CHAPTER

6

ENGINEERING MATERIALS AND HEAT TREATMENT

LEARNING OBJECTIVES

1. To know about the various Engineering Materials and their properties and their types.
2. To know about the metals and non-metals and Ferrous and non-ferrous metals, steels and cast Iron.
3. To know, the uses of all Engineering materials.
4. To know the purpose of heat treatment.
5. To know about the heat treatment of metals.
6. To know about the various process and types of heat treatment furnace.

TABLE OF CONTENT

6.1 INTRODUCTION

- In General, material may be anything else, it is consisting of whether pure or impure, single or composite. It may be a solid, liquid, and gas. Materials can be classified based on different properties, such as physical and chemical properties, etc.
- In Industry, Materials are input for production or manufacturing processes. They may be raw material to produce things in engineering fields. Synthetic materials are used in other fields like Medical, Textile and Home Appliances. Medicines, textile, petrol, fuels, soaps, glass, polymers, cements, etc., are synthetic materials. The materials are either natural or artificial.

- Natural materials are sand, clay, stone, lime wood, etc. The artificial materials are made from natural things.
- Different types of materials are used for different application according to their properties.
- To enhance such properties of the material some treatments are applied on them. On that heat treatment is a prominent method used in engineering field to enhance the properties of the materials.

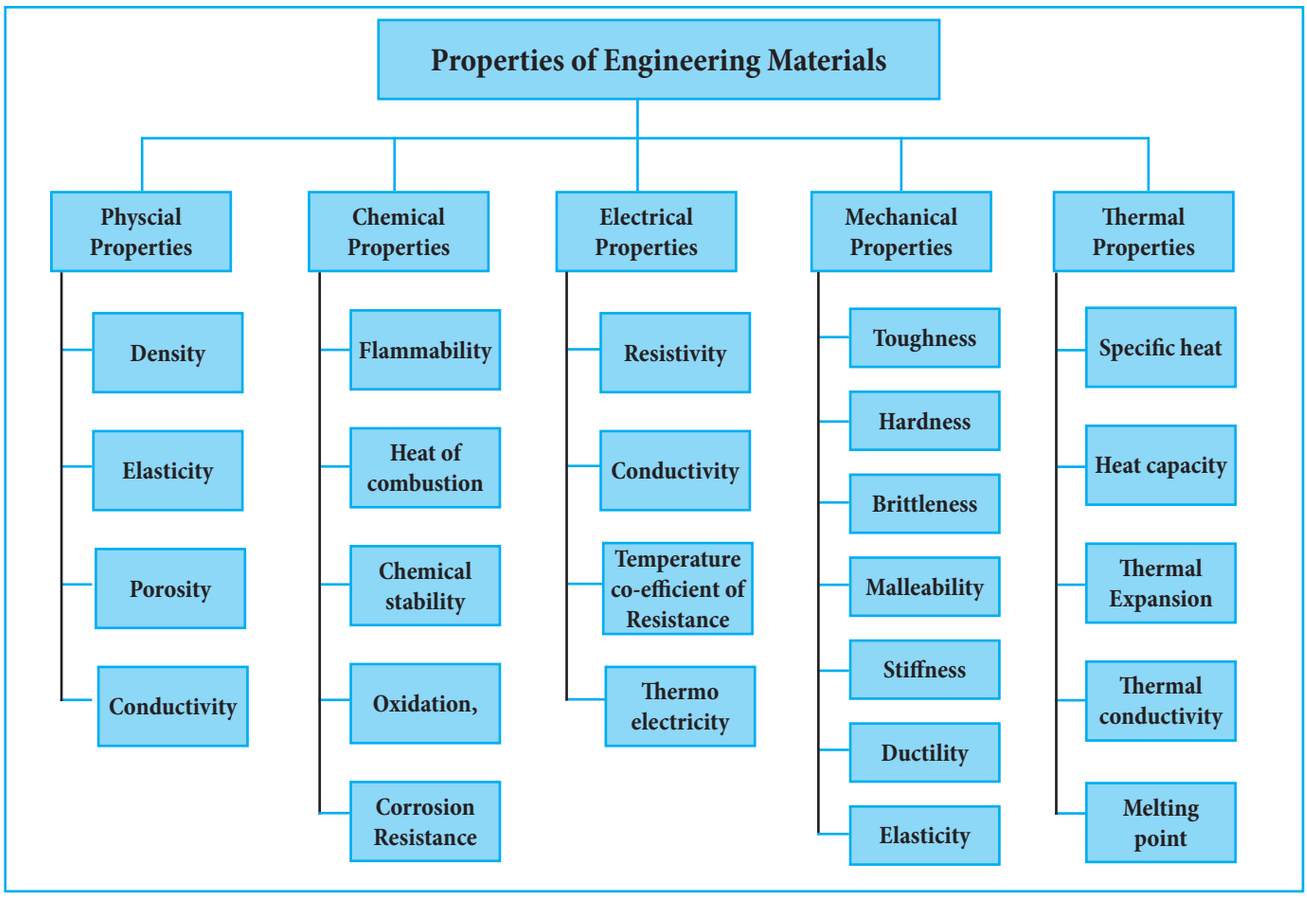
6.2 ENGINEERING MATERIALS

If we would like to fabricate an engineering part, like a hacksaw blade, we must go in search of material, like high carbon steel high speed steel which possess desirable properties as will permit the blade to perform its function successfully while in use. That is, any tool or cutting materials, should have high strength , high toughness, high hardness and high corrosion resistance. Tungsten carbide, vanadium carbide, molybdenum steels are used as tool or cutting materials using advanced technology, the high strength, abrasion resistance and heat resistance properties of metals are enhanced.

6.3 PROPERTIES OF MATERIALS

The practical application of engineering materials in manufacturing a component, we must have a thorough knowledge of their particular properties under a wide range of conditions. However, different materials have different types of properties, a few of them have important properties that are used in our engineering field.

Classification of properties	Description	Examples
Physical	Physical properties can be measured or observed without changing the composition of matter.	Density, Elasticity, Porosity, Thermal conductivity and Latent heat, Magnetic.
Chemical	Chemical properties can be measured or observed only when matter undergoes a change to become an entirely different kind of matter.	Flammability, Heat of combustion, Chemical stability. Oxidation, Corrosion Resistance.
Electrical	Electrical properties are their ability to conduct electrical current.	Resistivity, Conductivity, Temperature co-efficient of Resistance, Thermo electricity,
Mechanical	The mechanical properties of a material reflect the relationship between its response to deformation from an applied load or force.	Toughness, Hardness, Brittleness, Malleability, Stiffness, Ductility, Elasticity…
Thermal	Thermal properties are those properties of material which is related to its conductivity of heat.	Specific heat, Heat capacity, Thermal Expansion, Thermal conductivity, Melting point.



6.3.1. Mechanical Properties

Being an Engineer, we must have a thorough knowledge of mechanical properties of Engineering Materials, because they are of great importance in the design of tools, machines and structures. The most important and useful mechanical properties are briefly explained below.

Mechanical Properties	Description	Example
Toughness	Toughness is the ability of a material to withstand sudden external forces. It is the amount of energy absorbed by the material before it develops fracture.	Wrought Iron, Mild steel
Hardness	Hardness is a fundamental property which is the ability of a material to resist scratching, abrasion, and cutting.	High carbon steels, high speed steels. Diamond is the hardest material.
Brittleness	Brittleness of a material indicates that how easily it gets fractured when it is subjected to a force or load. The property of brittleness is associated with hardness.	Cast Iron

Mechanical Properties	Description	Example
Malleability	Malleability is a property of solid material which Indicates that how easily a material gets changed in shape under compressive force. Material can be formed into thin sheet by hammering (or) rolling.	Copper, Aluminium and silver
Ductility	Ductility is a property of solid materials which indicates that how easily a materials get changed in shape under tensile stress. Metals can be pulled into wire by using this property.	Copper, Aluminium, gold and silver.
Elasticity	This is the ability of a material to deform under load and regain to its original size and shape when the load is removed. Such a material is used to make springs.	Low Carbon Steel

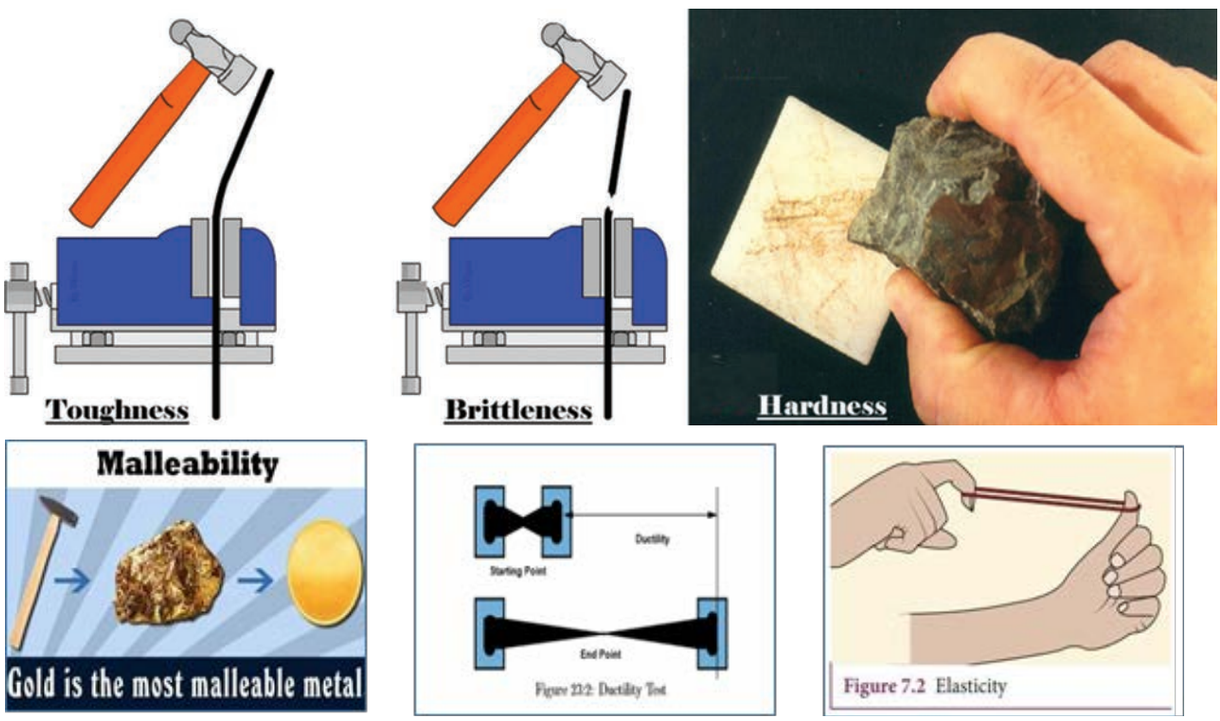
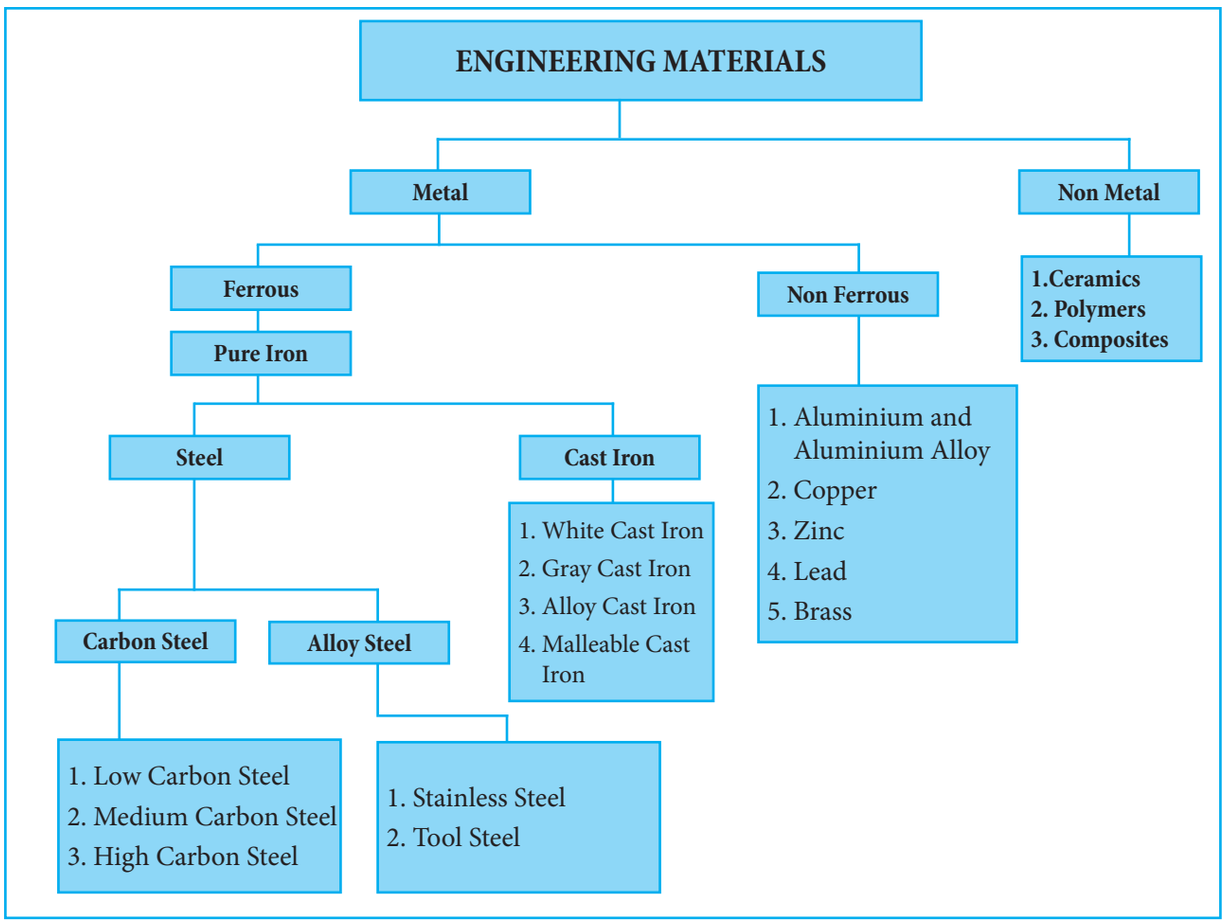


Figure 4 Toughness, Brittleness, Hardness

6.4 METALS

Metals are very useful in Industrial field. They are used to make tools because they can be strong and easy to shape. Bridges, buildings or ships are constructed by using Iron and Steel. Most metals are heavy and they melt only when they are heated at very high temperature. Heat and electricity can easily pass through metals. A lump of metals can be beaten into a thin sheet or can be pulled into thin wires. Most of the metals are solid at room temperature except mercury. Mercury is liquid at room temperature.

Metals are classified as ferrous and non-ferrous metals.



6.4.1. Ferrous Metals

Ferrous metals mostly contain Iron. They have small amounts of other metals or elements added, to give the required properties.

Pure Iron

Iron is a chemical element with symbols Fe and its atomic number is 26. It is an iron alloy with a very low carbon (0.1%) content. It is commercially known as pure Iron. It is relatively softer.

Types of ferrous metals

1. Steel
2. Cast Iron

Steel

Steel is an alloy of iron, carbon and other elements. It has carbon content range from 0.1% to 0.15%. Because of its high tensile strength and low cost, it is a major component used in buildings, infrastructure, tools, ships, automobiles, machines and weapons.

Steel can be broadly classified into two groups based on their chemical compositions:

1. Carbon Steel
   a. Low Carbon Steels
   b. Medium Carbon Steels
   c. High Carbon Steels
2. Alloy Steel
   a. Stainless Steel
   b. Tool Steel

Carbon Steel: Carbon steel or steel is a metal alloy. It is a combination of two metals. It is a combination of two elements like Iron and carbon. Other elements are present in small quantities. As carbon content rises the metal becomes harder and stronger but less

ductile and more difficult to weld. Carbon steels are further classified into three on the basis of percentage of carbon.

a) Low carbon steels or mild steels contain up to 0.3%of carbon.
b) Medium carbon steels contain 0.3% to 0.6% carbon.
c) High carbon steels contain 0.6% to 1.7% of carbon.

Alloy Steels: Alloy steels contain alloying elements (Example Manganese, silicon, nickel, titanium, copper, chromium and aluminum) in varying proportional in order to manipulate the steel's properties, such as its harden ability corrosion resistance, strength, weldability or ductility.

It is used for making pipes, spare part of vehicle, transformer, power generator and electrical motors.

a) **Stainless Steel:** The oxide film protects the surface of the steel from chemical reaction and rusted stains are not formed on the surface of the steel, hence it is called stainless steel. Stainless steel is generally contains 10-20% of chromium as the alloying elements. It is notable for its corrosion resistance, and it is widely used for food handling and cutlery devices.

b) **Tool Steel:** Tool steel contains tungsten, molybdenum, cobalt and vanadium in varying quantities to increase heat resistance and durability, making them ideal for cutting and drilling equipment.

Tungsten Steel: High speed Tungsten steel is high carbon tool steel, containing a large dose of tungsten; a typical HSS composition is 18% tungsten, 4% chromium, 1% vanadium, 0.7% carbon and the rest, Iron.

High speed Steel: High speed steel is a cutting tool material. The alloying elements are tungsten, molybdenum, vanadium and chromium. Tool made up of these materials are used in drilling, milling, turning, threading, boring, gear cutting and many other machining operations.

Cast Iron: Cast iron is a group of iron-carbon alloy with carbon content ranges from 2% to 4.5%. This high carbon content makes them excellent materials to use for casting.

Types of cast Iron

1. White Cast Iron
2. Gray Cast Iron
3. Alloy Cast Iron
4. Malleable Cast Iron

Important effects of major alloying elements in steel:

Elements	Percentage	Effects
Nickel	2.0 to 5.0 12.0 to 20.0	Toughens the steel. Corrosion resistance and increases the ductility.
Chromium	0.5 to 2.0 2.0 to 18.0	Increases hardenability, Corrosion resistance, heat resistance.
Molybdenum	0.2 to 5.0	Forms stable carbides. Helps formation of fine grains, eliminates the brittleness.
Vanadium	0.15	Improve the elasticity, strengthen the steel.
Tungsten	Upto 20	Helps retain hardness at high temperature

6.4.2. Non-Ferrous Metals

Non-ferrous metals do not contain Iron, we can also get non-ferrous metals as alloys. Eg, brass is an alloy of copper and Zinc. Non-ferrous metals are specified for structural applications because it has lesser weight, higher strength, higher melting points. They are also used for electronic applications. Some examples of Non-Ferrous metals are given below

S.No.	Non-Ferrous Metal	Description
1.	Aluminium	Ore : Bauxite Symbol : Al Atomic Number : 13 Melting Point : 658°C Uses : Sand casting
2.	Copper	Ore : Pyrites Symbol : Cu Atomic Number : 29 Melting Point : 1083°C Uses : Electrical wires and vessels
3.	Zinc	Ore : Sphalerite Symbol : Zn Atomic Number : 30 Melting Point : 419°C Uses : Coating material in iron and steel
4.	Lead	Ore : Galena Symbol : Pb Atomic Number : 82 Melting Point : 326°C Uses : Batteries, Pipes, Soldering electrode.
5.	Brass	Alloy : Copper and Zinc Symbol : - Atomic Number : - Melting Point : 930°C Uses : Locks, Gears, Bearings, Valves

Figure 5 Aluminium, Copper, Brass

6.5. HEAT TREATMENT

Heat treatment is a process in which a metal is heated to a certain temperature and cooled in a particular manner and speed to alter its internal structure for obtaining desired degree of physical and mechanical properties.

6.6 PURPOSE OF HEAT TREATMENT

1. Improvement in ductility
2. Relieving internal stresses
3. Refinement of grain size
4. Increasing hardness or tensile strength
5. Improvement in machinability
6. Alteration in magnetic properties
7. Improvement in toughness and development of re-crystallized structure.

6.7. LOWER AND HIGHER CRITICAL TEMPERATURE

While heating a solid metals, their internal structure starts to transform at a particular temperature. This temperature is known as Lower critical temperature of the metal. On further heating, the whole internal structure is transformed at particular temperature. This temperature is called upper critical temperature.

6.8 METHOD OF HEAT TREATMENT

1. Annealing
2. Normalising
3. Hardening
4. Tempering
5. Case Hardening
   a. Carburising
   b. Nitriding
   c. Cyaniding
   d. Flame Hardening

6.8.1. Annealing

Annealing is a process in which a metal is heated to a particular high temperature, held there for a period of several hours or several days, and allowed to cool slowly, by using sand, lime or ashes. This process is mainly applied to produce softening.

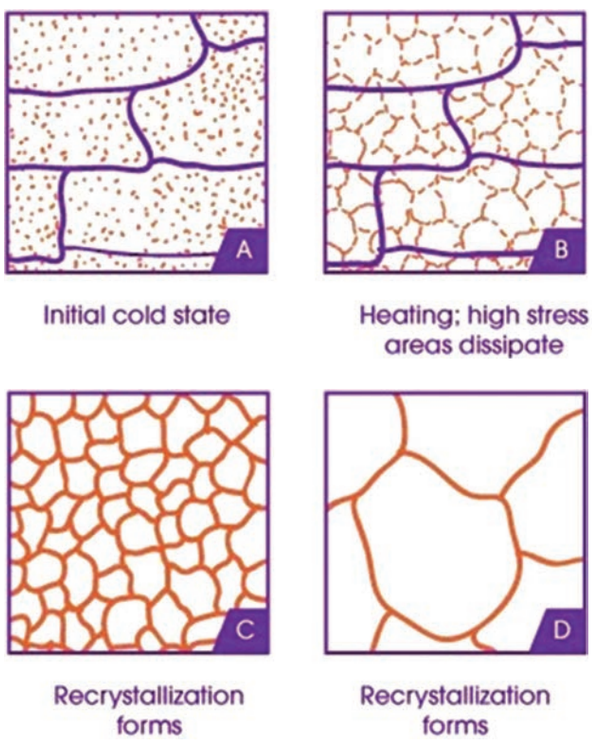


Figure 6 Annealing Process

Process of Annealing

1. In this process low carbon steel is heated to 30°C to 50°C above the higher critical temperature.
2. Maintain it in the same temperature for a considerable period of time.
3. Then the metal is slowly cooled by placing in to sand, ashes or lime that insures a slow rate of cooling.
4. Oil fired furnace, gas fired furnace or sintering (Electrical) furnace are used for heating.

The temperatures are monitored by thermocouple.

Purpose of Annealing

1. To soften the steel.
2. To improve machinability.
3. To increase ductility and toughness.
4. To relieve internal stresses.
5. To refine grain size.
6. To improve homogeneity

6.8. Normalising

Normalizing is a process in which a steel is heated above the critical temperature, holding for a period of time, and allowed to cool by air. The transformation of Internal structure are occurred during the cooling process.

After forging, rolling and casting, the steel parts are distorted in its structure. In this case, Normalizing is done to rectify the internal structure of the parts to its original position.

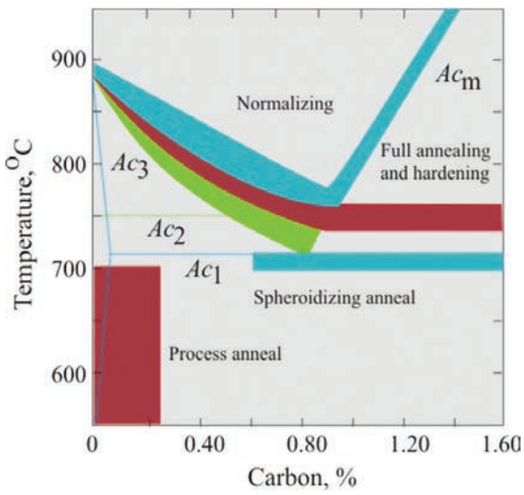


Figure 7 Normalising Chart

Process of Normalizing

1. In this process the steel is heat to 50°C above the higher critical temperature Holding it at that temperature for approximately 15 minutes
2. Cooling it in air

Purpose of Normalizing

1. To refine the grain size
2. To remove internal stresses
3. To improve machinability
4. To improve strength
5. For homogeneous structure

6.8.3. Hardening

This process makes the material stronger.

Process of Hardening

1. In the process of hardening, the steel is heated to the above critical temperature (from 750°C to 850°C)
2. Holding it at the temperature for a considerable period of the time and quenching it in water, oil or salt bath.
3. Hardness is depending on the following factors,
   a) Carbon content
   b) Rate of cooling
   c) Work size

Purpose of Hardening

1. To increase the hardness of the metal
2. To resist wear and enable it to cut other metals.
3. To improve strength, elasticity, toughness and ductility.

6.8.4. Tempering

Commonly used in steel making, tempering is a heat treatment used to improve hardness and toughness in steel as well as to reduce brittleness. The tempering process creates a more ductile and stable structure. If the steel (or) any tool is very hard it will brittle. So the tempering operation is done to reduce the brittleness.

Process of Tempering

1. The steel is heat at below lower critical temperature after hardening.
2. Holding it for a considerable time.
3. Then cooling it slowly.

Purpose of Tempering

1. To decrease the brittleness of hardened steel.
2. To achieve the best mechanical properties in metal
3. To stabilize the structure of metal.
4. To increase the toughness of steel.
5. To improve ductility.

6.8.5. Case Hardening

Case hardening is a process that is used to harden the outer surface of the metal while manufacturing a soft inner metal case. The case hardening process involves infusing addition carbon into the surface layer. In this process, chemical reaction made on the steel.

Purpose of case hardening

1. To provide adequate wear resistant on the surface.
2. To improve corrosion resistance
3. To improve heat resistance
4. To increase life of components made from low cost material.

Few processes of case hardening are

1. Carburizing
2. Nitriding
3. Cyaniding
4. Flame Hardening

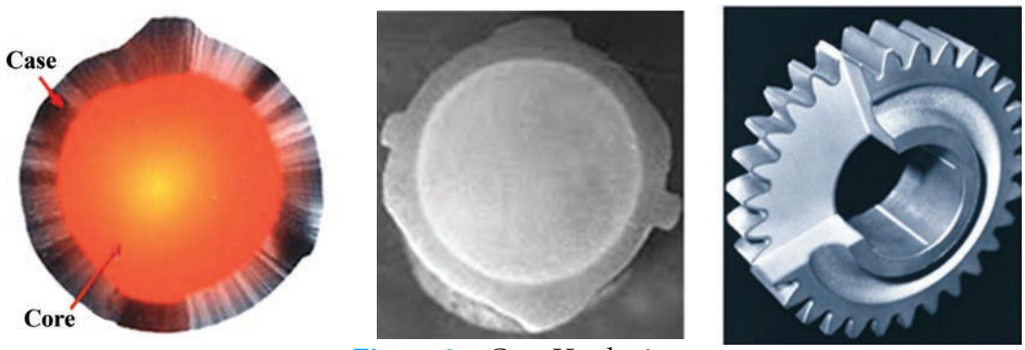


Figure 8 Case Hardening

Particulars	Carburizing	Nitriding	Cyaniding
Principle	Carbon is added to the surface	Nitrogen is added to the surface	Carbon and nitrogen are added to the surface
Surface Produced	Hard High carbon surface is produced on low carbon steel	Very hard nitride surface is produced on already hardened steel.	Carbon and nitride is produced on the surface of low carbon steel.
Temperature to be Maintained	900- 930°C	500- 575°C	800- 900°C
Quenching	Oil or Water	No Quenching required	Oil or water
Depth to be Hardened	0.1 - 0.25 mm	Upto 0.5 mm	Upto 0.4 mm
Application	Gears, Camshaft bearings	Crank pins, Shafts, Cutting tools	Screws, Nuts, Bolts, Gears, Cam etc.

6.9 QUENCHING

Quenching is sudden cooling process. It is done after the metal is heated. It is done with the water, oil or high pressure air.

The materials used for quenching are,

1. Sodium Solution
2. Cool Water
3. Salt Baths
4. Grade of Oil
5. Air

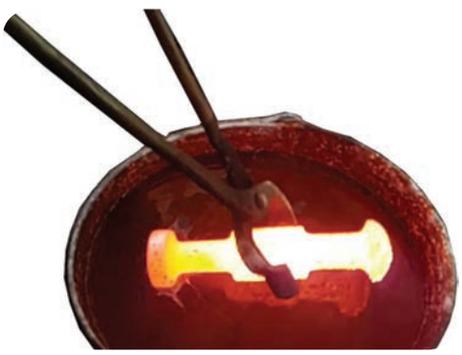


Figure 9 Quenching

6.10 HEAT TREATMENT FURNACES

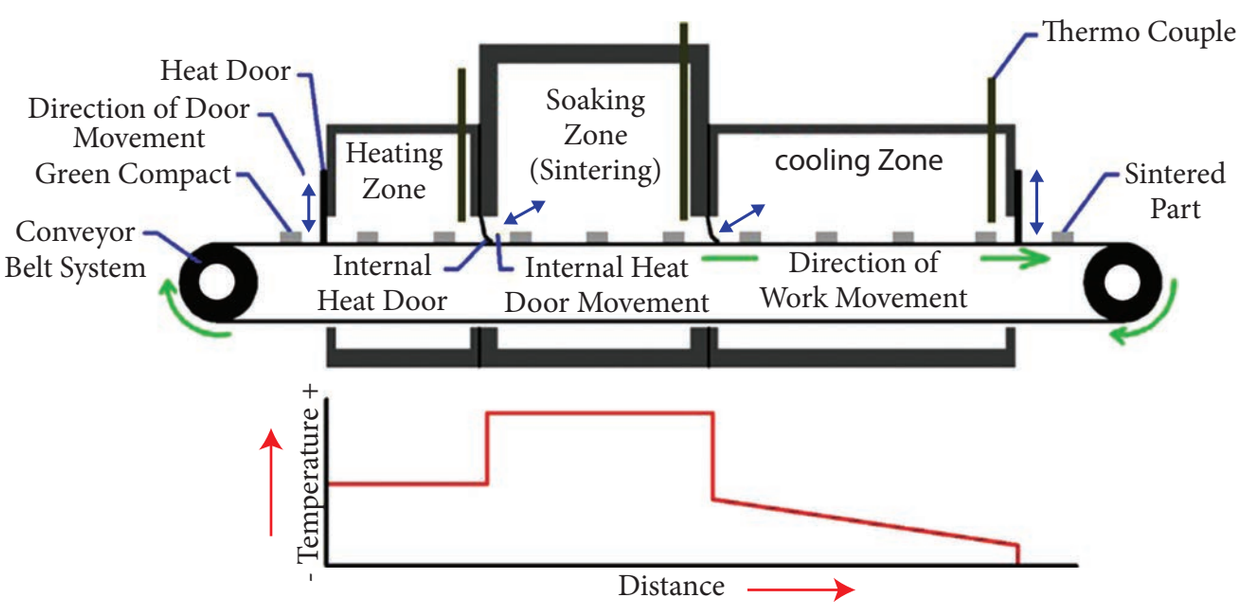
Some common types of heat treatment furnaces are mentioned below

1. Sintering Furnace
2. Oil fired Furnace
3. Gas fired Furnace
4. Salt bath Furnace

SINTERING FURNACE

Sintering furnace is one of the electric furnace. heat is supplied by passing electricity in a coil and it has three zones, namely heating zone, soaking zone and cooling zone. Heat is controlled by thermostat and the temperature is measured by thermocouple. Component is placed in the tray which is passed through the furnace by means of iron belt conveyers.

The component is heated in the heating zone, then it is maintained at the sintering temperature in the soaking zone. Finally the component is cooled in the cooling zone. In this process, increasing and decreasing of the Iron belt conveyers is controlled by the controlling unit



Glossary

1.	Brittleness	– சிதறும் தன்மை
2.	Malleability	– தகடாக நீளும் தன்மை
3.	Ductility	– கம்பியாக நீளும் தன்மை
4.	Elasticity	– மீள்தன்மை
5.	Galvanizing	– துத்தநாக முலாம் பூசுதல்
6.	Annealing	– மிருதுவாக்குதல்
7.	Hardening	– கடினப்படுத்துதல்
8.	Case Hardening	– புறக் கடினமாக்கல்
9.	Quenching	– விரைவாக குளிரச்செய்தல்
10	. Sintering Furnace	– மின்சார உலை

Activities

1. Collect small quantity of any Engineering Materials
2. List out the brittleness Materials.
3. Visit any one of the blacksmith workshops and submit the report. What are the various processes done there?

QUESTIONS

PART A

I. Choose the correct option :

1. corrosion resistance is
   a. Physical property
   b. Chemical property
   c. Electrical property
   d. Mechanical property

2. Elastic property is
   a. Physical property
   b. Mechanical property
   c. Electrical property
   d. Chemical property

3. Which material has brittleness property?
   a. Steel b. Copper
   c. Cast Iron d. Aluminium

4. Which material has elastic property?
   a. Steel b. Mild Steel
   c. Copper d. Spring

5. The atomic number of Pure Iron is
   a. 16 b. 26
   c. 6 d. 46

6. Which steel is used for making transformers?
   a. Carbon Steel b. Alloy Steel
   c. Tool Steel d. High Speed Steel

7. Which kind of steel is used to make milling tools?
   a. Carbon Steel
   b. Tool Steel
   c. Stainless Steel
   d. High Speed Steel

8. The Carbon content in Cast Iron is,
   a. 2% to 3% b. 2% to 4%
   c. 2% to 4.5% d. 2% to 5%

9. Which one is added to the surface of the steel while nitriding.
   a. Carton and Nitrogen
   b. Nitrogen
   c. Carbon
   d. Hydrogen

10. The Purpose of tempering is,
   a. To improve corrosion resistance
   b. To increase the hardness of the metal
   c. To decrease the brittleness
   d. To improve machinability

11. _____ is a method or case hardening
   a. Tempering b. Annealing
   c. Cyaniding d. Hardening

12. The temperature used for pack carburising is at/
   a. 925°c b. 750°c to 850°c
   c. 80°c to 50°c above the higher critical temperature
   d. 500°c to 600°c

PART B

II. Answer the following questions in one or two sentences:

13. List out some Engineering properties.
14. List out some Electrical properties.
15. What are different types of Steel.
16. What are the three kinds of carbon Steel.
17. What is mean by Stainless Steel?
18. Define "Heat treatment".
19. What are the methods of heat treatment?
20. What is lower critical temperature and upper critical temperature?

PART C

III Answer the following questions in about a page.

21. What are the properties of engineering materials and write short notes any two of them?
22. Explain the different kinds of Tool Steel
23. Write any five points about the purpose of Heat treatment.

PART D

IV. Answer the following questions in detail:

24. What are the mechanical properties of engineering materials and explain any four?
25. Explain the neat sketch of sintering furnase.