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).

- Yield-point run out affects low-carbon steels with two yield points.
- Second yield point is lower than first, and yield reduces rapidly after top yield point. The surface of low-carbon steel may produce louder bands if stressed between the higher and lower yield points. Low-carbon steels are easier to cold-form and handle.

Higher Carbon Steels:

- Carbon steels with heat-treatment potential have a carbon content of 0.30-1.70 % by weight. Trace impurities of other elements might affect steel quality. At working temperatures, trace levels of sulfur render steel red-short, brittle, and crumbly. A36 grade low-alloy carbon steel melts at 1,426–1,53°C (2,599–2,800°F) and contains 0.05% sulfur. Manganese helps low-carbon steels harden. Some definitions call this low-alloy steel, although AISI's carbon steel allows up to 1.65% manganese by weight.

Low Carbon Steels:

- Under 0.3% c.

Medium Carbon Steel:

- About 0.30–0.59% carbon. Suitable for large parts, forging, and automotive components because to its ductility, strength, and wear resistance.

High Carbon Steel:

- Carbon content: 0.6–0.99%. Strong, used for springs and cables.

Ultra-High Carbon Steel:

- Between 1.0 and 2.0% carbon. Hard-tempered steels. For non-industrial knives, axles, and punches. Most steels with above 1.2% carbon content are produced by powder metallurgy. Cast iron steel has carbon above 2.14%.

Alloy Steel:

- To enhance mechanical qualities, alloy steel is alloyed with various elements in amounts between 1.0% and 50% by weight. There are two types of alloy steels: low-alloy and high-alloy. Smith and has hemi define the difference at 4.0%, while Degarmo, et al. put it at 8.0%. Most people mean low-alloy steels by "alloy steel".

Types:

- According to the World Steel Association, there are approximately 3,500 classes of steel with distinct physical, chemical, and environmental qualities. Steel is made up of iron and carbon, but the qualities of each grade depend on the amount of carbon, impurities, and alloying elements present. Steel can have 0.1-1.5% carbon, however the most common types contain 0.1-0.25%. Manganese is useful, whereas phosphorus and sulphur are harmful to steel's strength and durability.
    - To differentiate steels depending on their qualities, different grading schemes are utilized. The American Iron and Steel Institute (AISI) divides steels into four chemical composition groups:
      1. Carbon Steels
      2. Alloy Steels
      3. Stainless Steels
      4. Tool Steels

Carbon Steels:

- 90% of steel output is carbon steel with trace alloying components. Carbon steels are divided into three carbon content groups:
    - Carbon content in low/mild steels can reach 0.3%.
    - Medium Carbon Steels: 0.3-0.6% carbon
    - High Carbon Steels: >0.6% carbon

Alloy Steels:

- Alloy steels use different quantities of alloying elements (e.g. manganese, silicon, nickel, titanium, copper, chromium, and aluminum) to control qualities including hardenability, corrosion resistance, strength, formability, weldability, and ductility. Pipelines, vehicle parts, transformers, power generators, and electric motors use alloy steel.

Stainless Steel:

- Corrosion-resistant stainless steels-include 10-20% chromium. Steels over 11% chromium concentration enable (200 times more corrosion-resistant)than mild steel. Crystal structure divides steels into III categories:
- Austenitic:- Non-magnetic, non-heat-treatable, and typically include 18% chromium, 8% nickel, and less than 0.8% carbon. Austenitic steels dominate the global stainless-steel industry, commonly used in food processing, kitchen utensils, and pipelines.
- Ferritic: Ferritic steels contain trace nickel, 12-17% chromium, less than 0.1% carbon, molybdenum, aluminum, and titanium. Heat treatment cannot harden these magnetic steels, but cold works can strengthen them.
- Martensitic:- Martensitic steel composition includes 11-17% chromium, <0.4% nickel, and up to 1.2% carbon. These magnetic, heat-treatable steels are utilized in blades, cutting tools, and dental/surgical equipment.
- Tool Steel: Tool steels, with variable amounts of tungsten, molybdenum, cobalt, and vanadium, enhance heat resistance and durability, making them excellent for cutting and drilling equipment.

- Steel goods are also categorized by shape and use:
- Long/Tubular Products: bars, rods, rails, wires, angles, pipelines, forms, and sections. These goods are popular in automotive and construction.
- Flat products are plates, sheets, coils, and strips. Automotive parts, appliances, packaging, shipbuilding, and construction employ these materials.
- Valve, fitting, and flange products are mostly utilized for pipelines.

Cast Iron:

- Cast iron is heat up until it liquefies then set into a mold to solidify. The material is mainly pig iron. Carbide impurities in white cast iron allow fractures to slip through, changing its color when broken. Graphite flakes in grey cast iron deflect a crack and cause many more when it breaks. The principal alloying elements are carbon (C) and silicon (Si), with 2.1–4% and 1–3%, respectively. Iron alloys with low carbon are steel. The binary iron–carbon phase diagram explains cast iron solidification, even though these base alloys are ternary Fe–C–Si alloys. Because most cast irons have compositions near the eutectic point of the iron-carbon system, melting temperatures typically range from-1,150 - 1,200°C (2,100 /2,190 °F), which is approximately 300 °C (/572 °F) lower than pure iron. Alloyants alter cast iron's characteristics. Silicon drives carbon out of solution, making it the most important alloying after carbon. Instead, carbon creates graphite, softening iron, reducing shrinkage, strength, and density. Sulfur generates iron sulfide, which inhibits graphite and hardens. Sulfur causes molten cast iron to slow down, leading to short-term flaws. Manganese is added to counteract sulfur's effects because they generate manganese sulfide instead of iron.
- As manganese sulfide is lighter than the melt, it tends to float away and into the slag. The manganese needed to neutralize sulfur is 1.7 times sulfur content + 0.3%.

- Manganese carbide formed when more manganese is added, increasing hardness and cooling, except in grey iron, where up to 1% manganese enhances strength and density.
- Nickel is a popular alloying element that refines pearlite and graphite structure, enhances toughness, and balances hardness across section thicknesses. Chrome is supplied in modest amounts to the ladle to reduce free graphite, induce cool, and stabilize carbides; nickel is often added too.
- A modest amount of tin can replaces 0.5% chromium. Copper is added to the ladle or furnace at 0.5–2.5% to reduce chill, refine graphite, and increase fluidity. Add 0.3–1% molybdenum to improve chill and refine graphite and pearlite structure. Combine it with nickel, copper, and chromium to make high-strength irons. Titanium enhances fluidity and degasses and deoxidizes. Cast iron receives 0.15–0.5% vanadium to stabilize cementite, increase hardness, and resist wear and heat. 0.1–0.3% zirconium deoxidizes, forms graphite, and increases fluidity.
- Bismuth (0.002–0.01%) is added to malleable iron melts to improve silicon addition. Boron is added to white iron to produce malleable iron and lessen the coarsening effect of bismuth.

GCI:

- Grey cast iron/GCI is characterized by its graphitic microstructure, resulting in grey fractures. This is the most widely used cast iron material based on weight. Cast irons typically contain 2.5–4.0% carbon, 1–3% silicon, and the rest iron. Grey cast iron has lower tensile and shock resistance than steel, but comparable compressive strength to low and medium carbon steel.

WCI/White- Cast Iron:

- Due to cementite, cast iron has a white cracked surface. Because white cast iron contains less silicon (graphitizing agent) and cools faster, the carbon precipitates out as metastable phase cementite, Fe_3C, rather than graphite. Cementite precipitates from the melt as big particles in a eutectic mixture with austenite (which may cool to martensite). In some steels, cementite precipitates may limit plastic deformation by inhibiting dislocation movement through the ferrite matrix, but these eutectic carbides are too big to precipitation harden. They increase the bulk hardness of cast iron by virtue of their own high hardness and large volume percentage, which can be approximated by a rule of mixes. They sacrifice toughness for hardness. White cast iron could be considered a cermet because carbide is a major component. White iron is too brittle for many structural components, but its hardness, abrasion resistance, and low cost make it useful in applications like slurry pump impellers and volutes, ball mill shell liners and lifter bars, and coal balls and rings.

- It's hard to cool thick castings fast enough to solidify the melt as white cast iron. Rapid cooling can solidify a white cast iron shell, while the rest cools slowly to produce a grey core.
- Chilled castings offer a hard surface and a slightly tougher interior. High-chromium white iron alloys may be sand cast, allowing a 10-tonne impeller to be made without a high cooling rate, and they are abrasion-resistant. These high-chromium alloys are hard because of chromium carbides. These carbides are primarily eutectic or primary M_7C_3 carbides, with "M" representing iron or chromium and varying based on alloy composition. Eutectic carbides arise as hollow hexagonal rod bundles perpendicular to the hexagonal basal plane. These carbides have 1500-1800HV hardness.

Malleable Cast Iron:

- MCI begins as white iron casting, which undergoes heat treatment at around 900 °C (1,650 °F). The slower separation of graphite allows surface tension to create spheroidal particles instead of flakes.
- Owing to their decreased aspect ratio, spheroids are petite and far distant and have a lower propagating fracture or phonon cross section. They feature broad borders, unlike flakes, which reduces stress concentration in grey cast iron. Overall, malleable cast iron behaves like mild steel. Due to its white cast iron composition, malleable iron parts are limited in size.

Ductile Cast Iron:

- Recent developments include nodular or ductile cast iron. Adding small amounts of magnesium or cerium to these alloys slows graphite precipitate formation by attaching to graphite plane edges. Controlling other elements and time enables carbon to segregate into spheroidal particles during solidification. The qualities are like malleable iron, although larger pieces can be cast.

Typical Uses:

- Historic Markers and Plaques
- Hardware (Hinge, Latches)
- Columns, Balusters
- Stairs
- Structural Connectors