APPLICATIONS OF Fe-C PHASE DIAGRAM
\[% \text{ Austenite} = \frac{6.67 - 3}{6.67 - 1.6} = 60\% \]
KEY POINTS OF Fe-C Diagram

Phases:
- Liquid Fe-Tmin=1148°C @ 4.3% C
- 1394°C < δ-Fe < 1538°C
- α-Ferrite (Ferrite) < 912°C; < 0.02% C
- Magnetic-nonmagnetic-770°C
- Cementite $F_3C = 6.67$ weight % C
- Austenite-727°C < T < 1495°C; 0 < % C < 2.11
PHASE TRANSFORMATION

Liquid to Austenite

- Eutectic transformation-1148°C,
- C-2.11%-4.3%
- Eutectic transformation-4.3% C, 1148°C
- Eutectic transformation L-γ+F₃C (fast)
- Eutectic trans L-γ+C (graphite) (slow)
EUTECTOID TRANSFORMATION

• $\gamma \rightarrow$ pearlite (ferrite+$\text{Fe}_3\text{C}$)
• 727 °C, 0.77 % C eutectic point
Cast Irons

- Iron-carbon alloys with more than 2.11% carbon are known as cast irons
- Relatively inexpensive with good fluidity and low liquidis temperatures make them ideal for casting
- Contain significant amounts of silicon, manganese, and sulfur
- High silicon content enhances oxidation and corrosion resistance of cast irons
White cast irons

• White cast irons
  – Excess carbon is in the form of iron carbide
  – White surface appears when the material is fractured
  – Very hard and brittle
Gray Iron

- **Gray iron** was the original "cast iron", and is an **iron alloy** characterized by its relatively high **carbon** content (usually 2% to 4%).

- When molten cast iron solidifies some of the carbon **precipitates** as **graphite**, forming tiny, irregular flakes within the **crystal** structure of the metal.

- While the graphite enhances the desirable properties of cast iron (improved casting & machining properties and better **thermal conductivity**), the flakes disrupt the crystal structure and provide a nucleation point for cracks, leading to cast iron's characteristic brittleness.
MALLEABLE IRON

• **Malleable iron** is cast as **White iron**, The structure being a metastable carbide in a perlitic matrix.
• Through an **annealing** heat treatment the brittle as cast structure is transformed.
• Carbon agglomerates into small roughly spherical aggregates of graphite leaving a matrix of ferrite or pearlite according to the exact heat treat used.
Malleable cast iron

• Malleable cast iron
  – Greater ductility than gray cast iron
  – Favorable graphite shape removes the internal notches

• Several types of malleable iron are recognized within the casting industry,
MALLEABLE IRON
DUCTILE CAST IRON

• In ductile iron the graphite is in the form of **spherical** nodules rather than flakes, thus inhibiting the creation of cracks and providing the enhanced ductility that gives the alloy its name.

• The formation of nodules is achieved by addition of "nodulizers" (for example, **magnesium** or **cerium**) into the melt.
DUCTILE IRON

• **Ductile iron**, also called **ductile cast iron, spheroidal graphite iron, or nodular cast iron**, is a type of **cast iron**. [1]

• While most varieties of cast iron are **brittle**, ductile iron is much more **flexible** and **elastic**, due to its nodular graphite inclusions.
DUCTILE CAST IRON
EUTECTOID TRANSFORMATION IN STEEL

- Temperature: °C (727 to 1148)
- % Carbon (0.02 to 2.0)

Key points:
- Ferrite
- Austenite
- Ferrite + austenite
- eutectoid
- Austenite
- Liquid + austenite
- Austenite + cementite
- Ferrite + cementite
- A_3
- A_1
- A_{cm}
PEARLITE

- **Pearlite** is a **two-phased, lamellar** (or layered) structure composed of alternating layers of **alpha-ferrite** (88 wt%) and **cementite** (12%) that occurs in some **steels** and **cast irons**.

- It forms by a **eutectoid** reaction as **austenite** is slowly cooled below 727 °C.

- The eutectoid composition of Austenite is approximately 0.8% **carbon** [1];
PEARLITE

- Steel with less carbon content will contain a corresponding proportion of relatively pure ferrite crystallites that do not participate in the eutectoid reaction and cannot transform into pearlite.
- Steel with more carbon content will contain a corresponding proportion of relatively pure cementite crystallites that do not participate in the eutectoid reaction and cannot transform into pearlite.
- Hypo- vs Hypereutectoid steels
KINDS OF THERMAL TREATMENT

![Thermal Treatment Graph](image-url)
Annealing

- Full annealing
  - Hypoeutectoid steels are heated to convert the grain structure to homogenous single-phase austenite, then control cooled
    - The cooling results in coarse pearlite with excess ferrite
    - Results in soft and ductile steel
  - Hypereutectoid steels undergo a similar process but the structure will be coarse pearlite with excess cementite
  - Full anneals are time and energy consuming processes
SPHEROIDIZING ANNEAL

- Applied to high-carbon (.0.6% C) steel
- Heated below A1
- Cementite form globules throughout a ferrite matrix
PROCESS ANNEAL

• Steel is heated to a temperature slightly below A1
• Held long enough to attain recrystallization with no phase change
• Recrystallization is induced after a material has been cold worked to reduce strain
Stress-relief anneal

- Reduces residual stresses in casting, welded assemblies, and cold-formed products
- Materials are heated and then slow cooled
NORMALIZING

• Carbon steel is heated to approximately 55°C above Ac3 or Acm for 1 hour;
• The steel completely transforms to austenite
• The steel is then air-cooled, which is a cooling rate of approximately 38°C (100°F) per minute
• This results in a fine pearlitic uniform structure, and a more-structure.
• Normalized steel has a higher strength than annealed steel;
• It has a relatively high strength and ductility.
Normalizing

• Normalizing vs. annealing
  – In normalizing, cooling will be different in different locations
  – Properties will vary between the surface and interior in normalized steel
  – Lower cost of normalizing is justified if uniform properties are needed
Tempering

• This is the most common heat treatment
• Involves reheating quenched steel to a temperature below the eutectoid temperature then cooling.
• The elevated temperature allows very small amounts of spheroidite to form
• This restores ductility, but reduces hardness.
Figure 5-7 Isothermal transformation diagram (T-T-T diagram) for eutectoid composition steel. Structures resulting from transformation at various temperatures are shown as insets. (Courtesy of United States Steel Corp., Pittsburgh, PA.)
CCT OF STEEL
MARTENSITE TRANSFORMATION

• Carbon steel with at least 0.4 wt% C is heated to normalizing temperatures and then rapidly cooled (quenched) in water, brine, or oil to the critical temperature.
• The critical temperature is dependent on the carbon content, but as a general rule is lower as the carbon content increases.
• The steel possesses a super-saturated carbon content.
• The steel is extremely hard but brittle, usually too brittle for practical purposes.
• The internal stresses cause stress cracks on the surface.
Tempering of Martensite

• Initially after it has been quenched, martensite lacks the toughness and ductility for engineering applications.
• Tempering is a subsequent heating to give the steel necessary ductility and fracture toughness
Maraging steels

- **Maraging steels** (a *portmanteau* of *martensitic* and aging) are iron *alloys* which are known for possessing superior strength and toughness without losing *malleability*.
- A special class of low carbon ultra-high strength steels which derive their strength not from carbon, but from precipitation of inter-metallic compounds.
- The principal alloying element is 15 to 25% *nickel*.[1]
- Secondary alloying elements are added to produce *intermetallic precipitates*, which include *cobalt*, *molybdenum*, and *titanium*.[1]
- Original development was carried out on 20 and 25% Ni steels to which small additions of Al, Ti, and Nb were made.
Quench Media

- Quenchants are the medium in which a material is quenched
  - Selected to provide necessary cooling rates

- Stages of quenching
  - Formation of the vapor jacket
    - Vapor jacket is the thin gaseous layer between the metal and the liquid during cooling
  - Nucleate boiling phase
    - Produces rapid rates of cooling down to the boiling point of the quenchant
  - Conduction and convection
    - Slower cooling from the boiling point to room temperature
Quenching Considerations

• Water is an effective quenching medium because of its high heat of vaporization and relatively high boiling point
  – The quenchant should be agitated due to the tendency of bubbles to form soft spots on the metal
  – A negative consequence is that it may oxidize the material
• Brine is similar to water as a quenching medium
  – Rapid cooling occurs because the salt nucleates bubbles
  – Corrosion problems may exist
Quenching Considerations

- Oil is utilized if slower quenching rates are desired
  - Oil may cause water contamination, smoke, fumes, etc.
  - More expensive than water or brine quenchants
- Water based polymer quenchants have properties between oil and water and brine
- Molten salt baths may be used for even slower cooling rates
- High pressure quenching uses a stream of flowing gas to extract heat
Cu-Al Phase Diagram
THERMAL TREATMENT OF Cu-Al ALLOY AT $\%$ of Al

![Graph showing the thermal treatment of Cu-Al alloy. The graph depicts the temperature in °F on the y-axis and the weight percentage of copper on the x-axis. Key points include the solvus, α + liq, 96% Al, 4% Cu, and 1018 °F.](image-url)
5.7 Furnaces

• Furnace types
  – Parts remain stationary in batch furnaces
  – Continuous furnaces move the components through heat treating processes that are compatible with other manufacturing processes
    • Box furnaces are horizontal batch furnaces
    • Car-bottom-box furnaces are used for large and long workpieces
  – Bell furnaces place a “bell” over the workpiece to control heating and cooling
    • Elevator furnaces
  – Vertical pit furnaces prevent horizontal sagging or warping
Furnace Atmospheres

• Artificial gas atmospheres
  – Prevents scaling or tarnishing

• Fluidized-bed
  – Inert particles are heated and suspended in a stream of gas

• Salt bath furnaces
  – Salt is heated by passing a current between two electrodes placed in the batch
  – Lead pot is a bath where lead is used instead of salt

• Electrical induction heating