WEEK-02

Heat Treatment of Steel, Objectives, Types, Annealing (Ductility) Normalizing (Machinability), Hardening (Hardness), Tempering (reduce hardness/ brittleness), Case Hardening – Carburizing, Nitriding, Cyaniding, Surface hardening- Induction Hardening, Flame hardening

HEAT TREATMENT OF STEEL:

Heat treatment is defined as controlled heating and cooling of a metal (steel) component in order to alter its physical and mechanical properties such as hardness, tensile strength, ductility, toughness and wear resistance, without changing the shape as well as chemical composition of the component.

Purpose or Objectives of Heat Treatment:

Heat treatment is carried out to achieve one or more of the following objectives

1. To improve mechanical properties such as tensile strength, impact resistance, ductility etc in metals, especially steels.
2. To increase the toughness or resistance to fracture of the metal.
3. To produce hard surface and tough interior portions.
4. To improve machinability
5. To refine the grain structure after hot working a metal.
6. To improve magnetic and electric properties.

Types of Heat Treatment Process:

The following heat treatment processes are

1. Annealing
2. Normalizing
3. Hardening
4. Tempering
5. Austempering
6. Surface hardening
    - Case hardening or carburizing
    - Cyaniding
    - Nitriding
    - Induction hardening
    - Flame hardening

Steps Involved in Heat Treatment:

1. **Heating:**

- The metal is heated to specific temperature depending on the type of metal and desired properties.
- Heating is done below or above the critical temperature depending on the process.
- The heating rate should be controlled to avoid thermal stresses and distortion.

2. **Soaking:**

- Once the desired temperature is reached, the metal is geld (soaked) at the temperature for specific time.
- This allows the metals internal structure to transform uniformly.
- Soaking time depends on size of the parts and the types of metal.

3. **Cooling:**

- After soaking, the metal is cooled at a controlled rate to obtain desired mechanical properties.

4. **Reheating (in some cases):**

- Some processes involve reheating to a lower temperature to reduce brittleness and improve toughness.

ANNEALING:

Annealing is heat treatment process, in which the metal is heated to a high temperature, holding (soaking) it there for a considerable time, and then allowing it to cool to room temperature at a predetermined rate.

Purpose of annealing:

The purpose of annealing is to achieve the following objectives:

1. Soften the metal, so improve machinability, formability.
2. To improve ductility.
3. To relieve internal stresses.
4. Refine grain structure.

Types of annealing:

1. Full annealing
2. Process annealing
3. Stress-relief annealing

Applications:

Steel & steel alloys, rails, wires, machine parts and cutting tools.

NORMALIZING OR AIR QUENCHING:

Normalizing is heat treatment process, in which metal is heated to about 50^{o}C above the upper critical temperature, holding it there for certain duration, and then allowing it to cool in the surrounding air to room temperature.

Purpose of Normalizing:

1. To refine the grain structure.
2. To improve machinability.
3. Reduces internal stresses.
4. To obtain a relatively good ductility without reducing the hardness and strength.

Applications:

Used in carbon steel & steel alloys, shafts, gears and automotive components.

HARDENING OR QUENCHING:

Hardening is a heat treatment process carried out in order to increase the hardness of steel. Hardening involves heating steel with a suitable carbon percentage to temperature about 30-50^{o}C above the upper critical temperature, so as to produce an austenite structure. It is held at this temperature for a duration of about 15-30 minutes per 25mm of cross section of steel specimen and then cooled rapidly(Quenched) in a suitable say water, oil or brine etc.

Purpose of hardening:

1. To increase the hardness of the steel for improving their cutting ability.
2. To increase the hardness of the steel articles to improve their wear resistance.
3. To improve magnetization property of steel by increasing its hardness for producing a permanent magnet.

Applications:

Cutting tools, knives, dies, punches, & springs.

TEMPERING:

Tempering is a heat treatment process that reduces the brittleness of steel without significantly lowering its hardness and strength. Tempering is done immediately after quench hardening, when the steel cools to about 40^{o}C. The process involves reheating the hardened steel to a temperature below the lower critical temperature followed by a slow cooling in air.

Purpose of Tempering:

1. To reduce brittleness of hardened steel (ductility increases).
2. To improve toughness of steel.
3. To relieve internal stresses.
4. Increase percentage elongation at high temperature.

Applications: Tools, machine components, automotive parts like gears, axils, springs & steel in constructions.

CASE HARDENING:

Case hardening is the process of hardening the surface of a metal object while allowing the metal deeper to remain soft thus forming a thin layer of harder metal at the surface. Case hardening is simple method of hardening steel. It is less complex than hardening and tempering.

Types of Case Hardening:

1. Carburizing
2. Nitriding
3. Cyaniding

Carburizing:

Carburizing is a method of introducing (adding) carbon to the surface of low carbon steels in order to produce a hard surface, while the inner core remains soft and ductile. Carburizing increases the carbon content of the steel surface by process of absorption and diffusion. Carburizing process is usually carried out on low carbon steels containing less than about 0.2%C.

Applications: Gears, cam shafts, pins, pistons, bearings etc.

Nitriding:

Nitridng is a process in which the steel is heated in a nitrogen (N_2) –rich gas (like ammonia, NH_3) at a temperature of about 500-550^oC. As a result nitrogen atoms diffuse into the surface, forming hard nitrides. This produces a very hard, wear-resistance and corrosion-resistance surface layer without the need for quenching.

Applications:

Aircraft engine parts, aero engine cylinder, crank pins, gears, fuel injection pumps etc.

Cyaniding:

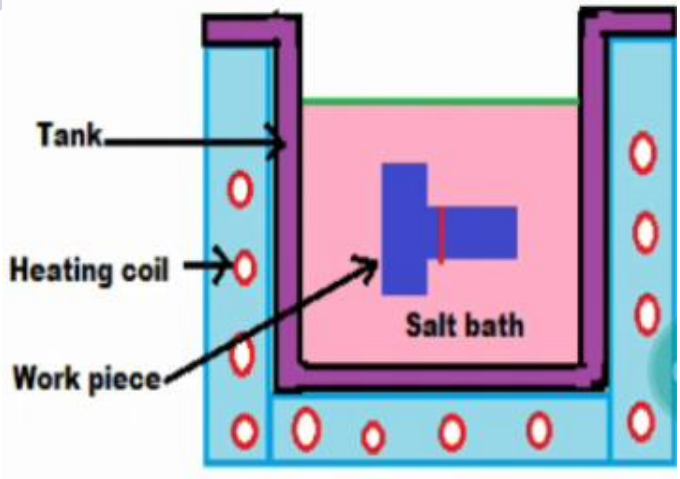

Figure: Cyaniding

Cyaniding is also called as liquid carburizing. Cyaniding is mainly used on low carbon steels. In this process in which both carbon and nitrogen are absorbed by metal surface to get it hardened. After heating the piece of low carbon steel is immersed in a bath of cyanide salt such as sodium cyanide maintained at 850 to 950^{o}C.The immersed steel piece is left in molten cyanide salt bath at the above temperature for about 15 to 20 minutes. It is then taken out of bath and quenched in water or oil.

Applications:

Small components like bolts, screws, small gears and tools.

SURFACE HARDENING:

It is a heat treatment process in which only the surface of a metal is hardened by heating and rapid cooling (quenching), without changing its chemical composition. This produce a hard outer surface and tough inner core, improving wear resistance while maintaining toughness.

Types of surface hardening.

1. Induction hardening
2. Flame hardening

Induction hardening:

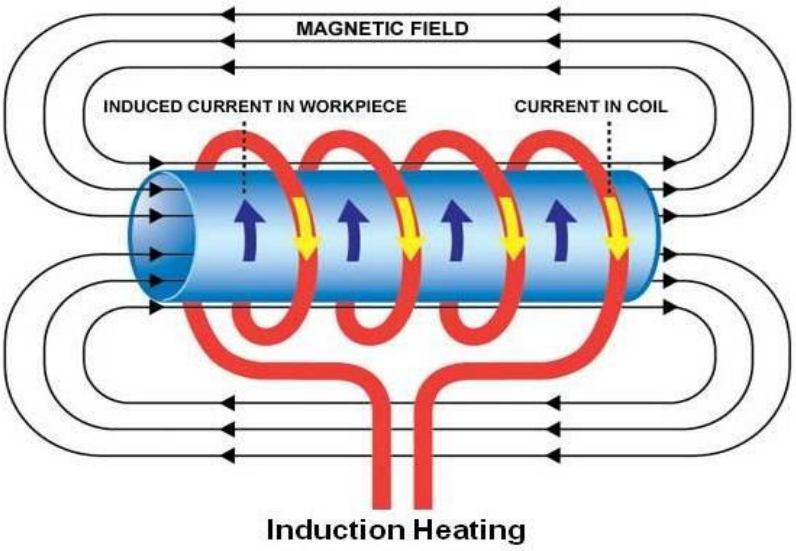

Figure: Induction Hardening

- It is a process in which the surface of the steel is heated by electromagnetic induction using a high frequency alternating current.
- The steel part is placed inside a coil that generates an alternating magnetic field, inducing eddy currents on surface.
- These eddy current rapidly heat the surface layer to a temperature of about 750-950^{o}C, while the core remains relatively cool.

- After heating, the surface is immediately quenched with water or oil, converting the surface austenite into hard martensite.

Applications: Gears, crankshafts, axles, shafts, camshafts and machine spindles.

Flame hardening:

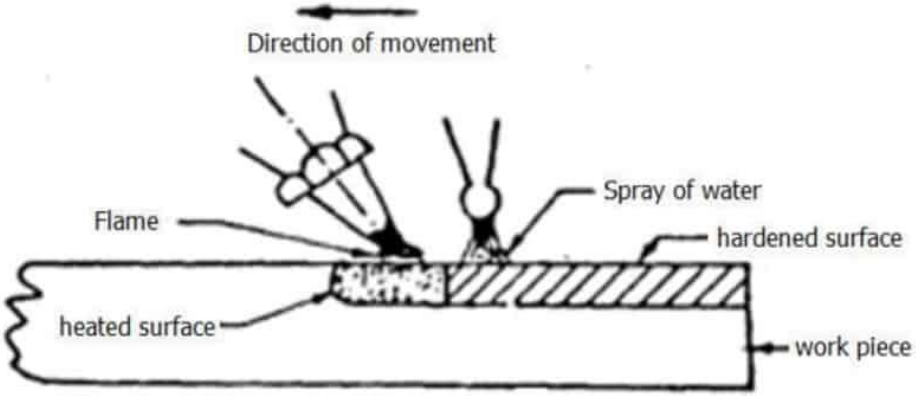

Fig: Principle of flame hardening

Figure: Flame Hardening

- It is a process in which the surface of steel is heated using a high temperature oxy-acetylene flame and then rapidly quenched with water, oil or air.
- The flame is directed only at the surface to heat it to the austenitizing temperature about 800-950^{o}C.
- After reaching this temperature, the surface is quickly cooled forming martensite on the surface while the core remains tough.

Applications: Gear teeth, cams, shafts, rails and machine ways.

COMPARISON BETWEEN CASE HARDENING AND SURFACE HARDENING:

Feature/Aspect	Case hardening	Surface hardening
Material type	Low carbon steel	Alloy steels and stainless steels
Wear resistance	High surface wear resistance	High surface wear resistance but shallower layer than case hardening
Process Duration	Longer duration	Shorter duration
Hardness Depth	Relatively deep hardened layer (0.5 - 2 mm typical)	Usually shallow hardened layer (0.1-0.5 mm)
Applications	Gears, shafts, cams and bearing surface made of low carbon steels	Stainless steel or alloy steel parts like spring,knives,cutting tools and precision components
Cost	Moderate to high depending on depth and method	Usually lower for small treatments, high for laser

EXERCISES

MULTIPLE CHOICE QUESTIONS AND ANSWERS

1. For steel, which one of the following properties can be enhanced upon annealing?

   a) Harness b) Toughness c) Ductility d) Resilience

   Ans: c)

2. In normalizing, cooling is done in which of the following medium?

   a) Air b) water c) Oil d) Furnace

   Ans: a)

3. Cyaniding is usually done for _____

   a) Plain carbon steel b) Cast iron c) Stainless steels d) Pig iron

   Ans: a)

4. Which of the process needs no quenching?

   a) Induction hardening c) Flame hardening

   b) Nitriding d) Carburizing

   Ans: b)

5. How is the heating of surface done in flame hardening technique?

   a) Oxy-acetylene torch b) Carburizing flame c) Electrode d) Direct sunlight

   Ans: a)

6. What are the applications of Nitriding?

   a) Gear, Camshafts c) Chain links,nuts,bolts and screws

   b) Valve guides and seatings d) Gears, nuts, bolts

   Ans: a)

7. Which one of the following is a case hardening process?

   a) Recrystallization c) Carburizing

   b) Strain hardening d) Spheroidizing

   Ans: c)

8. Which one of the following is NOT a case hardening process

   a) Carburizing c) Nitriding

   b) Normalizing d) Cyaniding

   Ans: b)

Review questions:

1. List objectives of Hardening process.
2. List the steps followed in Annealing process.

3. Explain the purpose of Heat treatment process.
4. Explain the steps involved in Heat treatment process.
5. Explain the purpose of Normalizing.
6. Explain Case hardening process.
7. Which heat treatment processes ensure both strength and surface hardness for engine components? Justify with process details and property changes.
8. Identify and explain the appropriate surface hardening process for the stainless steels used in various industrial applications.
9. Identify the heat treatment process suitable for steel shaft used in a high speed turbine. Highlight the properties improved after heat treatment.
10. Which heat treatment is suitable for shafts requiring hard surface and tough core? Explain principal, process and benefits.