Module-II Heat treatment of steels

- Heat treatment -controlled heating and cooling- of metals to modify their physical and mechanical properties without altering their shape. Welding and shaping heat or cool metal, requiring heat treatment. Heat treatment can improve machining, formability, and ductility following cold working in addition to enhancing material strength. This makes it a particularly enabling manufacturing process that can support other manufacturing processes and improve product performance by improving strength or other desirable features. Heat treatment works effectively on steels, which are used commercially more than any other material.
- Steels are heat treated for one of the following reasons:

  1. Softening

  2. Hardening

  3. Material modification
- Softening: Softening is performed to diminish strength or hardness, eliminate residual stresses, enhance toughness, restore ductility, refine grain size, or alter the electromagnetic characteristics of steel.
- Restoring ductility or eliminating residual stresses is essential when extensive cold working is to be conducted, as in cold-rolling or wire drawing processes. Annealing — The complete processes include spheroidizing, normalizing, tempering, aus tempering, and martempering.
- **Hardening:** Steels are hardened for strength and wear. A necessary condition for hardening is adequate carbon and alloy content. Steel can be immediately toughened if it has enough carbon content. Otherwise, the part's surface has to enhance carbon through diffusion treatment hardening.

- **Material Modification:** Heat treatment (HT) alters material properties beyond hardening and softening. These processes modify the behavior of the steels in a beneficial manner to maximize service life, e.g., stress relieving, or strength properties, e.g., cryogenic treatment, or some other desirable properties.
- **Full annealing** involves gradually increasing the temperature approximately 50 ºC (90 ºF) above the A3 or ACM lines for hypoeutectoid steels (containing < 0.77% carbon) and 50 ºC (90 ºF) into the Austenite-Cementite region for hypereutectoid steels (containing > 0.77% carbon).
- The material is kept at this temperature for long enough to completely change into Austenite or Austenite-Cementite, depending on the case. The material is cooled in a kiln at a rate of about 20ºC/hr (36ºF/hr) per hour until it reaches 50ºC (90ºF). This is where the Ferrite-Cementite region starts. At this point, natural airflow may cool it down in the air around it. Depending on whether it is hypo- or hyper-eutectoid, the grain structure is made up of coarse pearlite mixed with ferrite or cementite. The steel becomes flexible and easy to shape.
- **Normalizing**-The process of increasing the temperature to a level that exceeds 60 º C (108 ºF), completely entering the Austenite range, above line A3 or line ACM. It is maintained at this temperature to complete the conversion of the structure to Austenite. Subsequently, it is withdrawn from the furnace and cooled to room temperature through natural convection. This leads to a particle structure of fine Pearlite that contains an excess of Ferrite or Cementite. The material that results is soft; the extent of its tenderness is contingent upon the precise ambient cooling conditions. This process is significantly less expensive than complete annealing due to the absence of the additional expense associated with controlled furnace cooling.
- **Procedure Annealing** -employed to process work-hardened components fabricated from low-carbon steels (less than 0.25% carbon). This enables the components to remain sufficiently malleable for additional cold processing without shattering. Process annealing is conducted by

elevating the temperature to just below the Ferrite-Austenite boundary, denoted as line A1 on the diagram. The temperature is approximately 727 ºC (1341 ºF), hence heating it to around 700 ºC (1292 ºF) should be adequate. This is maintained for a sufficient duration to facilitate the recrystallization of the ferrite phase, followed by cooling in stagnant air. The material remains in a consistent phase throughout the operation, with the sole alterations being in the size, shape, and distribution of the grain structure. This technique is more economical than full annealing or normalizing, as the material is neither subjected to elevated temperatures nor cooled in a furnace.

- **Stress Alleviation Annealing** -employed to alleviate residual tensions in substantial castings, welded components, and cold-formed elements. Such components often experience strains resulting from temperature cycling or job hardening. Components are subjected to temperatures ranging from 600 to 650 ºC (1112 to 1202 ºF), maintained for a considerable duration (about 1 hour or longer), and thereafter cooled gradually in stagnant air.

- **Spheroidization** is an annealing technique employed for high carbon steels (Carbon > 0.6%) that will undergo machining or cold forming thereafter. This can be accomplished using one of the following methods: Elevate the component's temperature to slightly below the Ferrite-Austenite line, designated as line A1, or beneath the Austenite-Cementite line, namely below 727 ºC (1340 ºF). Maintain the temperature for an extended duration and subsequently implement gradual cooling.

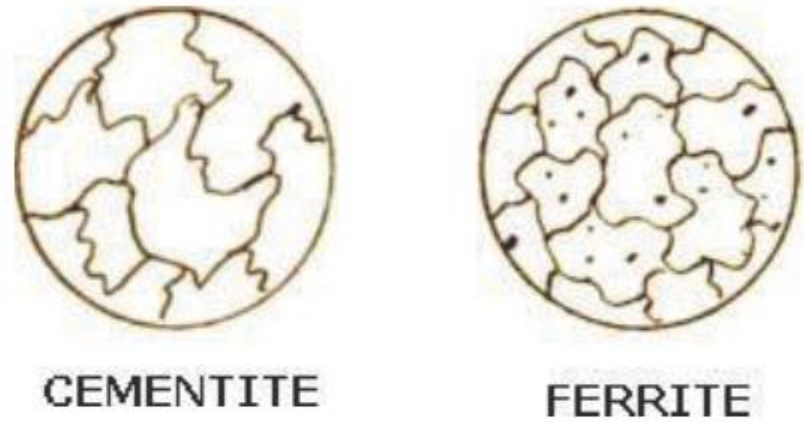
(or)

- Continuously oscillate between temperatures slightly exceeding and falling short of 727 ºC (1340 ºF), namely between 700 and 750 ºC (1292 - 1382 ºF), succeeded by a slow cooling phase.

(or)

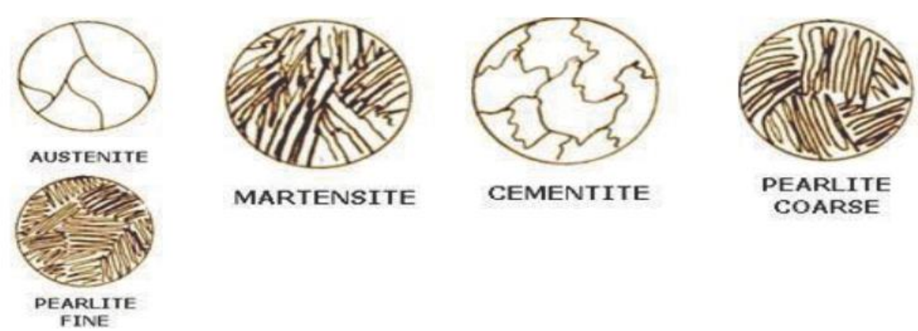
- To prepare tool and alloy steels, heat to 750-800 ºC (1382-1472 ºF) for many hours and then slowly cool. All procedures produce a structure with cementite in minute globules (spheroids) scattered throughout the ferrite matrix. This design enhances machining in continuous cutting activities like lathes and screw machines. Spheroidization enhances abrasion resistance.

- **Tempering** follows quench hardening. Quench-hardened parts can be overly brittle. Martensite predominates, causing brittleness. Tempering eliminates this brittleness. Tempering produces a desired mix of hardness, ductility, toughness, strength, and structural stability. Tempering is distinct from tempers on rolled stock, which indicate the level of cold work done.
- Steel and tempering temperature determine tempering mechanism. Martensite, the dominant structure, is somewhat unstable. Heating Martensite causes carbon atoms to disperse, forming a carbide precipitate and stable Ferrite and Cementite. On the Rockwell C scale, tool steels lose 2 to 4 points of hardness. Although some strength is lost, impact strength indicates significant growth in toughness. To increase toughness, springs and other parts are tempered to a lower hardness. Tempering immediately follows quench hardening. Once the steel cools to approximately 40ºC (104 ºF) after quenching, it can be tempered. The component is warmed at 150-400 ºC (302-752 ºF). Troostite forms here, softer and harder. As an alternative, heating the steel to 400-700ºC (752-1292 ºF) creates a softer Sorbite structure. This is ductile and tougher than Troostite but weaker. For optimal tempering, immerse parts in oil up to 350 ºC (662 ºF) and heat the oil with the parts to the desired temperature. Bath heating guarantees that the entire section is heated and tempered the same way. For temperatures beyond 350 ºC (662 ºF), a nitrate salt bath is recommended. The salt baths can reach 625ºC (1157 ºF). No matter the bath, steady heating prevents steel breaking. After 2 hours at the desired temperature, the components are taken from the water and chilled in still air.



Hardening

- Steel hardness depends on carbon content. To harden steel, its structure must transition from the body-centered cubic structure at room temperature to the face-centered cubic structure in the Austenitic zone. The steel is heated to the autenitic area. Martensite forms when quenched quickly. This structure is robust but fragile. Austenite and Pearlite, a partially hard and partly soft structure, form when gently quenched. During gradual cooling, Pearlite, a soft material, is predominant.
- Hardening and cooling occur mostly at the surface when hot steel is quenched. This penetrates the substance. By choosing the appropriate alloy, one can attain desirable qualities for a specific application and aid in hardening.



Quench Media

• Water: Plunging hot steel in water quenches it. When water near heated steel vaporizes, it does not directly contact the steel. This slows cooling until bubbles split, allowing water to contact hot steel. Boiling water removes much heat from steel. Proper agitation prevents bubbles from clinging to steel, preventing soft areas.

Good agitation makes water a fast quencher. Water can corrode steel, and quick cooling might cause distortion or breaking.

Salt Water: Salt water cools parts faster than plain water because bubbles break readily. But salt water is considerably more caustic than plain water, so rinse it off promptly.

Oil: For slower cooling, apply oil. The high boiling point of oil slows the transition from Martensite formation to finish, reducing the risk of cracking. Fumes, spills, and fires result from oil quenching.

Precipitation hardening:

1. Involves a single-phase solution formed by dissolving all solute atoms through heat treatment.

2. Fast cooling across the solvus line to exceed solubility. A supersaturated solid solution remains stable (metastable) at low temperatures, preventing diffusion.

3. Precipitation heat treatment, where the supersaturated solution is heated to an intermediate temperature to precipitate and aged. Hardness decreases with long-term use. This is over aging.

For precipitation hardening, the solubility curve must decrease rapidly with temperature and have a significant maximum solubility.

• alloy composition below maximum solubility

• Polymers: Lightweight and flexible materials, such as plastics and rubber.
• Composites: A combination of materials engineered for qualities, such as fiberglass.
• Semiconductors: Materials with intermediate conductivity, such as silicon and germanium.

Precipitation Hardening:

Dislocation-blocking ultrafine precipitates increase hardening. Overcoming the solubility limit causes precipitates. Because it hardens over time, precipitation hardening is also called age hardening.

Case Hardening:

Case hardening creates a durable surface over a strong core. The main case hardening methods are carburizing, cyaniding, and nitriding. Only ferrous metals case-harden. Case hardening is particularly useful for parts that need a durable surface and can endure strong loads. Case hardening works best with low-carbon and low-alloy steels. High-carbon steels become brittle when case hardened due to core penetration. During case hardening, the metal surface is chemically altered by adding high carbide or nitride content. The core is chemically unchanged. Heat treatment hardens the high-carbon surface and toughens the core.

Carburizing:

Carburizing - a case-hardening- procedure that adds carbon to the surface -of low-carbon steel. This produces carburized steel with a high-carbon surface and low-carbon inside. Heat-treating carburized steel hardens the casing but leaves the core soft and tough. Steel is carburized two ways. Steel can be heated in a carbon monoxide furnace. In another approach, steel is placed in a charcoal (carbon-rich container) and further heated in a furnace. You can air-cool the parts / leave the container- in the furnace to cool. Both components anneal with slow cooling. Carbon penetration varies on soaking time. Modern carburizing uses gas atmospheres virtually exclusively.

Cyaniding:

This case hardening is rapid and effective. Steel soaks in a heated cyanide bath. It is quenched and rinsed to eliminate cyanide after removal. This method generates a thin, rigid shell that is harder than carburizing and takes 20–30 minutes instead of hours. The biggest downside is that cyanide salts are fatal.

Nitriding:

This approach yields the toughest surface of all hardening processes. The pieces are heat-treated and tempered before nitriding, unlike previous procedures. The pieces are heated in an ammonia-gas furnace. No quenching is needed, reducing the risk of warping or deformation. The case hardening method is utilized for wear-resistant and high-heat engine parts including gears, cylinder sleeves, camshafts, and others.

Flame Hardening:

Metal surfaces can also be hardened by flame hardening. Using an (oxyacetylene type) flame quickly heats a tiny layer on the part to its critical temperature, which is subsequently quenched with a water spray and cool base metal. The internal parts keep their qualities as the thin, rigid surface is created. Here in, Torch burns/ heats metal quickly, and temperatures are usually measured visually, thus a close astute watch is needed whether the operation is manual or mechanized. Manual or automated flame hardening. Automation is better since it generates consistent outcomes. Further, automatic M/C's typically have variable travel speeds and can accommodate pieces of different sizes and forms. Parts determine torch size and form. The torch has- mixing head, extension tube, 90^o extension head, adjustable -yoke, and water-cooled tip-as important components.

Various tips are available for hardening components-flats, rounds, gears, cams, cylinders, and other shapes. Use a hand-held welding torch to harden isolated regions. To avoid sputtering -in corners and grooves- usage of a slightly oxidizing flame instead of neutral for regular heating is preferred. Be careful not to overheat comers and grooves. Dark streaks on metal indicate overheating, so move the flame away. Accordingly, position the torch with the inner cone tip -approximately an eighth of an inch from the surface and direct the flame at right angles to the metal- for optimal heating effects. To get better results, you may need to modify this angle, but rarely more than 30 degrees. Adjust torch travel speed based on metal type, part mass and shape, and desired hardness. You must also choose steel with appropriate qualities. For surface hardness, use carbon steel, and for core physical qualities, alloy steel. Flame hardening requires more than 0.35% carbon in plain carbon steels. The effective carbon range for water quenching is 0.40%–0.70%. If heating and quenching rates are not regulated, parts having more above 0.70% carbon will surface crack. Flame-hardened sections have the same surface hardness as furnace-hardened sections. A relentless drop in hardness occurs - between the casing and core. Since flame hardening does not impact the core, spalling and flaking are unlikely during use. Thus, flame hardening creates a wear-resistant casing and a core that preserves its qualities. Flame hardening has the following main methods:

1. stationary, 2. circular band progressive 3. straight-line progressive 4. spiral band progressive and 5. circular.

Module – III FERROUS MATERIALS AND ALLOYS

Various types of carbon steel

Carbon steel has 0.12–2.0% carbon as the predominant interstitial alloying element. Carbon steel is defined by the American Iron and Steel Institute (AISI) as: Carbon steel is defined as steel with no minimum or required content of chromium, cobalt, molybdenum, nickel, niobium, titanium, tungsten, vanadium, or zirconium, or any other element for alloying, copper minimum of 0.40 percent, Manganese 1.65, silicon 0.60, copper 0.60 or maximum content of any of the elements noted

Types:

Carbon content divides carbon steel into four classes

Mild and Low Carbon Steel:

- Mild steel (plain-carbon steel) is the most often used type of steel due to its low cost and versatile qualities, surpassing iron. Low-carbon steel is malleable and ductile due to its carbon content of 0.05-0.320%. Although mild steel has low tensile strength, it is affordable and pliable. Carburizing can increase its surface hardness. Large quantities of structural steel are often made from it. Mild steel has a density of 7.85 g/cm3 (7850 kg/m3 or 0.284 lb/in3) and a Young's modulus of 210 GPa (30,000,000 psi).