

# ESE 2021

UPSC ENGINEERING SERVICES EXAMINATION

## Preliminary Examination

### General Studies and Engineering Aptitude

### Basics of Material Science and Engineering

Comprehensive Theory *with* Practice Questions  
*and* ESE Solved Questions



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### **ESE 2021 Preliminary Examination : Basics of Material Science and Engineering**

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# Preface

The compilation of this book **Basics of Material Science and Engineering** was motivated by the desire to provide a concise book which can benefit students to understand the concepts of this specific topic of General Studies and Engineering Aptitude section.

This textbook provides all the requirements of the students, i.e. comprehensive coverage of theory, fundamental concepts and objective type questions articulated in a lucid language. The concise presentation will help the readers grasp the theory of this subject with clarity and apply them with ease to solve objective questions quickly. This book not only covers the syllabus of ESE in a holistic manner but is also useful for many other competitive examinations. All the topics are given the emphasis they deserve so that mere reading of the book clarifies all the concepts.

We have put in our sincere efforts to present detailed theory and MCQs without compromising the accuracy of answers. For the interest of the readers, some notes, do you know and interesting facts are given in the comprehensive manner. At the end of each chapter, sets of practice question are given with their keys and detailed explanations, that will allow the readers to evaluate their understanding of the topics and sharpen their question solving skills.

Our team has made their best efforts to remove all possible errors of any kind. Nonetheless, we would highly appreciate and acknowledge if you find and share with us any printing and conceptual errors.

It is impossible to thank all the individuals who helped us, but we would like to sincerely thank all the authors, editors and reviewers for putting in their efforts to publish this book.



**B. Singh** (Ex. IES)

With Best Wishes

**B. Singh**

CMD, MADE EASY Group

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## 10.1 Introduction

- The ferrous metals are iron based metals and they include all varieties of irons and steels. Iron, cast iron and steel are ferrous metals in which constituent iron is the major element. Pig iron is a crude and impured form of iron which is extracted from iron ore by melting the ore in a blast furnace. Wrought iron is the purest form of iron which contains 99.5 to 99.8% of pure iron.
- As wrought iron does not flow like cast iron, hence it is not suitable for casting. It has to be forged or rolled into the desired shape. Cast iron is obtained from pig iron by remelting pig iron in cupola furnace with definite amount of limestone and steel scrap. Cast iron is highly suitable for casting in foundry. The content of carbon in cast iron varies from 2 to 4.3%. Carbon steels basically differ from cast iron in the amount of carbon content in it. Steel has carbon content varying from 0.5% to 1.5%. Alloy steel is a carbon steel to which one or more elements are added to improve its properties.

## 10.2 Pig Iron

- Iron is quite reactive and it is not found in free state in nature. Iron is found in combined state in the form of oxide, carbonate and sulphide.

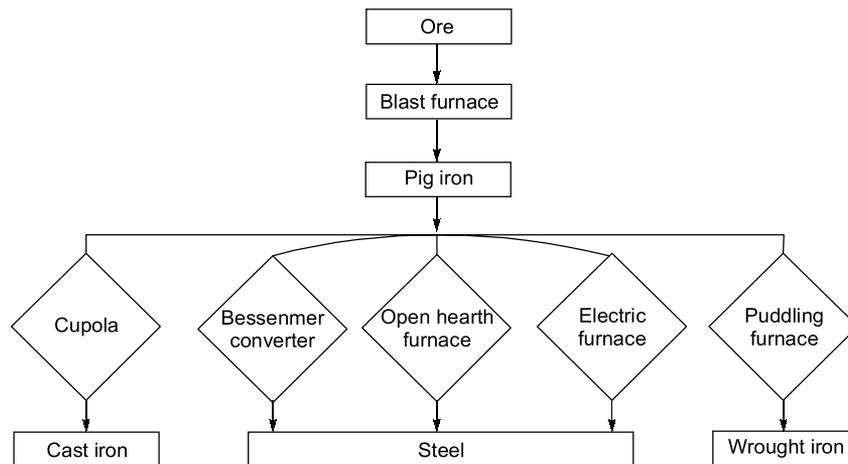
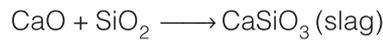
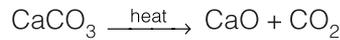
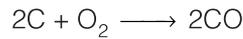


Fig. 10.1 Furnaces to produce various types of iron

- In the combined state, iron is mined out from the earth. This is called iron ore which can be
  - Haematite ( $\text{Fe}_2\text{O}_3$ )
  - Magnetite ( $\text{Fe}_3\text{O}_4$ )
  - Limonite ( $\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ ) and
  - Siderite ( $\text{FeCO}_3$ ).
- Most of iron metal is produced from haematite ( $\text{Fe}_2\text{O}_3$ ).
- Haematite has iron with iron oxide and sand (silicon dioxide) as impurity. Therefore, we have to carry out two things to get iron metal from the ore which include using

- (i) a reducing agent to reduce haematite and
- (ii) a suitable flux (solvent) to remove the sand present in the ore.
- The reducing agent used is carbon monoxide (CO) which is obtained by burning coke (carbon) in the blast furnace whereas sand is removed by using calcium oxide (CaO) obtained by heating limestone. The reactions are:



- The blast furnace is used for obtaining iron from the ore. The furnace is named as blast furnace as very high temperature (1300°C) is generated inside it by means of forcing a blast of hot air and burning of coke. The molten iron is called pig iron when it is extracted from the blast furnace. Pig Iron is a “crude and impure form of iron (90% iron).

### 10.3 Cast Iron

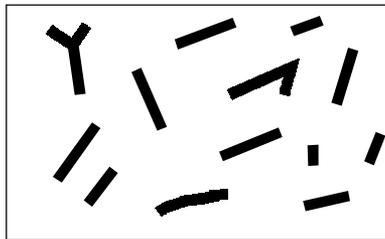
- The pig iron is unsuitable for casting process as it contains high percentage of impurities. To make it suitable for casting and other manufacturing processes, it is refined in a furnace known as cupola. The refined iron with carbon content varying from 2 to 5% is called cast iron.

#### 10.3.1 Forms of Carbon in Cast Iron

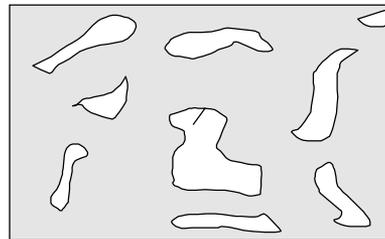
- The carbon in cast iron is found in two forms which are:
  - (i) Carbon or graphite.
  - (ii) Combined form with iron, i.e., iron carbide ( $\text{Fe}_3\text{C}$ ) which is called cementite.
- Free carbon (graphite) imparts grey colour to cast iron. It exists in carbon in the form of small flakes. It is comparatively more softer and less brittle. However, cementite is combined form of iron and carbon (iron carbide) and it is very hard as well as brittle substance. Cementite makes cast iron unsuitable for machining job. Cementite is formed when cast iron is cooled rapidly after melting.

#### 10.3.2 Grey Cast Iron

- Grey cast iron is a cast iron in which most of the carbon is present in the form of free graphite. Graphite is greyish in colour which provides greyish colour to the cast iron. Graphite exists in the form of small flakes. The graphite content varies from 2.5 to 4%. The properties of grey cast iron are:
  - (a) Presence of graphite provides a sort of natural lubrication. Hence, grey cast iron is very suitable for sub-applications where sliding friction is desired.



(a) Grey cast iron [graphite flakes (black) and ferrite (white)]



(b) White cast iron [cementite (white) in pearlite (dark)]

**Fig. 10.2** Grey and white cast iron

- (b) It has high compressive strength but low tensile strength. High compressive strength makes cast iron highly suitable for making such parts which are subjected mainly to compressive loadings such as legs and bases of heavy machinery.
- (c) It is extensively brittle. Hence, it is unsuitable for parts which are subjected to sudden and impact loading.
- (d) It has poor ductility and plasticity. Hence, it is unsuitable for forging and metal forming processes.
- (e) It has good machinability.
- (f) It has good fluidity in liquid form which makes it very suitable for casting processes.
- (g) It has excellent damping properties. Hence, it is extensively used for making of structures of machinery.
- Grey cast iron is mainly used for making
  - (i) legs and bases of heavy machinery
  - (ii) cast iron pipes
  - (iii) pipe fittings
  - (iv) manhole covers
  - (v) cylinder blocks and heads
  - (vi) flywheels

### 10.3.3 White Cast Iron

- White cast iron is cast iron in which carbon content is about 1.75 to 3.6% and that too in the combined form of iron carbide (cementite). Due to the presence of cementite, the white cast iron shows white colour at fracture. The cementite is extremely hard and brittle. The properties of cast iron are:
  - (a) It is extremely hard and brittle due to the presence of cementite. Hence, it is unsuitable for machining.
  - (b) It has good wear resistance
  - (c) It has low fluidity. Hence it is unsuitable for casting processes.
- White cast iron is used in producing
  - (i) plough
  - (ii) crushing equipment
  - (iii) cast wheels
  - (iv) brake blocks
  - (v) ball mills
  - (vi) rollers for paper industry
  - (vii) hammers
  - (viii) as raw material for the manufacturing of malleable cast iron

**Table 10.1** Comparison of white and grey cast iron

White cast iron	Grey cast iron
1. Carbon is present in combined form called cementite.	1. Carbon is present in the free form as graphite.
2. It is obtained on rapid cooling of molten cast iron.	2. It is obtained by slow cooling of molten cast iron.
3. It has low fluidity and it cannot be used in foundry work.	3. It has high fluidity and is used for foundry work.
4. It is hard and brittle. It can be machined by grinding.	4. It can be easily machined.
5. It has good wear resistance and it is used for ball mills, brakes, rollers and hammer.	5. It has self-lubricating property and is used in the applications subjected to sliding.
6. It has no damping capacity.	6. It has excellent damping capacity.

### 10.3.4 Malleable Cast Iron

- White cast iron is generally used for producing malleable cast iron. Malleable cast iron is produced from white cast iron by (i) converting cementite of white cast iron gradually into free graphite, i.e.,  $\text{Fe}_3\text{C} \rightarrow 3\text{Fe} + \text{C}$  and (ii) reducing the presence of graphite to about 2 to 2.5%.

- The removal of carbon in malleable cast iron makes it more or less similar in composition to that of wrought iron. In order to achieve this, white cast iron is melted in cupola and then it is casted in sand moulds.
- These castings are kept with any material rich in oxygen at temperature of about 800 to 1000°C in an annealing furnace. The liberated oxygen combines with carbon of the castings of white cast iron, thereby reducing the proportion of carbon present in the casting.
- The castings so obtained are quite tough and they have good resistance to shock and impact loading. The properties of malleable cast iron are:
  - (a) It has high ductility and it can be easily bent without breaking.
  - (b) It has high yield strength.
  - (c) It has lower hardness and brittleness.
  - (d) It has high toughness, good wear and shock resistance.
  - (e) It has good machineability due to low hardness.
- The malleable cast iron is used for making
  - (i) hardware, hinges, hand levers and spanners
  - (iii) gear wheels
  - (iii) guns
  - (iv) surgical instruments
  - (v) conveyer chains
  - (vi) crankshafts

### 10.3.5 Nodular Cast Iron/Ductile Cast Iron

- The production of nodular cast iron involves the changing of graphite of cast iron from flake form to nodular form by the addition of magnesium to the molten cast iron. The carbon content is same as in grey cast iron (2.5% to 4%) but there is lower brittleness graphite is present in nodular form, thereby no sharp point or condition of stress raiser is existing.
- The properties of nodular cast iron are:
  - (a) It has high fluidity and it is castable.
  - (b) It has graphite which helps in providing high machinability and high surface finish
  - (c) It can be easily welded.
  - (d) It can be easily galvanised.
  - (e) It can be used as replacement to great extent for both malleable cast iron and steel.
  - (f) It has high toughness.
  - (g) It has high ductility.
- It is commonly used for
 

<ol style="list-style-type: none"> <li>(i) pipes and pipe fittings</li> <li>(iii) punch and dies</li> <li>(v) engine frames</li> <li>(vii) lifting jack blocks</li> <li>(ix) gears</li> <li>(xi) cylinder heads</li> </ol>	<ol style="list-style-type: none"> <li>(ii) housing of gears</li> <li>(iv) bed plates and brackets</li> <li>(vi) railways and locomotive rolling stocks</li> <li>(viii) flywheels</li> <li>(x) hand tools</li> <li>(xii) bodies of electric motors</li> </ol>
--	---

#### NOTE



1. Increasing order of hardness and brittleness—  
Spheroidal cast iron < Nodular cast iron < Grey cast iron < White cast iron < Chilled cast iron.
2. Increasing order of ductility and toughness—  
Chilled cast iron < White cast iron < Grey cast iron < Nodular cast iron < Spheroidal cast iron

### 10.3.6 Carbon Equivalent

- As we add Si and P in cast iron the carbon diagram is shifted towards left so graphitization will appear at much lower % of carbon.
- In the pool of liquid cast iron when we add silicon, graphite is discharged in red hot condition. Graphite having less density, so due to effect of buoyancy graphite comes over the surface of molten metal and sprinkles which is called kish.
- Due to effect of Si, P the value of carbon % decreases in cast iron.  
Eg: In grey cast iron %C = (2.4% to 4.0%)

$$\text{Carbon equivalent} = \% \text{ carbon} + \frac{1}{3} [\% \text{Si} + \% \text{P}]$$

### 10.3.7 Alloy Cast Iron

- A large variety of alloy cast irons have been developed by suitable addition of varying proportions of different alloying elements in cast iron. Alloy cast irons are developed largely to overcome the inherent drawbacks in cast iron. The main alloying element in most of these alloy cast irons is nickel.
- The effects of alloying of various elements with cast iron are:
  - (a) Nickel:** It improves carbon structure present in cast iron, thereby improving physical properties and machinability.
  - (b) Silicon:** It promotes the formation of free graphite and decreasing the combined carbon (cementite). Hence, silicon is used as a softener in cast iron.
  - (c) Chromium:** It acts as a carbide stabiliser, thereby improving hardness, strength and corrosion resistance.
  - (d) Copper:** It promotes graphite formation, thereby improving machinability, castability and toughness.
  - (e) Sulphur:** It promotes the formation of cementite. Hence, it increases hardness and brittleness but decreases fluidity.
  - (f) Phosphorus:** It improves the castability of cast iron.
  - (g) Molybdenum:** It improves machinability, toughness and fatigue strength.
  - (h) Manganese:** It reduces the effect of sulphur on cast iron, thereby reducing hardness and brittleness.
  - (i) Carbon:** If cooled slowly, graphite tough iron is made which is easy to machine. But if rapidly cool cementite is formed which have high tensile strength and difficult to machine.
  - (j) Vanadium:** Vanadium improve hardness, strength and machinability of cast iron.
- Alloy cast irons, are used for
  - (i) cylinder head
  - (ii) piston rings
  - (iii) grinding and crushing machinery

### 10.4 Wrought Iron

- Wrought iron is the purest form of iron which contains 99.5 to 99.8% of pure iron. It cannot flow like cast iron when melted at high temperature and hence it is unsuitable for casting process, However, it has high plasticity at high temperature, thereby enabling it to be hammered into thin sheet or two of its pieces can be jointed by hammering. It is capable to be forged or rolled into desired shapes when it is red hot.
- Wrought iron cannot be hardened by heating and quenching as it does not have carbon content. It is very ductile and malleable and hence it is suitable for making sheets and wire drawing.

- The properties of wrought iron are:
  - (a) It has high resistance to corrosion
  - (b) It has high ductility and malleability
  - (c) Its ultimate strength can be increased by cold working
  - (d) It is never cast and all manufacturing processes from this material are accomplished by hammering, pressing and rolling.
  - (e) It has high resistance to fatigue failure.
- The maximum applications of wrought iron are for forged articles specially which are made by forge welding and parts which are likely to be subjected to conditions encouraging rusting.
- Wrought iron is commonly used in
  - (i) shipbuilding
  - (ii) pipes for steam, oil and water
  - (iii) nuts and bolts
  - (iv) agriculture implements
  - (v) chains
  - (vi) crane-chokes
  - (vii) railway couplings

## 10.5 Steel

- Steel basically differs from cast iron in the amount of carbon content in it. Secondly, it is not only the quality of carbon content but also the form in which it is present in metals. Steel has carbon content upto 1.5% and it is completely in the combined form. Since steel is an alloy of iron with small amount of carbon, it can be produced by either extracting carbon from cast iron or adding small amount of carbon to wrought iron.
- Generally speaking, higher is carbon content in steel (not, above 1.5%), harder and stronger is the steel. In fact, steel is an alloy of iron and carbon with carbon content not exceeding 1.5%. These steels having 1.5% carbon are called plain carbon steels because their properties are dependent on the percentage of their carbon content.
- The plain steels can be classified as
  - (i) dead mild steels with carbon content less than 0.15%.
  - (ii) mild steel with carbon content varies from 0.15 to 0.25%.
  - (iii) medium carbon steels with carbon content varying from 0.25 to 0.60%.
  - (iv) high carbon steel with carbon content varying from 0.60 to 1.5%.

**Table 10.2** Comparison between steel with cast iron

Steel	Cast iron
1. Carbon content is low (upto 1.5%).	1. Carbon content is high (1.5 to 4.5%).
2. Carbon exists in combined form.	2. Carbon exists in free form of graphite.
3. Besides carbon, other alloying elements are alos generally present.	3. Generally, no alloying element is present except carbon.
4. It has good value of strength, hardness and ductility.	4. It is hard and brittle.
5. It is commonly used for forging, rolling and welding in making parts.	5. It is commonly used for casting in making parts.
6. It is malleable and ductile.	6. It is brittle and hard.
7. The structure is ferrite and pearlite.	7. The structure is cementite and ludeburite.
8. Bessemer converter is used with pig iron to manufacture.	8. Cupola is used with pig iron to manufacture.

### 10.5.1 Classification of Carbon Steel with Percentage of Carbon

- Plain carbon steels are alloys of iron with carbon content to a maximum of 1.5%. They owe their properties mainly due to the percentage of the carbon present in them.

- The properties and uses of the various types of steels are given in Table 10.3.

**Table 10.3** Properties and uses of various steels

Types of steel	Percentage of carbon	Properties	Applications
1. Dead mild steel	0.15%	1. Highly ductile 2. Highly malleable 3. Most soft among all steels 4. Can be easily forged, welded, machined and stamped to shape	1. Wire 2. Thin steels 3. Rods 4. Welded and solid drawn tubes 5. Chains 6. Stamping
2. Mild steel	0.15 to 0.25%	1. Soft and offers good ductility 2. Tough but has low wear resistance 3. Less malleable 4. Can be easily forged 5. Can be easily welded 6. Can be easily machined 7. Can be easily stamped	1. Screws 2. Nuts 3. Bolts 4. Rivets 5. Small forging 6. Wires 7. Stamping of automobile parts
3. Medium carbon steel	0.25 to 0.60%	1. Harder but less ductile 2. Good tensile strength 3. Can be welded and brazed 4. Heat treatment can be given	1. Shafts and axles 2. Rods 3. Bolts 4. Tubes 5. Tools such as hacksaw frames, hammer head and fitter's square
4. High carbon steel	0.60 to 1.5%	1. Strong and less ductile 2. Hardness and toughness depend on heat treatment 3. Highest tensile strength 4. Low ductility 5. Low machinability	1. Hand tools 2. Cutting 3. Drills 4. Milling cutters 5. Wood working tools 6. Punches 7. Die and taps 8. Wheels 9. Springs

### 10.5.2 Properties of Different Phase and Phase Mixtures of Iron and Steel

- $\alpha$ -Iron or  $\alpha$  Ferrite:** It is a phase of Iron.
  - It is the purest form of iron at room temperature.
  - It has BCC structure.
  - It is magnetic below 768°C and magnetic properties disappear and becomes para-magnetic above 768°C.
  - $\alpha$ -ferrite is solid solution of iron and carbon with maximum solubility of carbon 0.02% in  $\alpha$ -iron.
- Austenite or  $\gamma$ -Iron:** It is a phase of Iron.
  - $\gamma$ -Iron has FCC structure.
  - It is soft, tough and ductile form of iron. It is para-magnetic in nature.
  - Maximum solubility of carbon in  $\gamma$ -iron is 2.10%.
- $\delta$ -Iron or  $\delta$ -Ferrite:** It is a phase of Iron.
  - It has BCC structure.
  - The solubility of carbon in  $\delta$ -ferrite is very less but it is more than  $\alpha$ -ferrite.
  - Heat treatment process is not used for  $\delta$ -ferrite.
- Pearlite:** It is a phase mixture of Iron.
  - It has plate like structure of  $\alpha$ -ferrite and cementite.
  - For pure pearlite form % of carbon must be equal to 0.83% in  $\alpha$ -ferrite (Hypo-Eutectoid steel has less than 0.83% of carbon and Hyper eutectoid steel has carbon % in between 0.83% to 2.1%)
  - It is relatively hard and stronger than  $\alpha$ -ferrite.

5. **Cementite or Iron Carbide:** It is a phase of Iron.
- It is very hard and brittle.
  - It has 6.67% of carbon in iron in purest form.
  - Chemical formula of cementite is  $\text{Fe}_3\text{C}$ .
  - Cementite has orthorhombic structure.
  - It is very strong in compression and weak in tension.
6. **Ledeburite:**
- It is eutectic mixture of austenite and cementite. At eutectic point % of carbon soluble in iron is 4.3%.
  - It is not a stable phase mixture. It breaks down into others phase mixture due to its unstable nature.
  - Eutectic composition is used in MCB. Because at eutectic point alloy have definite melting point.
7. **Bainite:**
- It is produced by austempering (cooling at constant tempering)
  - It is mixture of  $\alpha$ -ferrite and iron carbide.
8. **Martensite:**
- It has BCT (Body centered tetragonal) structure.
  - It can be produced by cooling austenite at more than critical cooling rate.
  - It is the most hard and brittle phase of iron.
  - For pure martensite formation % of carbon must be equal to 0.83%. It can have maximum 2% carbon.

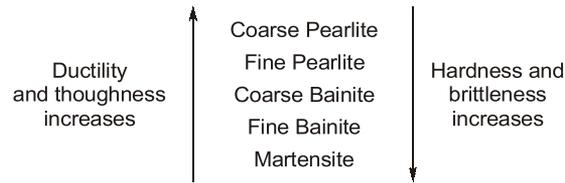


Table 10.4

Phase of Iron	Phase Mixture of Iron
1. $\alpha$ -Iron	1. Pearlite
2. Austenite	2. Ledeburite
3. $\gamma$ -ferrite	3. Bainite
4. Martensite	
5. Cementite	

### 10.5.3 Alloy Steel

- Alloy steel is carbon steel to which one or more elements are added to improve its properties. The commonly added elements to improve the properties are:
  - nickel
  - chromium
  - molybdenum
  - tungsten
  - manganese
  - vanadium
  - copper
  - aluminium
  - boron
  - silicon
  - cobalt
- The elements are added in the alloyed steel for the following reasons:
  - To improve tensile strength while maintaining ductility
  - To improve toughness
  - To improve resistance to corrosion

- (d) To improve wear resistance
- (e) To improve hardenability
- (f) To improve cutting ability as well as ability to resist distortion at elevated temperatures
- (g) To improve case hardening properties
- (h) To promote fine grain size

#### 10.5.4 Effect of Alloying Elements on Carbon Steels

- The various alloying elements which are added to improve the properties of steel are:
  - (a) **Nickel:** It improves (i) toughness, (ii) tensile strength, (iii) ductility and (iv) corrosion resistance.
  - (b) **Chromium:** It improves (i) tensile strength, (ii) thermal resistance, (iii) hardness, (iv) toughness and (v) magnetic properties.
  - (c) **Cobalt:** It improves (i) tensile strength, (ii) thermal resistance, (iii) Hardness, (iv) toughness and (v) magnetic properties
  - (d) **Manganese:** It improves (i) strength, (ii) toughness and (iii) hardness. It minimises the bad effects of sulphur.
  - (e) **Silicon:** It improves (i) elasticity and (ii) magnetic permeability. It also decreases hysteresis losses.
  - (f) **Molybdenum:** It increases (i) wear resistance, (ii) thermal resistance, (iii) hardness and (iv) red hot hardness.
  - (g) **Tungsten:** It improves, (i) toughness, (ii) hardness, (iii) shock resistance, (iv) wear resistance and (v) red hot hardness.
  - (h) **Vanadium:** It improves (i) tensile strength, (ii) elastic limit, (iii) density, (iv) shock resistance and (v) hardenability.
  - (i) **Boron:** It improves hardenability
  - (j) **Aluminium:** It promotes fine grain growth.
  - (k) **Titanium:** It promotes grain growth.
  - (l) **Copper:** It improves (i) strength and (ii) corrosion resistance.
  - (m) **Niobium:** It improves (i) ductility and (ii) impact strength. It promotes fine grain growth and decreases hardenability.
  - (n) **Lead:** Lead improves machinability at steel.
  - (o) **Cerium:** Improve toughness and deoxidizes steel.
  - (p) **Phosphorus:** Increase strength and hardness and helps in chip formation.
  - (q) **Calcium:** It improves toughness and works as deoxidizer.
  - (r) **Sulphur:** Improves machinability.
  - (s) **Tin:** Tin promotes hot shortness.
  - (t) **Antimony and Arsenic:** Both of these cause temper embrittlement.

### 10.6 Special Alloys Steels

- Special alloy steels have been developed for special applications and specific requirements by modifying the properties of the steels.
- The special alloy steels are:
 

(i) stainless steels	(ii) magnetic steels
(iii) high resistance steels	(iv) high speed steels.

#### 10.6.1 Stainless Steels

- Stainless steels are also called corrosion resistant steels. The main alloying element in this steel is chromium while some other elements like nickel and manganese can also be added in small amounts.
- About 12% chromium metal is added to the steel which forms chromium oxide with atmospheric oxygen. The chromium oxide is highly corrosion resistant in nature and it protects the items made of this steel.

- Stainless steel is used in
  - (i) utensils
  - (ii) cutlery
  - (iii) surgical instruments and
  - (iv) furnace parts

### 10.6.2 High Speed Steels

- These steels are meant for the manufacturing of cutting tools. As the amount of heat generated during metal cutting is very high, these tools are required to retain their hardness even at elevated temperatures.
- When tools fail to retain their hardness at elevated temperature, they tend to become soft and fail to perform any cutting. This is the reason why high carbon steels are not used at high cutting speeds and this has necessitated the need of special alloy steels called high speed steels. The property of retaining hardness and toughness at elevated temperatures is called red hot hardness.
- High speed steel has:
  - (i) tungsten 18%
  - (ii) chromium 4%
  - (iii) vanadium 1%
- The high speed steel with 18:4:1 composition is most commonly used tool material as it has good:
  - (i) hardness
  - (ii) corrosion resistance
  - (iii) toughness at high temp.

### 10.6.3 High Temperatures Resisting Alloys

- These are also called super alloys. Super alloys have high nickel-based steels which have high red-hot-hardness.

### 10.6.4 Magnetic Steels

- Carbon, chromium, tungsten and cobalt steels are used for permanent magnets as these steels have high magnetic retentive power.
- A typical alloy may have iron, nickel, cobalt, aluminium, chromium and manganese.

### 10.6.5 Cryogenic Steels

- Cryogenic steels are nickel-based steels. Cryogenic steels are used to store and transport liquefied gases below the temperature of  $-157.5^{\circ}\text{C}$ .
- To serve this purpose, various nickel based cryogenic steels are used. As the nickel percentage increases, the nickel based steels can handle gasified liquid of more lower temperature.
- For example, 5% nickel based steel can work suitably at  $-120^{\circ}\text{C}$  while 9% nickel is suitable at  $-190^{\circ}\text{C}$ .

### 10.6.6 Manganese steels

They are also called had field steel.

- They contains carbon 0.15% and manganese less than 2%.
- There type of steels are having high abrasive resistance and hard.
- Their main applications are making bulldozers, railway equipments connecting rods, cranks and Agricultural machinery equipments.

### 10.6.7 Free cutting steels

- These type of steels have high sulphur in the form of manganese sulphide at grain boundaries. MnS have low shear strength so this decreases power consumption during machining. So it is also called machining steel.
- Free cutting steel is used for screws, nails and mass production of bolts and nuts.

### 10.6.8 Tool and Die steel

- These are mainly used for making dies, tools and punches.
- These types of alloy steels have impact toughness, high strength and high wear resistance at room and elevated temperature.

**10.6.9 Killed and Semikilled Steel**

- To produce killed steel  $O_2$  is passed through liquid iron to convert coke into  $CO_2$ . When supply of  $O_2$  is stopped, a portion of  $O_2$  will trap in the liquid iron pool. Silicon is added to remove this  $O_2$ . Silicon after combining with  $O_2$  produces  $SiO_2$ . When quantity of silicon is such that complete  $O_2$  is removed then it is called killed steel.

When the removal of  $O_2$  is partial then this is called semikilled steel.

- Killed steel is free from blow holes and porosity but semikilled steel have some porosity.

**10.6.10 Rimmed Steel**

- Rimmed steel is a low carbon steel with carbon % less than 0.15.
- Rimmed steel involves the least deoxidation and has clean surface and is easily bendable.
- Rimmed steel contains an amount of iron such that continuous generation of carbon monoxide during solidification.

**10.6.11 Weathering Steel**

- These type of steel exhibits increased resistance to corrosion when compared to conventional low carbon steel by forming a firmly protective rust coloured oxide layer.
- It is a copper chromium alloy steel.
- Weathering steel is used to make shipping containers.

**10.6.12 Dual Phase Steel**

- Dual phase steel is a type of low carbon steel which has a mixture of ferritic-martensitic microstructure.
- Dual phase steels are used for making bumpers, wheels and automotive body panels.
- It have high weldability, ductility and formability compared to steels.

**Previous ESE Prelims Questions**

**Q.1 Statement (I):** Manganese is always added to steels since it combines with the sulphur content to form manganese sulphide.

**Statement (II):** If manganese is not added, iron sulphide which is not harmful for steel, would form.

- Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
- Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I)
- Statement (I) is true but Statement (II) is false
- Statement (I) is false but Statement (II) is true

[ESE Prelims : 2017]

**Ans. (c)**

If manganese is not added, iron sulphide is formed which develops crack in the material; so formation of iron sulphide is harmful. Hence statement (II) is false.

**Q.2** Malleable cast iron is produced

- By quick cooling of cast iron.
- By adding magnesium to molten cast iron.
- From white cast iron by annealing.

Which of the above statements is/are correct?

- 1 only
- 2 only
- 3 only
- 1, 2 and 3

[ESE Prelims : 2018]

**Ans. (c)**

**Q.3** **Statement (I)** : Mechanically, pearlite has properties intermediate between the soft ductile ferrite and the hard brittle cementite.

**Statement (II)** : Alpha iron can be made magnetic above 768°C.

- (a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)  
 (b) Both Statement (I) and Statement (II) are individually true, but Statement (II) is not the correct explanation of Statement (I)  
 (c) Statement (I) is true, but Statement (II) is false  
 (d) Statement (I) is false, but Statement (II) is true

[ESE Prelims : 2018]

**Ans.** (c)

Alpha iron is magnetic below 768°C (Curie temperature). Hence statement II is wrong.



### Objective Brain Teasers

**Q.1** Mild steel belongs to the following category

- (a) low carbon steel  
 (b) medium carbon steel  
 (c) high carbon steel  
 (d) alloy steel

**Q.2** Mild steel is an alloy of iron and carbon with percentage of carbon ranging from

- (a) upto 0.2%                      (b) 0.15-0.3%  
 (c) 0.3-0.5%                      (d) above 0.5%

**Q.3** Which of the following is purest form of iron

- (a) pig iron                      (b) cast iron  
 (c) wrought iron                      (d) steel

**Q.4** **Assertion (A)** : Cast iron is generally hard, brittle and wear resistant.

**Reason (R)** : Cast iron contains more than 20% carbon and as such the percentage cementite in it is higher.

- (a) both A and R are true and R is the correct explanation of A  
 (b) both A and R are true but R is not a correct explanation of A  
 (c) A is true but R is false  
 (d) A is false but R is true

**Q.5** In malleable iron carbon is present in the form of

- (a) cementite  
 (b) free carbon  
 (c) flakes  
 (d) rosettes

**Q.6** The hardness of steel increases if it contains

- (a) Austenite                      (b) Martensite  
 (c) Pearlite                      (d) Cementite

**Q.7** Consider following options and choose the correct option about carbon as alloying element in iron.

It is an example of

- (a) substitutional solution  
 (b) interstitial solid solution  
 (c) intermetallic compounds  
 (d) all of the above

**Q.8** Consider the following statements and choose the correct options with respect to mild steel:

1. It has high ductility
2. It has yield strength same in both tension and compression

Which of the above statement is/are correct?

- (a) 1 only                      (b) 2 only  
 (c) Both 1 and 2                      (d) Neither 1 nor 2

**Q.9** Addition of magnesium to cast iron increases its

- (a) hardness  
 (b) ductility and strength in tension  
 (c) Corrosion resistance  
 (d) creep strength

[ESE : 1995]

**Q.10** A given steel test specimen is studied under metallurgical microscope. Magnification used is 100 X. In that different phases are observed. One of them is  $\text{Fe}_3\text{C}$ .

The observed phase  $\text{Fe}_3\text{C}$  is also known as

- (a) ferrite                      (b) cementite  
 (c) austenite                      (d) martensite

[ESE : 1997]

**Q.11** In low carbon steels, presence of small quantities sulphur improves

- (a) weldability (b) formability  
(c) machinability (d) hardenability

[ESE : 1995]

**Q.12** Consider the following statements:

1. Cast Iron has poor ability to damp vibrations.
2. Cast Iron has higher compressive strength compared to that of steel.
3. Cast Iron parts are suitable where permanent deformation is preferred over fracture.

Which of these statement(s) is/are correct?

- (a) 1, 2 and 3 (b) 1 and 3  
(c) 3 only (d) 2 only

[ESE : 2005]

**Q.13** Which of the following pairs regarding the effect of alloying elements in steel are correctly matched?

1. Molybdenum : Forms abrasion resisting particles
2. Phosphorous : Improves machinability in free cutting steels
3. Cobalt : Contributes to red hardness by hardening ferrite
4. Silicon Reduces oxidation resistance

Which of these statements are correct?

- (a) 2, 3 and 4 (b) 1, 3 and 4  
(c) 1, 2 and 3 (d) 1, 2 and 4

[ESE : 1996]

**Q.14 Assertion (A) :** Austenitic stainless steel contains 18% chromium and 8% nickel. Since it retains its austenitic structure at room temperature, it is called austenitic stainless steel.

**Reason (R) :** Chromium present in the steel improves its corrosion resistance by forming a thin film of chromium oxide on the surface.

- (a) both A and R are true and R is the correct explanation of A  
(b) both A and R are true but R is not a correct explanation of A  
(c) A is true but R is false  
(d) A is false but R is true

[ESE : 1997]

**Q.15** Match **List-I** (Alloying element in steel) with **List-II** (Property conferred on steel by the element) and

select the correct answer using the codes given below the lists:

**List-I**

- A. Nickel  
B. Chromium  
C. Tungsten  
D. Silicon

**List-II**

1. Corrosion resistance
2. Magnetic permeability
3. Heat resistance
4. Hardenability

**Codes:**

	A	B	C	D
(a)	4	1	3	2
(b)	4	1	2	3
(c)	1	4	3	2
(d)	1	4	2	3

[ESE : 1998]

**Q.16** Match **List-I** (Steel type) with **List-II** (Product) and select the correct answer using the codes given below the lists:

**List-I**

- A. Mild steel  
B. Tool steel  
C. Medium carbon steel  
D. High carbon steel

**List-II**

1. Screws
2. Commercial beams
3. Crane hooks
4. Blanking dies

**Codes:**

	A	B	C	D
(a)	2	4	1	3
(b)	3	1	4	2
(c)	2	1	4	3
(d)	3	4	1	2

[ESE : 2004]

**Q.17** Match **List-I** (Alloying Element) with **List-II** (Effect on Steel) and select the correct answer using the codes given below the lists:

**List-I**

- A. Vanadium  
B. Molybdenum  
C. Silicon  
D. Chromium

**List-II**

1. Increases endurance strength
2. Improves creep properties
3. Increases hardness
4. Increases resistance to high temperature oxidation

**Codes:**

	A	B	C	D
(a)	2	1	3	4
(b)	1	3	2	4
(c)	2	1	4	3
(d)	1	2	4	3

[ESE : 2005]

**Q.18** Match **List-I** (Steel) with **List-II** (Application) and select the correct answer using the codes given below the lists:

**List-I**

- A. Mild Steel
- B. Tool Steel
- C. High Carbon Steel
- D. Medium Carbon Steel

**List-II**

- 1. Ball bearing
- 2. Cold chisels
- 3. Shaft and axles
- 4. Rolled steel sections

**Codes:**

	A	B	C	D
(a)	2	1	4	3
(b)	4	3	2	1
(c)	2	3	4	1
(d)	4	1	2	3

[ESE : 2005]

**Q.19** Vanadium in high speed steel :

- (a) Has a tendency to promote decarburization
- (b) Forms very hard carbides and thereby increases the wear resistance of the tool
- (c) Helps in achieving high hot hardness
- (d) Has a tendency to promote retention of Austenite

[ESE : 2013]

**Q.20** Consider the following statements:

Machine tool beds are made using grey cast iron due to

- 1. high tensile strength and ductility
- 2. high compressive strength and damping property
- 3. castability and low cost of production
- 4. machinability and low material cost

Which of the above statements are correct?

- (a) 1, 2 and 3 only
- (b) 1, 3 and 4 only
- (c) 2, 3 and 4 only
- (d) 1, 2, 3 and 4

[ESE : 2014]

**Q.21** Which one of the following alloying elements increases the corrosion resistance of steel?

- (a) Vanadium
- (b) Chromium
- (c) Nickel
- (d) Copper

[ESE : 2015]

**Q.22** A suitable material for audio and TV transformers is

- (a) ferrite
- (b) Fe-4% Si
- (c) Fe-30% Ni
- (d) very pure Fe

**Q.23** Grey cast iron is

- (a) gray color iron
- (b) iron where all the carbon is in combined form
- (c) iron where part of the carbon is in graphite form
- (d) graphite present is in spherical form

**Q.24** Chief constituent present in stainless steel which prevents it from corrosion is

- (a) Manganese
- (b) Carbon
- (c) Chromium
- (d) Nickel

**Q.25** By puddling process, which material is obtained from pig iron?

- (a) Cast iron
- (b) Cast steel
- (c) Steel
- (d) Wrought iron

**Q.26** Consider the following types of steel

- 1. Dead mild steel
- 2. High carbon steel
- 3. Mild Steel
- 4. Medium carbon steel

Arrange the above types of steel in ascending order of carbon content.

- (a) 1, 4, 3, 2
- (b) 2, 1, 3, 4
- (c) 1, 3, 4, 2
- (d) 2, 4, 3, 1

**Q.27** Which of the following factors influence hardness in a plain carbon steel?

- 1. Percentage carbon
- 2. Quenching media
- 3. Work size

Select the correct answer using the code given below :

- (a) 1 and 2 only
- (b) 2 and 3 only
- (c) 1 and 3 only
- (d) 1, 2 and 3

[ESE : 2007]

**Answers**

1. (a) 2. (b) 3. (c) 4. (c) 5. (d)  
 6. (d) 7. (b) 8. (c) 9. (b) 10. (b)  
 11. (c) 12. (d) 13. (c) 14. (b) 15. (a)  
 16. (d) 17. (d) 18. (d) 19. (b) 20. (c)  
 21. (b) 22. (a) 23. (c) 24. (c) 25. (d)  
 26. (c) 27. (d)

**Explanations**

10. (b)  
Cementite has  $\text{Fe}_3\text{C}$  composition, inter metallic compound.
11. (c)  
Sulphur forms  $\text{MnS}$  when manganese is added which increases mechanability. Its amount is controlled because formation of  $\text{FeS}$  leads to hot shortness as  $\text{FeS}$  is low melting eutectic.
12. (d)  
Cast iron shows brittle failure and have better ability to damp vibration.
13. (c)  
Silicon are strong oxidizer.
15. (a)  
Nickel : Increases hardenability  
 Chromium : Corrosion resistance  
 Tungsten : Heat resistance  
 Silicon : Improves magnetic permeability
16. (d)  
Tool steel - Blanking die, milling cutters etc.  
 Crane hooks are preferentially made up of wrought iron which is the purest form. (in the given option mild steel only). Medium carbon steel is popularly known as machinery steel.

18. (d)  
Mild steel - structural steel  
 Medium carbon steel - machinery steel  
 High carbon steel - Tool steel.  
 The most suitable combination has to made.
19. (b)  
Cr, V, Mo are ferritic stabilizers which forms hard carbides to improve the wear resistance of the tool.
20. (c)  
The good damping capacity of grey cast iron and the high compressive strength make it suitable as a base for erection of machinery.  
 $\therefore$  statement (1) is wrong.
27. (d)  
The correct option is (d)  
 Factor affecting hardenability  
 1. Grain size  
 2. Carbon content  
 3. Alloying element  
 4. Severity of quench  
 5. Mass effect  
 It has been observed that the maximum hardness if obtained on the surface of the bar of small diameter and decreases as diameter increases. The centre-hardness continues to drop as the diameter of bar increases. To standardize this factor, the hardenability is measured in terms of depth of penetration of hardness.

