into sheets, and turned tubes.
- Very often 1 to 3% of lead is added to brass for improving its machining properties.
- The colour of brasses range from reddish colour to nearly white depending on the amount of zinc present.

Types of brasses:

There are various types of brasses, depending upon the properties of copper and zinc. The table presents composition, properties, and applications of some commonly used brasses.

S.NO	ALLOY NAME	COMPOSITION (WT %)	PROPERTIES	TYPICAL APPLICATIONS
1.	Gliding metal(or commercial bronze)	90 cu, 10 zn	*Gold-like colour. *Good ductility. *Ability to be brazed and enabled.	*Imitation jewellery. *Decorative work. *Making coins, metals, fuse caps.
2	Cartridge brass	70 cu, 30 zn	*High strength *Excellent ductility	* For deep-drawing. *Manufacturing cartridges and shell cases.
3.	Standard brass(or cold working	65 cu, 35 zn	*General purpose cold-working alloy.	*For press-work, cold forming,

	brass)		*High strength.	radiator cores, springs, screws, rivets, tubes, etc.
4.	Muntz metal(or yellow metal)	60 cu, 40 zn	*Can be hot-rolled, and extruded.	*For extruding rods and tubes. *For making condenser and heat exchanger plates.
5.	Naval brass	59 cu,40 zn,1 sn(i.e.1% tin+Muntz metal)	*Can be forged and extruded. *Corrosion resistant.	*For marine and engineering structural uses.
6.	Admiralty brass	70 cu, 29 zn, 1 sn (i.e, 1% tin+cartridge brass)	*Corrosion resistant.	*For making tubes and some parts of condensers, pump impellers.
7.	High tensile brass(or manganese brass)	35 zn,2 Mn, 2 Al, 2 fe, balance cu.	*High tensile strength. *Can be cast, hot worked.	*For pump-rods, stampings and pressings. *As marine castings such as propellers, water-turbine runners, rudders, etc.
8.	Free cutting brass(or leaded brass)	59 cu, 39 zn, 2 pb	*Heat resistant. *Excellent strength.	*Suitable for high-speed machining.
1.	Bell bronze	78 cu, 22sn	*Hard and brittle. *Possesses resonance.	*For making bells.
2.	Phosphor bronze	88 cu, 10 sn, 0.3 p, 1 zn, pb 0.7	*When bronze contains phosphorus it is called phosphor bronze. *Phosphor increases the strength, ductility, and quality of castings. *Possesses high corrosion resistance.	*For bearings , worm wheels, gears, nuts for machine lead screws, pump parts, linings, springs, etc.
3.	silicon bronze	95 cu, 3 si, 1 mn, 1 fe.	*Effect of silicon is to strengthen, harden, and improve corrosion resistance. *Can be cast, rolled, forged, and pressed hot or cold.	*For bearings, boiler parts, marine hardware's, roll mill sleepers, die cast parts, etc.
4.	Aluminium bronze	89 cu, 7 al, 3.5 fe, 0.35 sn	*Iron is added to aluminium bronzes to	*For making gears,

			increase the strength and hardness. *High corrosion resistance. *Good cold working properties.	propellers, condenser bolts, pump components, tubes, air pumps, slide valves, buses, cams, rollers, etc.
5.	Coinage bronze	95.5 cu, 3 sn, 1.5 zn.	*Good strength and corrosion resistant.	*For making copper coins.
6.	Leaded bronze	.75 cu, 5 sn, 18 pb, 2 ni.	*Can carry greater loads. *Can work at higher speeds because of its quick heat dissipation	*Used as bearings alloys.

2. Bronzes:

- Bronze is an alloy of copper and tin.
- The bronzes are high-strength alloys with a good corrosion resistance than brasses.
- The strength of the bronze increases with increase in tin content. However, tin content is kept below 12% because they tend to be brittle.
- Bronze can be shaped or rolled into wires, rods, and sheets.

3. Gun metals:

- Gun metals are alloys of copper, tin, and zinc.
- The zinc acts as a deoxidiser and it also improves fluidity during casting.
- A small amount of lead may be added to improve cast ability and machinability.
- Since zinc is considerably cheaper then tin, the total cost of the alloy is reduced.

S.NO	ALLOY NAME	COMPOSITION (WT %)	PROPERTIES	TYPICAL APPLICATIONS
1.	Admiralty gun metal	88 cu,10 sn, 2 zn, 2(max)ni.	*High corrosion resistance. *Good casting properties.	*For pumps valves, statuary, and miscellaneous castings(mainly for marine work)
2.	Leaded gun metal(or red brass)	85 cu,5 sn, 5 zn, 5 pb, 2 ni.	*Good pressure tightness. *High strength.	*For bearings, stream pipe fittings, marine castings, hydraulic, valves and gears etc.

4. Cupronickels:

- Cupronickels are alloys of copper and nickel.
- The metals copper and nickel mix in all properties in the solid state. That is, a copper-nickel alloy of any composition consists of only one phase-a uniform solid solution. Thus all copper nickel alloys are relatively ductile and malleable.
- They have better corrosion resistance than many other copper alloys in sea water.
- They can be hot-worked or cold-worked.
- They can be shaped by rolling, forging, pressing, drawing, and spinning.

Types of cupronickels:

s.no	Alloy name	Composition (wt %)	properties	Typical applications
1.	cupronickel	70 cu,30 ni	*Excellent corrosion resistant. *Can be cast into any forms.	*For salt water piping, condenser tubing, and for bullet envelopes.
2.	monel metal	29 cu, 68 ni, 1.25 fe, 1.25 mn	*Excellent corrosion resistant. *Good mechanical properties.	*For making propellers, pump fittings, condenser tubes, steam turbine blades, sea water exposed parts, tanks, and chemical and food handling plants.
3.	'k' monel	29 cu, 66 ni, 2.75 al, 0.4 mn, 0.6 ti.	*Aheat-treated alloy. *Good mechanical properties.	*Used for motor-boat propeller shafts.

<u>2. Using the A1-Cu alloy system as example, explain the concept of Precipitation heat treatment. Explain the steps involved in precipitation hardening treatment.</u> **(Nov/Dec 2006, 2009) (May/June 2007) (Nov/Dec 2007) (May/June 2009) (April / May 2008) (Nov/Dec 2010) (April / May 2012)**

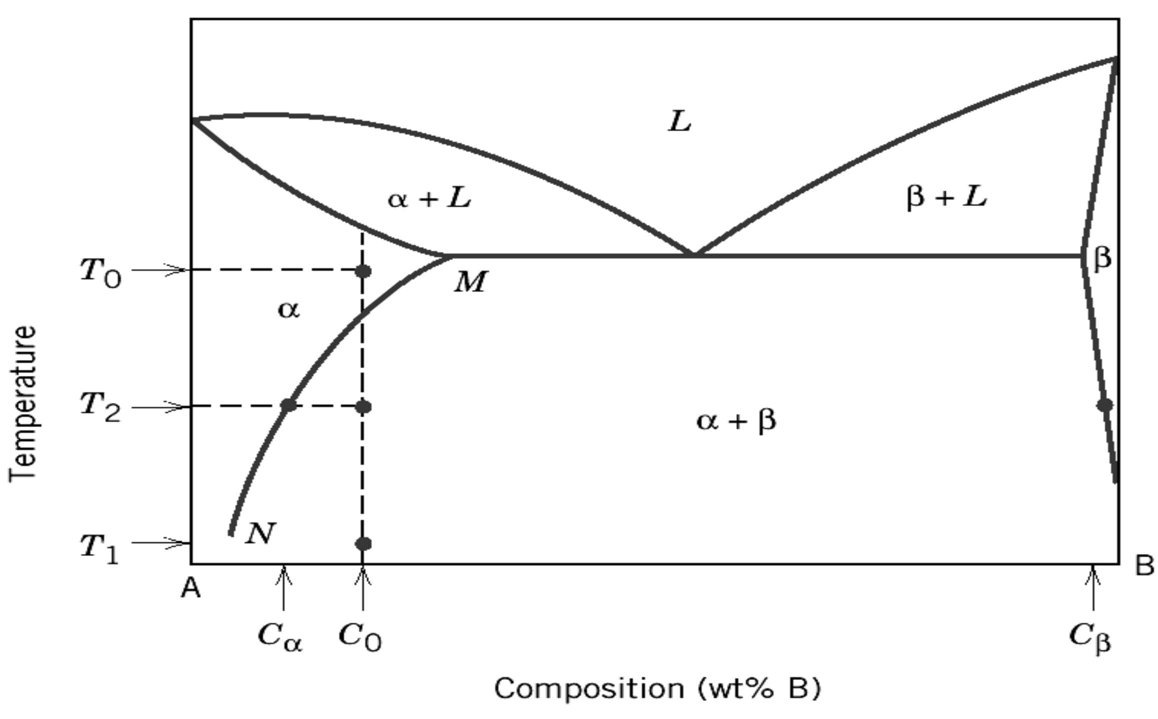
PRECIPITATION STRENGTHENING TREATMENT (AGE HARDENING)

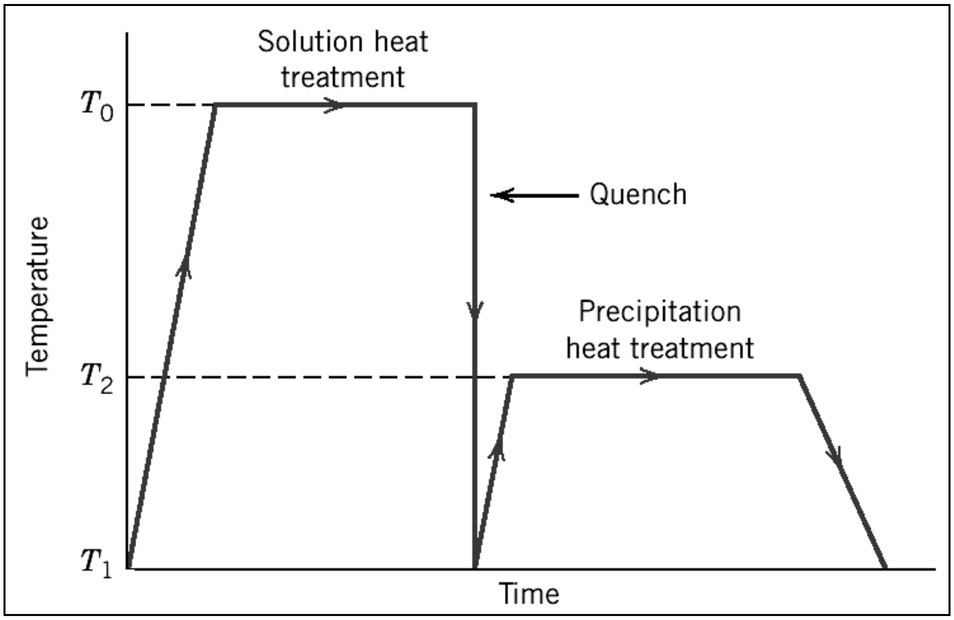
What is precipitation hardening?

- Precipitation hardening, also known as age hardening, is the most important method of improving the physical properties of some of the non-ferrous alloys by solid state reaction.

- ❖ It is mostly applicable to the alloys of aluminium, magnesium and nickel it is occasionally used for the alloys of copper and iron.
- ❖ Examples of alloys that are hardened by precipitation treatments include aluminium-copper, copper-beryllium, copper-tin and magnesium-aluminium.
- ❖ This process is called precipitation hardening because the fine precipitate particles of the new phase are formed on this hardening process.

Alloy name	**Composition (wt %)**	**Properties**	**Typical application**
1.Duralumin	94 al,4 cu, 0.5 mg, 0.5 mn, 0.5 si, 0.5 fe.	*It is a wrought alloy. *Possesses maximum strength age hardening. *High strength-to-weight-ratio.	*For aircraft and automobile industries. *For making electric cables, in surgical and orthopaedic implements or gadgets etc.
2.y-alloy	92.5 al, 4 cu, 2 ni, 1.5 mg.	*It is a cast alloy. *Better strength then duralumin at high temperatures.	*For making pistons of engines, cylinder heads, gear boxes, propeller blades, pistons, etc.

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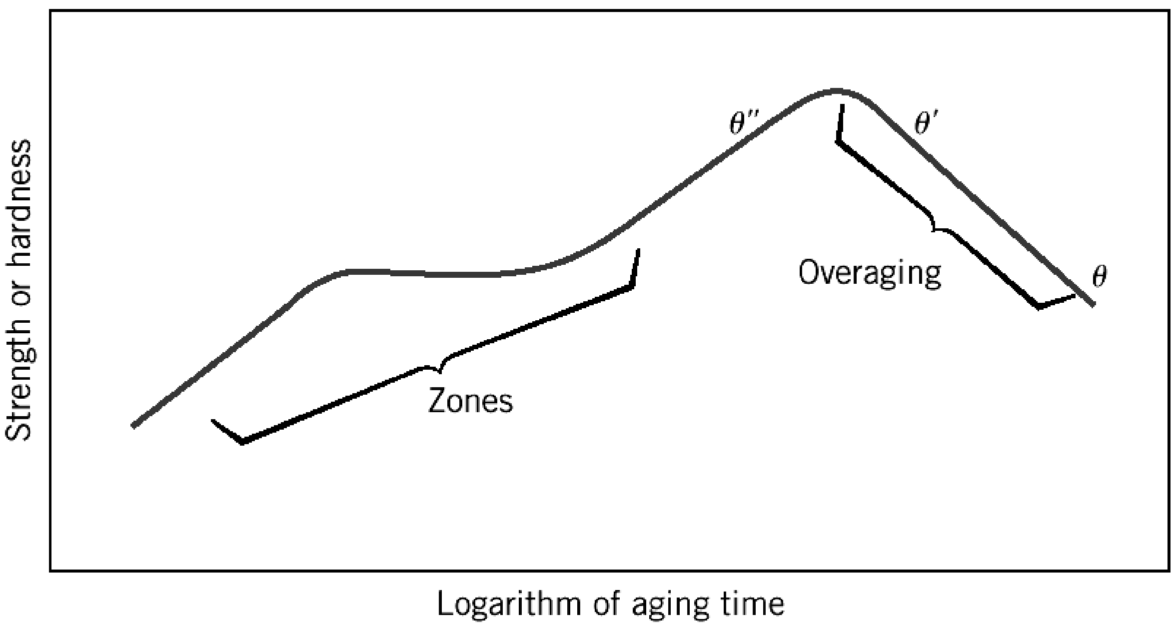
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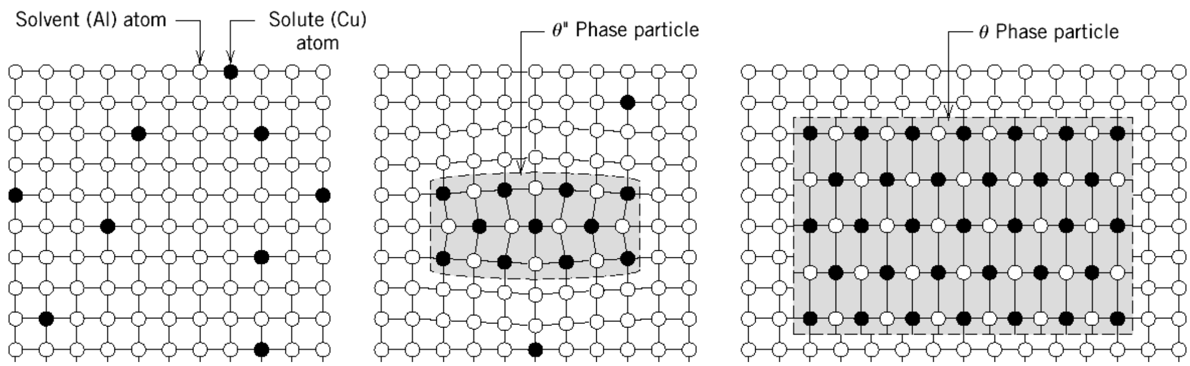

Process of precipitation heat treatment:

The process of precipitation heat treatment consists of three steps. The three step process is explained for an aluminium alloy, say Al-4% cu alloy below.

Step: 1 Solution treatment

- First the alloy is heated above the soleus temperature to obtain its solid solution.
- The alloy is held at this temperature until a homogeneous solid solution αis produced.
- This step dissolves the Ø precipitate and reduces any segregation present in the original alloy.
- As the al 4 % cu alloy is solutions-treated between 500^{o}c and 548^{o}c.

Step: 2 Quenching process:

- After solution treatment, the alloy is quenched i.e. rapidly cooled.
- On this rapid cooling, there is no sufficient time for diffusion of cu atoms to form the precipitate particles. Therefore a supersaturated solution α_{ss} is obtained at room temperature is not a stable structure.

Step: 3 Ageing process:

- Finally, the supersaturated solid solution $\alpha_{ss}$is heated below the solvus temperature.
- At this ageing temperature, the diffusion of unstable α_{ss}may take place and precipitate particles can form.
- Then, if we hold the alloy for a sufficient time at the ageing temperature, the stable α+cuAl_2 struture is produced.
- This fine precipitate particles of cuAl_2increase the hardness and strength of the alloy.

3. What is bearing metal? Give its classification, composition, properties and uses. **(May/June 2009) (Nov/Dec 2009) (Nov/Dec 2010) (April / May 2012) (May/June 2013)**

BEARING MATERIALS:

The widely used bearing materials are:

1. White metals
2. Copper-base alloys
3. Aluminium-base alloys
4. Plastic materials, and
5. Ceramics.

The selection of a particular bearing materials depends upon types of loading, running speed, and service conditions.

1. White bearing metals:

- White bearing metals are either tin-based or lead-based alloys.
- All white bearing metals contain about 10% of antimony (sb). Tin and antimony combines to form an intermetallic compound sbsn. This forms small hard cubic crystals, termed cuboids. These cuboids are hard, and have low-friction properties, which constitutes the necessary bearing surface in white metals.

a) Tin-base bearing alloys

- The tin-base bearing alloys are known as babbit metals, after Isaac babbit, their originator.
- composition: the composition of a typical'babbit' metal is given below:
  Sb 10%, zn 82%, cu 4%, pb 4%.
- The tin-base bearing alloys are of better-quality high-duty bearing metals then the lead-base bearing alloys.
- Uses: they are suitable for use in many medium- and high-duty bearing applications, particularly in the automotive industries.

b) Leads-base bearing alloys:

- The lead-base bearing alloys are cheaper than tin-base bearing alloys.
- composition: the composition of a typical lead-base bearing alloy is given below:
  Sb 13%, sn 12%, cu 0.75%, as 0.25%, pb 74%.
- Uses: they are used for low pressure/low speed bearing applications.

2. Copper-base bearing alloys:

- copper-base bearing alloys include:
  1. Plain tin bronze-cu 85%, sn 15%
  2. Phospher bronzes- cu 88%, sn 10%,p 0.3%, zn 1%, pb 0.7%.
  3. Lead bronzes- cu 75%, sn 5%, pb 18%,ni 2%
  4. Sintered bronzes-cu power 90%, sn powder 10%.

- The phosphor bronzes provide improved load bearing capacity.

- The leaded bronzes are less strong than other bearing bronzes. But they will sustain higher loads at higher speeds than white metals.
- Sintered bronzes are made by compacting and sintering cu-sn powder. They are usually self-lubricated.

Uses:

- Leaded bronzes are used in the manufacture of main bearings in aero –engines, and for automobile and diesel crankshaft bearings.
- Self-lubricating sintered bearings are used widely in the automobile industries and in domestic equipment's such as vacuum cleaners, washing-machines, extractor fans, and audio equipment.

3. Aluminium -base bearing materials:

- Aluminium-base alloys containing tin, copper, and nickel are widely used as bearings materials.
- Now days, more expansive tin-base bearings are replaced by aluminium-base bearings alloys.
- Composition: the composition of a typical al-sn alloy is given below.
  Sn 5.5-7.0%, cu0.7-1.3%,ni 0.7-1.3%, balance is al.
- Uses: they are used as main and big-end bearings in automobile design.

4. Plastic bearing materials:

- The well-known plastic bearings materials are:
  1. Nylons
  2. Poly tetra fluro ethylene
- They have very low coefficients of friction.
- Uses: they are used for low load applications, particularly where oil lubrication is impossible or undesirable.

5. Ceramic bearings materials:

- Ceramic materials are used as bearings in small precision instruments, for example jewel bearings in watch movements.
- Modern industrial ceramics such as alumina are used bearings in large speed precision movements.

<u>4. Discuss the Characteristics of aluminium and also mention its alloys their properties and uses.</u> (April / May 2008) (April / May 2011)

ALUMINIUM ALLOYS:

Aluminium-copper alloys:

In 1906, dr.alfred wilm, a German metallurgist first discovered a heat treatable al-cu alloy and named it as duralumin. The alloy contains al,4% cu,0.5% mg,0.5% si, 0.7%fe and 0.7% mn. During the treatment, the $cual_2$ and $cual_2$ mg precipitates come out and used under the promote the strength and hardness. Today, a number of alloys are used under the general trade name of duralumin. The average composition if these alloys is al, 3-4.5% cu, 0.35-1.5%mg, 0.5%si, 0.5%si,0.5%fe and 0.5-0.6% mn. The tensile strength is 167-314 mpa and hardness is 70-100 hb. These alloys are mainly used for aircraft applications.

Aluminium –magnesium silicide alloys:

These alloys contain small of magnesium and silicon. They are usually present in the required ratio to form magnesium silicide. The alloy most commonly used in structural applications has the composition of 0.7% mg, 1.0% si and 0.6% mn. During age hardening mg_2si precipitation occurs. These alloys have medium strength, good formability, satisfactory corrosion resistance and adequate weldability.

These alloys are used for a wide variety of applications including architectural sections, container bodies railway, bogies etc. they cannot be used where elevated temperature service is required.

Aluminium –zinc alloys:

These alloys contain zinc as the major alloying element and a little of other elements like mg, cu, mn, and cr. The alloys are divided into those containing mn alone and those with mn and cr.

During the treatment, the precipitation hardening phase is mg zn_2. These alloys have the highest strength of all aluminium alloys. Strength in the order of 600 mpa is achieved. They are mainly used in aircraft structural applications in the form of sheet, forging and extrusions.

5. Write a short note on compositions, properties and Applications of the following steel: [may/june2013]

a. Austenitic stainless steel (April / May 2010) (May/June 2007) (Nov/Dec 2006, 2007)
b. HSLA Steel. (Nov/Dec 2010) (April / May 2011) [may/june2006]
c. Martensitic stainless steel.
d. Maraging steel.

What is stainless steel?

- Stainless steels are alloy of iron, chromium, and other elements that resist corrosion from many environments.
- Stainless steels are also known as crosion-resistantst steels or chromium-bearing steels.

Types of stainless steels:

The stainless steels are divided into three classes on the basis of the predominant phase of the constituent of the microstructure as:

- Austenitic stainless steels,
- Ferritic stainless steels, and
- Martensitic stainless steels.

Table 3.6 lists several stainless steels, by class, along with composition, typical mechanical properties, and applications.

Before discussing the above steels, it should be reminded that the alloying elements in steels can be either austenite stabilizers or ferrite stabilizers.

(a) Austenite stabilizers

- The austenite stabilizers are Ni, Mn, Cu, Co.
- These elements enhance the retention of austenite as steel is cooled.
- For example, when 12% or more Mn is present, or when 20% or more Ni is present, it is impossible to cool steel slowly enough to allow austenite to transform to ferrite.

(b)Ferrite stabilizers

- The important ferrite stabilizers are Cr, W, Mo, V, and Si.
- These elements tend to prevent transformation of steel to austenite upon heating.
- Thus, whether a steel is austenitic, ferritic, or martensitic depend upon the balance between the amounts of austenite and ferrite stabilizers prevent, and the heating-cooling cycle to which the steel has been subjected. This can be explained in the following sections.

AISI Number	Composition (wt %)*				Condition**	Mechanical properties			Typical application
	C	Cr	Ni	Other		Tensile Strength (MPa)	Yield Strength (MPa)	Ductility (%EL in 50mm)	
					FERRITIC				
409	0.08	11	-	1.0Mn 0.75Ti	Annealed	448	240	25	Automotive exhaust
446	0.20	25	-	1.5Mn	Annealed	552	345	20	Values(high temp) glass molds
					AUSTENITIC				
304	0.08	19	9	2.0Mn	Annealed	586	240	55	Food

									process-ing
316L	0.03	17	12	2.0Mn, 2.5Mo	Annealed	552	240	50	Welding construs-tion
					MARTENSITIC				
410	0.15	12.5	-	1.0Mn	Annealed	483	275	30	Rifle barrels, cutlery
440A	0.70	17	-	1.0Mn 0.75Mo	Q and T Annealed Q and T	965 724 1790	690 414 1655	23 20 5	Cutlery, surgical tools

1. Austenitic Stainless Steels

- The austenitic stainless steels have the austenite structure retained at room temperature.
- It should be noted that when a layman speaks of stainless steel it is usually implies an austenitic stainless steel.
- These steels are produced and used in greatest tonnage.
- Austenitic steels contain both chromium and nickel. When nickel is present, the tendency of nickel to lower the critical temperatures override the opposite effect of chromium. Thus the structure may become completely austenitic.
- In these steels, carbon contents are kept below 0.15% in order to minimize the formation of chromium carbides in the structure, as this would cause a reduction in corrosion resistance.
- Carbides may form in these steels if they are allowed to cool slowly from high temperature, or if they are heated in the range 500-700 c. The later condition may apply in the heat-affected zones adjacent to welds. The type of corrosion failure that can occur, due to the presence of carbide particles, is known as weld decay.
- In order to prevent the weld decay, the stabilizer such titanium or niobium is added in small amounts with the austenitic stainless steels.

- An austenitic stainless steel with improved strength, hardness and wear resistance can be achieved by introducing a fine dispersion of titanium nitride particles throughout the materials (using the powder metallurgy methods).

Composition: Typical composition of austenitic stainless steel is given below:

C - 0.03 to 0.15 Mn - 2 to 10%

Si - 1 to 2% Cr - 16 to 26%

Ni - 3.5 to 22% P and S - normal

Mo and Ti in some cases

Properties: Some important properties of austenitic stainless steels are;

- Highest corrosion resistance.
- Good strength and scale resistance at high temperature.
- Non-magnetic.
- Good ductility at cryogenic temperature i.e., below 0 C.
- Very tough and can be welded, forged or rolled.

Applications: The typical applications of austenitic stainless steels include aircrafts industry (engine parts), chemical processing (heat exchanger), food processing (Kettles, tanks), households (cooking utensils), dairy industry (milk cans), transportation industry (trailers and railway cars), etc.

Ferritic stainless steels:

- Ferritic stainless steels are ferritic in structure at all temperatures upto their melting points.
- Ferritic stainless steels contain between 12 and 25% of chromium and less than 0.1% of carbon.
- As austenite cannot be formed, it is impossible to form hard martensitic structures by quenching the steels from high temperature.
- This type of steel cannot be heat treated, but may be strengthened by work hardening.

Composition: A typical composition of ferritic stainless steel is given below:

C - 0.08 to 0.10% Si - 1%

Mn - 1 to 1.5% Cr - 12 to 25%

Properties: The important characteristics of the ferritic stainless steel are:

- They are magnetic.
- They are good ductility.
- They have great strength, toughness, and good resistance to corrosion.
- These steels can be welded, forged, rolled, and machined.

Application: The typical applications of ferritic stainless steels include lining for petroleum industry, heating elements for furnaces, interior decorative work, screws and fittings, oil burner parts, etc.

Martensitic stainless steels:

- Martensitic stainless steels contain between 12 and 25% of chromium, together with carbon contents ranging from 0.1 to 1.5%.
- The presence of carbon restores the alpha to gama transition. These compositions can be heated to the austenitic range of temperatures and will transform to martensite upon cooling at suitable rates.

Composition: A typical composition of martensitic stainless steel is given below:

C	- 0.1 to 1.5%	Si	- 1%
Mn	- 1%	Cr	- 12 to 25%

Properties: Some of the important characteristic of martensitic stainless steels are:

- Good hardness, ductility, and thermal conductivity.
- Good toughness and corrosion resistance.

Applications: The typical applications of martensitic stainless steels include pumps and valve parts, rules and tapes, turbine buckets, surgical instruments, etc.

HSLA STEELS

What are HSLA Steels?

- HSLA steels are nothing but high-strength low-alloy steels.
- HSLA steels, also known as micro-alloyed steels, are low carbon steels containing small amounts of alloying elements.
- The primary purpose of HSLA steels are widely used as structural or constructional alloy steels.
- For structural applications, high yields strength, good weldability, and corrosion resistance are most desired, with only limited ductility and virtually no hardenability.
- These low-alloy structural steels have about twice the yield strength of the plain-carbon structural steels.
- The increase in strength, coupled with resistance to martensite formation in weld zone of HSLA steel, is obtained by adding low percentage of several elements, such as manganese, silicon, niobium, vanadium, etc.
- About 0.20% Cu is usually added to improve corrosion resistance.

Compositions and properties of HSLA steels

Presents four of the common HSLA steels, their compositions, and strength properties.

Typical compositions and strength properties of several groups of HSLA steels

Group	Chemical composition (%)					Strength properties		
	C	Mn	Si	Cr	V	Yield (MPa)	Tensile (MPa)	Ductility (% elongation In 50 mm)
Niobium or Vanadium	0.20	1.25	0.30	0.01	0.01	379	483	20
Low Manganese-Vanadium	0.10	0.50	0.10	-	0.02	276	414	35
Manganese-copper	0.25	1.20	0.30	-	-	345	517	20
Manganese-Vanadium-Copper	0.22	1.25	0.30	-	0.02	345	483	22

Characteristics of HSLA Steels

The HSLA steels poises the following important properties.

- HSLA steels have very high yield strength.
- They can be welded becoming brittle.
- These are very light *i.e.,* weight savings upto 202 to 30% can be achieved without compromising its strength.
- They have high corrosion resistance.
- They are ductile, formable, and machinable.

Application of HSLA steels

The HSLA steels are widely used as structural materials. The structural applications (wherever possible, substantial weight saving is desired) include bridges, towers, columns in high-rise buildings, pressure vessels, automobiles, trains, *etc.*

MARAGING STEELS

What are maraging steels?

- Maraging steels are low-carbon, highly alloyed steels.
- These are very high-strength materials that can be hardened to obtain tensile strengths upto 1900MPa.

Composition: Maraging steels contain 18%nickel, 7% cobalt, and small amounts of other element such as titanium. The carbon content is low, generally less than 0.05%

- ❖ These compositions develop martensite upon cooling (usually by air quenching) from the austenitizing temperature. The martensite formed in these steels, unlike the martensite of other alloy steel, is ductile and tough. The ductility and toughness of this martensite result from its very low carbon content.
- ❖ In the martensitic condition, these steels can be cold worked and can be hardened by precipitation at temperatures below the austenitizing temperature to achieve high tensile strength.

Composition and mechanical properties of typical maraging steels

Presents the composition of typical maraging steels and their mechanical properties.

Composition and mechanical properties of typical maraging steels

Composition (%)						**Typical mechanical properties**			
Ni	Co	Mo	Ti	Al	C	Tensile Strength (N/mm^2)	0.2% Proof Stress (N/mm^2)	Elongation (%)	Impact Strength (charpy) (J)
18.00	8.50	3.00	0.20	0.10	0.01	1565	1430	9	52
18.00	9.00	5.00	0.50	0.10	0.01	1965	1930	7.5	21
17.50	12.5	3.75	1.60	0.15	0.01	2460	2390	8	11

Characteristics of Maraging steels

- ❖ The important properties of maraging steels have very high tensile strength and impact strength.
- ❖ These steels combine considerable toughness with high strength and are far superior to conventional alloy constructional steels.
- ❖ They are also very suitable for surface hardening by nitriding.
- ❖ They can be welded, if welding is followed by the full solution and ageing treatment.

Applications of maraging steels

Maraging steels find a wide variety of uses such as the flexible drive shafts for helicopters, barrels for rapid-firing guns, die-casting dies, and extrusion rams space-vehicle cases, *etc.*

Heat resisting steels:

- ❖ Steels which can resist the creep and oxidation at high temperatures and retain sufficient strength are called heat resisting steels.
- ❖ A typical composition of heat resisting steel is given below:

0.4%C, 10%Cr, 0.2%Si, 1.4%Mo, 36%Ni.

Applications: Such steels are used for exhaust valves of IC engines, conveyor chains and other furnace parts, racks for enamelling stoves, annealing-boxes, rotors for steam and gas turbines, and other fittings.

Hadfield's manganese steels:

- ❖ This is a high-alloy steel that contains 12-14% of Mn, and 1% of C. It is a non-magnetic.
- ❖ This type of steel is unique in that any attempt to deform, or abrade, the material greatly increases the surface hardness.

Applications: Because of the exceptionally high resistance to abrasion, Hadfield's manganese steels are used for pneumatic drill bits, rock crusher jams, excavator bucket teeth, and railway points and switches.

Free-machining steels:

- ❖ These steels, also known as free cutting steels, machine readily and form small chips so as to reduce the rubbing against the cutting tool and associated friction and wear.
- ❖ They have higher sulphur (or lead) content than other carbon steels.

Magnet alloys: The temporary magnets are made from iron along with nickel, cobalt, and the rate earth metal gadolinium.

6. Discuss the effects of various alloying elements on the properties of steel. (April / May 2008) (May/June 2009) (Nov/Dec 2009) (Nov/Dec 2010) (April / May 2011, 2012) (Nov 2013)

- ❖ In general, alloying elements are added to steel in small percentages to improve strength or hardenability. Otherwise, alloying elements are added to steel in much larger amounts usually upto 20 percent to produce special properties such as corrosion resistance or stability at high or low temperatures.
- ❖ The properties of all steels are determined by the kinds and amounts of phases of which they are composed, by the properties of the phases, and by the way in which these phases are distributed among one another.
- ❖ Steels consist of two or more phases known as ferrite, austenite, carbides and graphite.

- The alloying elements in steels affect the stability of these phases, the relative amounts of the phases, and how the phases are distributed or dispersed throughout one another. Thus, the alloying elements affect and control the properties of steels.
  - ✓ The alloying elements such as Ni, Mn, Cu and Co tend to stabilize austenite.
  - ✓ The alloying elements such as Cr, W. Mo, V and Si tend to stabilize ferrite.
  - ✓ Some alloying elements such as Cr, W, Ti, Mo, Nb, V, and Mn tend to form carbides.

  Other elements such as Si, Co, Al, and Ni tend to destabilize carbides and from graphite.

Alloying element	**Typical ranges in alloy steels (%)**	**General effects**	**Typical steels**
Manganese (Mn)	0.3-2.0	✓ Increases the strength and hardness and forms carbide. ✓ Increases hardenability. ✓ Lowers the critical temperature range. ✓ Promotes an austenitic structure. ✓ Acts as a deoxidizer and a desulphurizer.	1.***Pearlitic steels*** (Upto 2% Mn) with high hardenability used for shafts, gears and connecting rods. 2.***hadfield's steel*** (13% Mn) a tough austenitic steel.
Silicon (Si)	2	✓ Acts a general purpose deoxidizer. ✓ Improves electrical and magnetic properties. ✓ Improves oxidation resistance. ✓ Strengthens low alloy steels. ✓ Increases hardenability of steels carrying non graphitizing elements.	1.***Silicon steels*** (0.07%C,4%Si) Used for transformer cores. 2. Silicon used with chromium for its high temperature oxidation resistance in IC engine valves.

Chromium (Cr)	0.3-4	✓ Increases corrosion and oxidation resistance ✓ Increases hardenability. ✓ Increases high-temperature strength ✓ Resists abrasion and wear(with high carbon)	1. 0.1 – 1.5% Cr in medium and high carbon steels for gears, axles, shafts, springs, ball bearings and working rolls. 2. 12 – 30% Cr in martensitic and ferritic stainless steels.
Nickel (Ni)	0.3 – 5	✓ Strengthens unquenched or annealed steels. ✓ Toughens pearlitic ferrite steels. ✓ Increases hardenability ✓ Improves resistance to fatigue ✓ Strong graphite forming tendency	1. 0.3 – 0.4% C with upto 5% Ni used for crankshaft and axles, and other parts subject to fatigue. 2. a) Cr-Ni steels(0.15% C with Ni and Cr) used for case carburizing b) Cr – Ni steels (0.3% C with Ni and Cr) used for gears, shafts, axles and connecting rods. c) Cr- Ni steels (18% Cr and 8% Ni) give austenitic stainless steels.
Tungsten (W)	-	✓ Forms hard, abrasion resistant particles in tools steels. ✓ Promotes red hardness and strength ✓ Raises the softening temperature	1. Major constituent in high-speed tool steels 2. Also used in some permanent magnet seels.
Molybdenum (Mo)	0.1-0.5	✓ Improves high temperature creep resistance. ✓ Reduces temper brittleness in Ni-Cr steels. ✓ Stabilizes carbides. ✓ Increases hardenability.	1. A constituent of high-speed tool steels and creep resistant steels. 2. Upto 0.5% Mo often added to pearlitic Ni-Cr seals to reduce temper-brittleness.
Vanadium (V)	0.1-0.3	✓ Stabilizes carbides. ✓ Raises softening temperature of hardened steels.	1. Not used alone, but it is added to high-speed steels, and to some pearlitic chromium steels

		✓ Has a scavenging action and produces clean, inclusion-free steels. ✓ Increases strength while retaining ductility. ✓ Promotes fine grain size.	
Titanium (Ti)	-	✓ Strong carbide forming element. ✓ Reduces martensitic hardness and hardenability in medium chromium steels. ✓ Prevents formation of austenite in high chromium steels.	1. Not used alone, but added as carbide stabilizer to some austenitic stainless steels
Aluminium(A)	<2	✓ Aids nitriding. ✓ Restricts grain growth. ✓ Deoxidizes efficiently.	1. Added to nitriding steels to restrict nitride formation to surface layers.
Cobalt(Co)	-	✓ Increases strength ✓ Decreases hardenability.	1. Used in "Stellite" type alloys, magnet steels, and as a binder in cemented carbides.
Niobium (Nb)	-	✓ Strong carbide former. ✓ Increases creep resistance.	1. Added for improved creep resistance and as a stabilizer in some austenitic stainless steels.
Copper (Cu)	0.2 – 0.5	✓ Increases strength. ✓ Increases corrosion resistance.	1. Added to cast steels to improve fluidity, cast ability, and strength. 2. Used in corrosion resistant architectural steels.
Lead(Pb)	-	✓ Insoluble in iron. ✓ Improves machinability.	1. Added to low-carbon steels to give machining properties.

7. Explain the various types of cast iron. **(May/June 2007) (Nov/Dec 2009)**

GREY CAST IRON

- Grey cast iron is the least expensive and the most common type of cast iron.
- It is an alloy of carbon and silicon with iron.

Composition : Typical composition of grey cast iron is given below:

Carbon	2.5 to 4%
Silicon	1 to 3%
Manganese	0.4 to 1%
Phosphorus	0.15 to 1%
Sulphur	0.02 to 0.15%
Iron	Remaining

Microstructure of Grey Cast iron

- The microstructure of grey cast iron consists of graphite flakes, which resemble a number of potato crisps glued together at a single location.
- The graphite flakes are normally surrounded by α ferrite or pearlite matrix.
- Because of the graphite flakes in the structure, the fractured surface appears in a grey colour. That's why this cast iron is described as grey cast iron.
- The graphite flakes do not have appreciable strength and hence the essentially act as voids in the structure.
- In addition, the pointed edges of the flakes act as preexisting notches or crack initiating sites which make the grey cast iron to behave as a brittle material.
- It should be noted that the shape, size and distribution of the graphite flakes can have a significant effect on the overall properties of the grey cast iron. For instance, presence of small uniformly distributed graphite flakes gives maximum strength to grey cast iron.

Designation of grey cast iron

- Grey cast iron is commonly designated by a grade number. A class or a grade number represents the minimum tensile strength in psi of the iron in a standard test piece machined from a 30 mm diameter cast test bar.

- For example, a class (or a grade) 20 irons means the cast iron has minimum tensile strength of 20 * 10^3 psi and a class 40 iron means the cast iron has minimum tensile strength of 40*10^3psi(~276MPa)

Designations, compositions, mechanical properties, and typical applications of some grey cast irons.

Grade (class number	Composition (wt %)	Tensile strength(psi * 10^3 MPa)	Ductility(% elongation in 500 mm)	BHN	Yield strength(MPa)	Typical applications
25	3.5 C, 2.5 Si, 0.7 Mn	25(173)	0.4	150	138	Pipe. sanitary ware
40	3.2 C 2 Si 0.8 Mn	40(276)	0.4	220	241	Machine tools, engine, blocks, brake drums
70	3.2 C 2 Si 1 Ni 1Mo	70(483)	0	300	483	Camshafts
80	3.2 C 2 Si 1Ni 1 Cr 0.4 Mo	80(525)	0	500	552	Wearing surfaces

Characteristics of Grey Cast iron

- Grey cast iron possess excellent compressive strengths. In fact, the compressive strength of grey cast iron is three to five times higher than its tensile strength. This is due to the fact that compressive forces do not promote crack propagation.
- It has good torsional and shear strengths
- It has good corrosion resistance, which may be attributed to high silicon content.
- .It has excellent fluidity and hence it can be cast into any complex shapes.

- ❖ It posses good wear resistance in adhesive wear conditions. This is due to the presence of graphite flakes which provide self lubrication.
- ❖ It exhibits excellent machinability. This is because graphite acts to break urn the chips and lubricate contact surfaces.
- ❖ It also has outstanding sound and vibration damping capacity. This is again due to the fact that graphite flakes absorbs transmitted energy.

Applications of grey cast iron

The typical applications of grey cast iron include machine tool bodies, engine blocks, engine cylinders, brake drums, cam shafts, pipes and pipe fittings, rolling mills, ingot moulds, house hold and agricultural appliances, etc.

WHITE CAST IRON

- ❖White cast iron derives its name from the face that its fracture surface has white or silvery appearance
- ❖White iron has all the carbon in the combined form as cementite on a pearlitic matrix. When the rate of cooling is fast, nearly all the carbon in a cast iron exists ass cementite.

Microstructure of white cast iron

- ❖Since cementites caused by quick cooling of molten iron, white cast iron is very hard and brittle.
- ❖It is used only in applications where hardness and wear resistance are important.
- ❖Most white cast irons are hypo-eutectic.

Characteristics of white cast iron

- ❖White cast iron is very hard and brittle
- ❖It possess high abrasion resistance.
- ❖It has a high tensile strength and low compressive strength
- ❖Since it is hard, it cannot be machined.
- ❖White iron castings can be made in sand moulds.

Applications of white cast irons

- ❖White cast iron is used as raw material in the production of malleable cast iron.
- ❖The typical applications of whit cast iron include rolls, wear plates, pump linings, balls, etc.
- ❖It is also used for inferior casting and I place where hard coating is required as in the outer surface of car wheels.

8. Name non ferrous materials for the following articles. (May/June 2013)

(1) **Bush**

Copper foil, copper sheet & strip, brass sheet, gun metal bush, bronze bush

(2) **Furnace Heating element**

Nichrome

(3) **Type writer parts**

Aluminium

(4) **Coins**

Coinage bronze, Gliding metal or commercial bronze.

(5) **Girders for Airship**

Aluminium

(6) **Big end bearing**

Aluminium base bearing material (Sn,Cu,Ni,Al)

(7) **Filament of electrical lamp**

Tungsten

(8) **Turbine blades**

Monel metal (Ni,Cu,Si,Mn,C)