COURSE CODE: SC202(CHEMISTRY)

COURSE INSTRUCTOR: DR. DEBARATI MITRA &
DR. SANGITA TALUKDAR
DEPT. OF SCIENCE AND MATHEMATICS
IIITG, GUWAHATI

LECTURE-ANNEALING

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Introduction

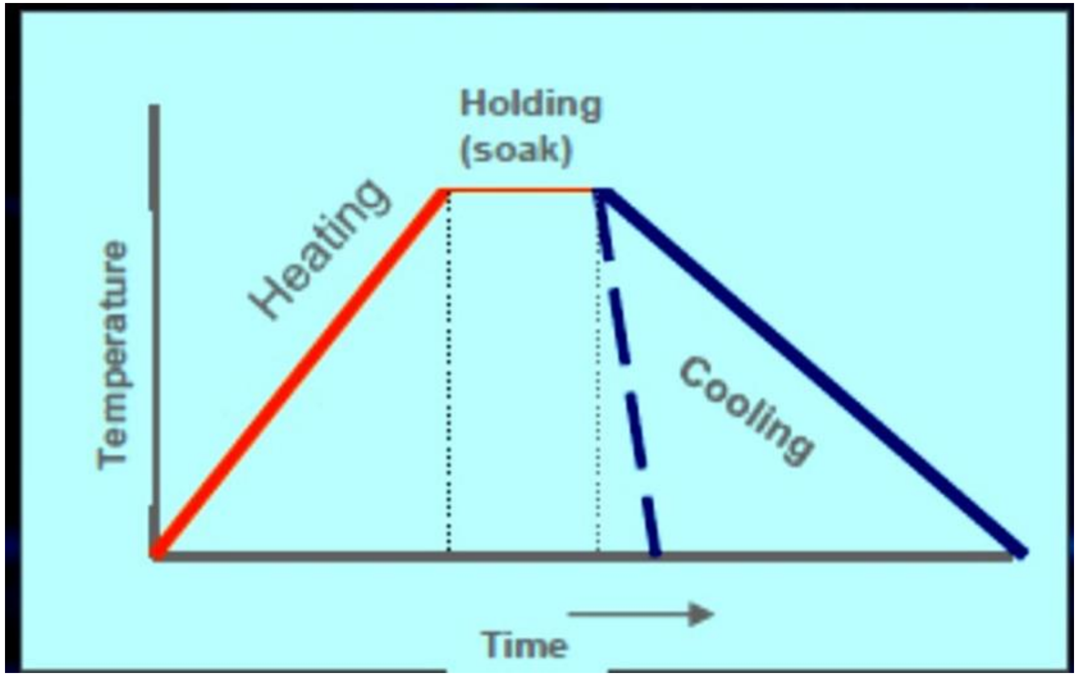
- The heat treatment includes heating and cooling operations or the sequence of two or more such operations applied to any material in order to modify its metallurgical structure and alter its physical, mechanical and chemical properties.
- Usually it consists of heating the material to some specific temperature, holding at this temperature for a definite period and cooling to room temperature or below with a definite rate.
- The four widely used heat treatment processes are *Annealing*, *Normalizing*, *Hardening* and *Tempering*.
- Steels being the most widely used materials in major engineering fabrications, undergo various heat treatment cycles depending on the requirements. Also aluminum and nickel alloys are exposed to heat treatment for enhancement of properties.

Annealing

- Annealing involves heating the material to a predetermined temperature and hold the material at the temperature and cool the material to the room temperature slowly.
- It is performed primarily for homogenization, recrystallization or relief of residual stress in typical cold worked or welded components.

- The process involves:

1) Heating of the material at the elevated or predetermined temperature.
2) Holding the material (Soaking) at the temperature for longer time.
3) Very slowly cooling the material to the room temperature.



Annealing

The various purpose of these heat treatments is to

1) Relieve internal stresses developed during solidification, machining, forging, rolling or welding

2) Improve or restore ductility and toughness

3) Enhance machinability

4) Eliminate chemical non-uniformity

5) Refrain grain size

6) Reduce the gaseous contents in steel.

Heat Treating Processes

ANNEALING

a. Full annealing
b. Isothermal annealing
c. Spheroidise annealing
d. Recrystallization annealing
e. Stress relief annealing

NORMALIZING

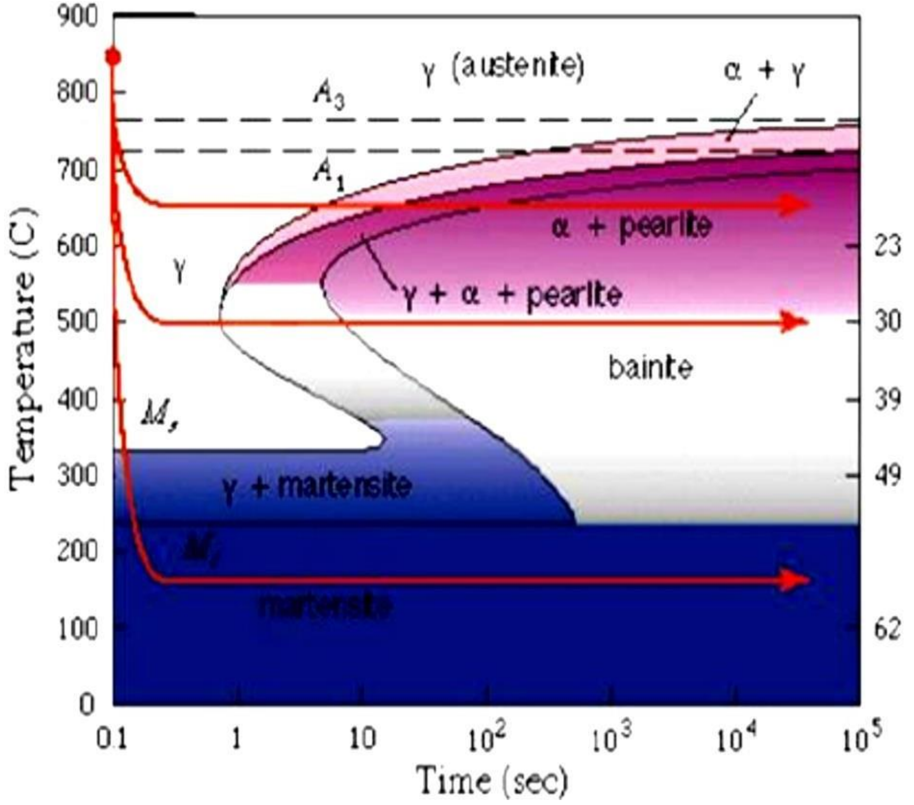
HARDENING & TEMPERING

a. Conventional hardening
b. Martempering
c. Austempering

Time Temperature Transformation (TTT) Diagram:

TTT diagram is a plot of temperature versus the logarithm of time for a steel alloy of definite composition.

- It is used to determine when transformations begin and end for an isothermal heat treatment of a previously **austenitized** alloy.
- TTT diagram indicates when a specific transformation starts and ends and it also shows what percentage of transformation of austenite at a particular temperature is achieved.



*The temperature at which the steel and ferrous alloys are heated above their critical temperatures is called the **austenitizing temperature**. Generally the austenitizing temperature ranges from **400°C** to **800°C** for different grades of carbon, alloys and tool steels.*

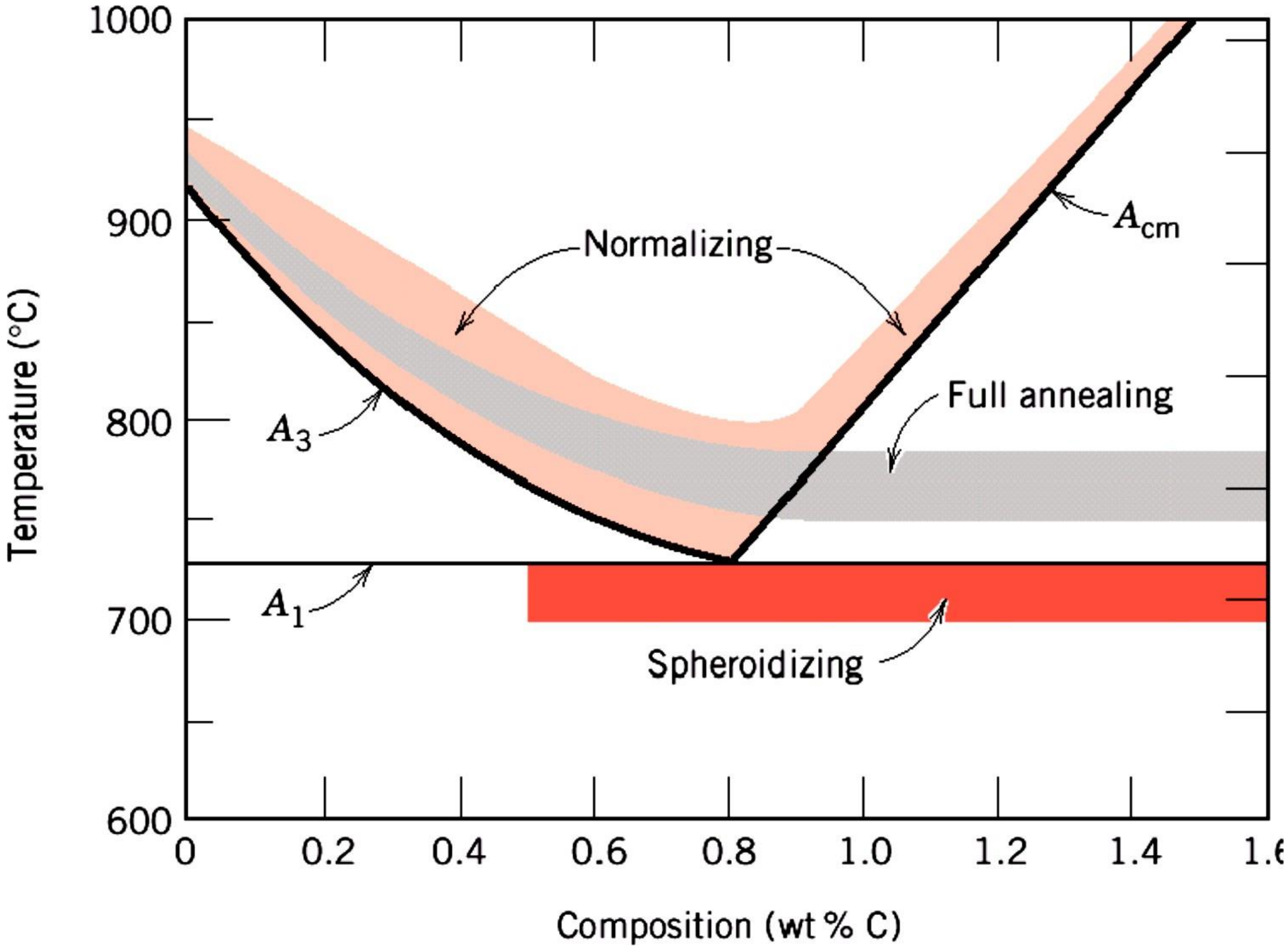


Fig. 1: Steel heat treating ranges

- Lower critical temperature A_1 below which austenite does not exist
- Upper critical temperature lines, A_3 and A_{cm}, above which all material is austenite
- Austenitizing: complete transformation to austenite

Ref: F.C. Campbell, Ed., *Elements of Metallurgy and Engineering Alloys*, ASM International, 2008

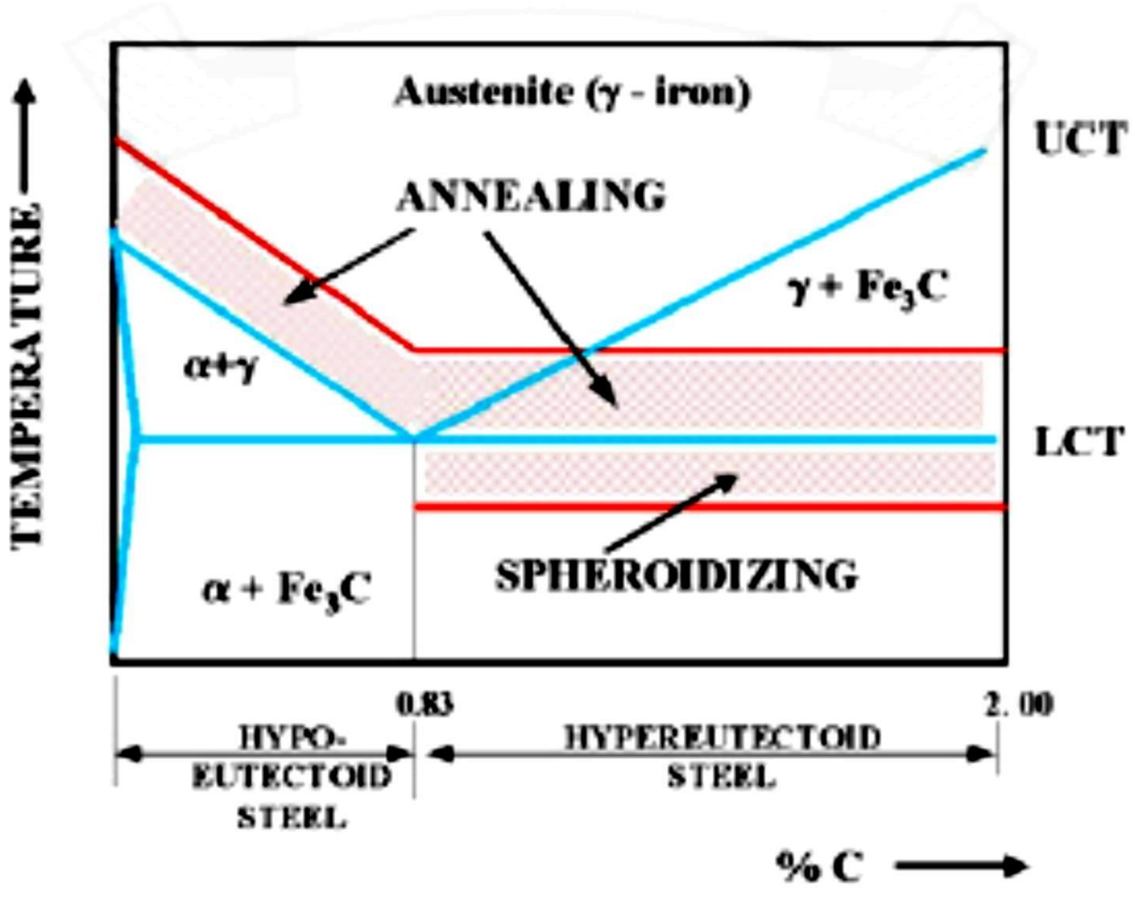


Figure 2 Schematic representation of annealing operation [2]

Ref: http://info.lu.farmingdale.edu/depts/met/met205/ANNEALING.html

Full annealing (conventional annealing)

Full annealing process consists of three steps.

- First step is heating the steel component to above A_3 (upper critical temperature for ferrite) temperature for hypoeutectoid steels and above A_1 (lower critical temperature) temperature for hypereutectoid steels by 30-50^{0}C . In *Figure 2*, the terms α, γ and Fe_3C refer to ferrite, austenite and cementite phases.

- The second step is holding the steel component at this temperature for a definite holding (soaking) period of at least 20 minutes per cm of the thick section.

- Final step is to cool the hot steel component to room temperature slowly in the furnace, which is also called as *furnace cooling*.

Isothermal annealing

Isothermal annealing consists of four steps.

- The *first step* is heating the steel components similar as in the case of full annealing.
- The *second step* is slightly fast cooling from the usual austenitizing temperature to a constant temperature, just below A_1.
- The *third step* is to hold at this reduced temperature for sufficient soaking period for the completion of transformation.
- The *final step* involves cooling the steel component to room temperature in air.

Spheroidise annealing

Spheroidise annealing is one of the variant of the annealing process that produces typical microstructure consisting of the globules (spheroid) of cementite or carbides in the matrix of ferrite.

Recrystallization annealing

- Recrystallization annealing process consists of heating a steel component below A_1 temperature i.e. at temperature between 625^{o}C and 675^{o}C (recrystallization temperature range of steel), holding at this temperature and subsequent cooling.
- Recrystallization annealing relieves the internal stresses in the cold worked steels and weldments; and improves the ductility and softness of the steel.
- Refinement in grain size is also possible by the control of degree of cold work prior to annealing or by control of annealing temperature and time.

Stress relief annealing

Stress relief annealing process consists of three steps.

- The *first step* is heating the cold worked steel to a temperature between 500^{o}C and 550^{o}C i.e. below its recrystallization temperature.
- The *second step* involves holding the steel component at this temperature for 1-2 hours.
- The *final step* is to cool the steel component to room temperature in air.
- The *stress relief annealing* partly relieves the internal stress in cold worked steels without loss of strength and hardness i.e. without change in the microstructure.
- Since only low carbon steels can be cold worked, the process is applicable to hypoeutectoid steels containing less than 0.4% carbon. This annealing process is also used on components to relieve internal stresses developed from rapid cooling and phase changes.

Normalizing

Normalizing process consists of three steps.

- The *first step* involves heating the steel component above the A_3 temperature for hypoeutectoid steels and above A_{cm} (upper critical temperature for cementite) temperature for hypereutectoid steels by 30^0C to 50^0C (*Figure 3*).
- The *second step* involves holding the steel component long enough at this temperature for homogeneous austenization.
- The final step involves cooling the hot steel component to room temperature in still air. Due to air cooling, normalized components show slightly different structure and properties than annealed components.

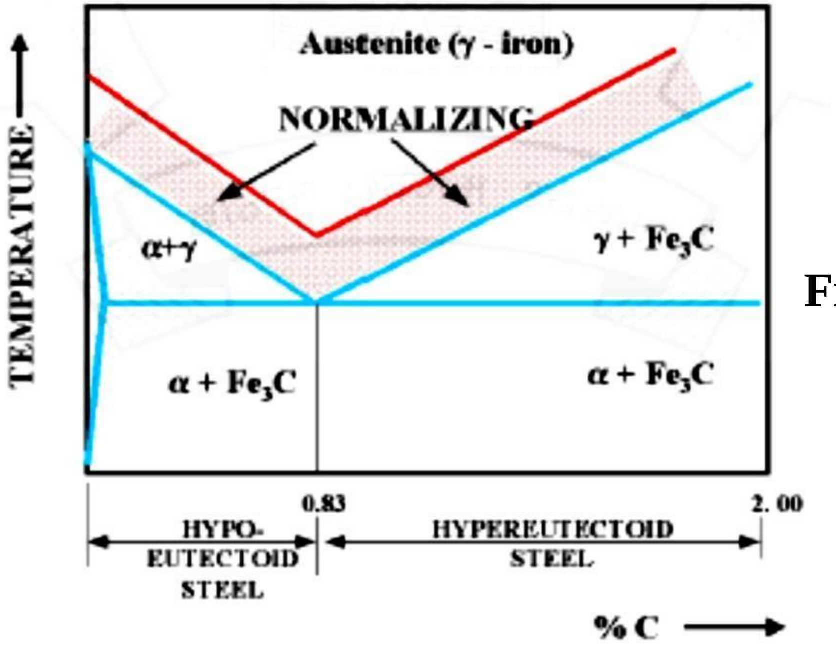


Figure 3 Normalizing

http://info.lu.farmingdale.edu/depts/met/met205/normalizing.html

Table 1 The variation in the properties of the annealed and normalized components

Annealed	Normalised
• Less hardness, tensile strength and toughness. • Pearlite is coarse and usually gets resolved by the optical microscope. • Grain size distribution is more uniform. • Internal stresses are least.	• Slightly more hardness, tensile strength and toughness. • Pearlite is fine and usually appears unresolved with optical microscope. • Grain size distribution is slightly less uniform. • Internal stresses are slightly more.

The three distinct processes that occur during annealing:

a. Recovery

b. Recrystallization

c. Grain growth

- **Recovery:** During recovery, there is a rearrangement of internal defects, known as dislocations, into lower-energy configurations; however, the grain shape and orientation remain the same. There is also a significant reduction in residual stresses, but the strength and ductility are largely unaffected.
- **Recrystallization** is characterized by the nucleation and growth of strain-free grains out of the matrix of the cold-worked metal. During recrystallization, the badly deformed cold-worked grains are replaced by new, strain-free grains.
- **Grain growth** is the growth of some recrystallized grains, and it can only happen at the expense of other recrystallized grains. Because fine grain size leads to the best combination of strength and ductility, in almost all cases, grain growth is an undesirable process.

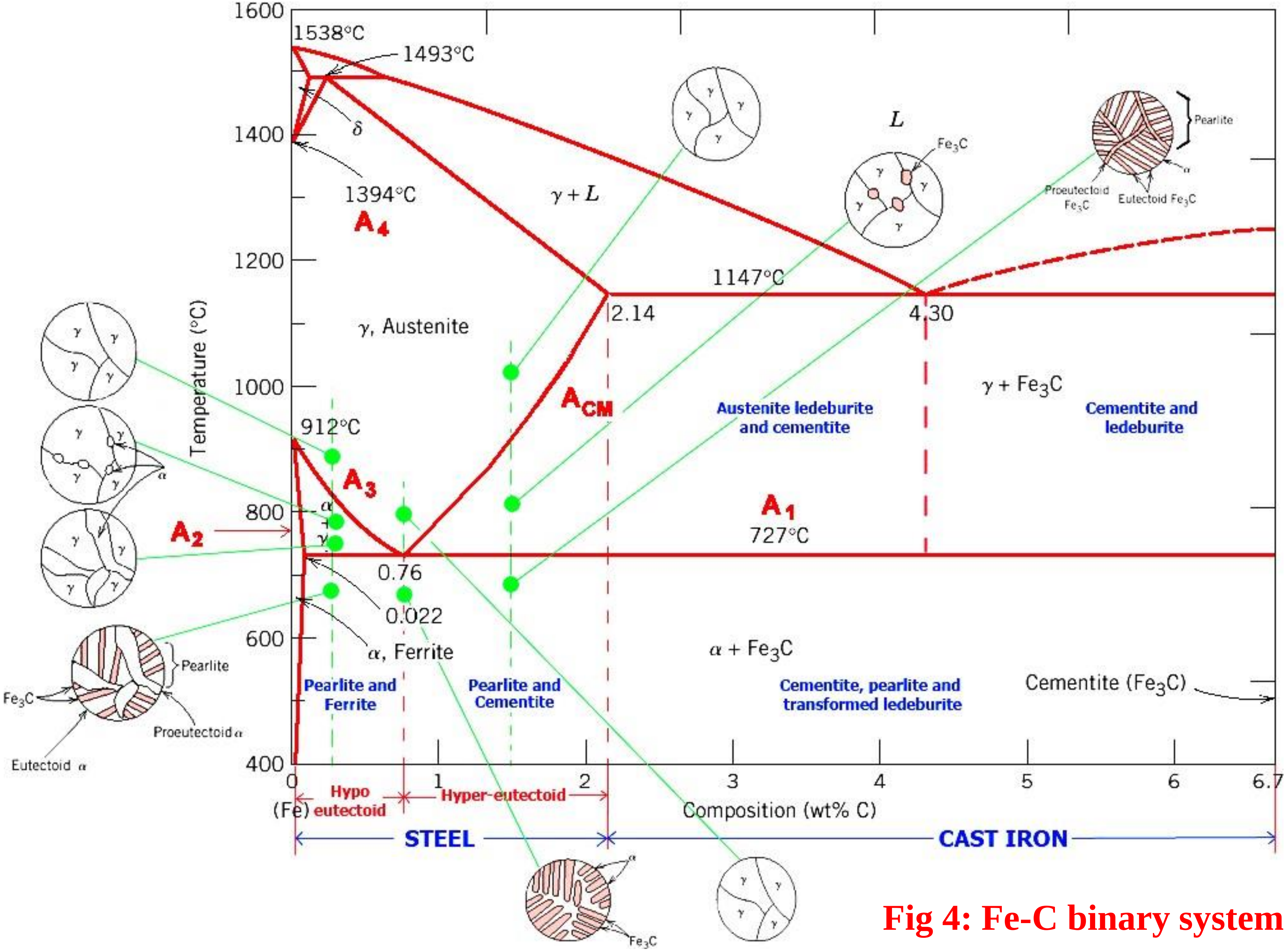


Fig 4: Fe-C binary system –Phase transformations

Fe-C binary system –Phase transformations (contd….)

➢ $Fe\text{-}Fe_3C$ phase diagram is characterized by *five individual phases*:

α–ferrite (BCC) Fe-C solid solution, ***γ***-austenite (FCC) Fe-C solid solution, ***δ***-ferrite (BCC) Fe-C solid solution, Fe_3C (iron carbide) *or* cementite -an inter-metallic compound and liquid Fe-C solution and *four invariant reactions*:

-peritectic reaction at 1495 ^{o}C and 0.16 %C, ***δ***-ferrite + ***L***↔ ***γ***-iron (austenite)

-eutectic reaction at 1147 ^{o}C and 4.3 %C, ***L***↔ ***γ***-iron + Fe_3C (cementite) [ledeburite]

-eutectoid reaction at 723 ^{o}C and 0.8 %C, ***γ***-iron ↔ ***α***–ferrite + Fe_3C (cementite)

[pearlite]

- Fe-C alloys are classified according to wt.% C present in the alloy for technological convenience as follows:

Commercial pure irons	% C < 0.008
Low-carbon/mild steels	0.008 -%C -0.3
Medium carbon steels	0.3 -%C -0.8
High-carbon steels	0.8-%C -2.11
Cast irons	2.11 < %C

- Cast irons that were slowly cooled to room temperature consists of cementite, look whitish –*white cast iron*. If it contains graphite, look grayish –*gray cast iron*. It is heat treated to have graphite in form of nodules –*malleable cast iron*. If inoculants are used in liquid state to have graphite nodules –*spheroidal graphite (SG) cast iron*.

Commonly Used Equipment for Heat Treating Operations

Metal Cleaning (Wash-Rinse) Equipment

- Gas fired furnaces

– Direct fired using burners fired directly into a furnace

– Indirect fired furnaces: radiant tube, muffle, retort, etc.

– Molten salt (or lead) bath

– Fluidized bed

- Electrically heated Furnaces

– Induction heating

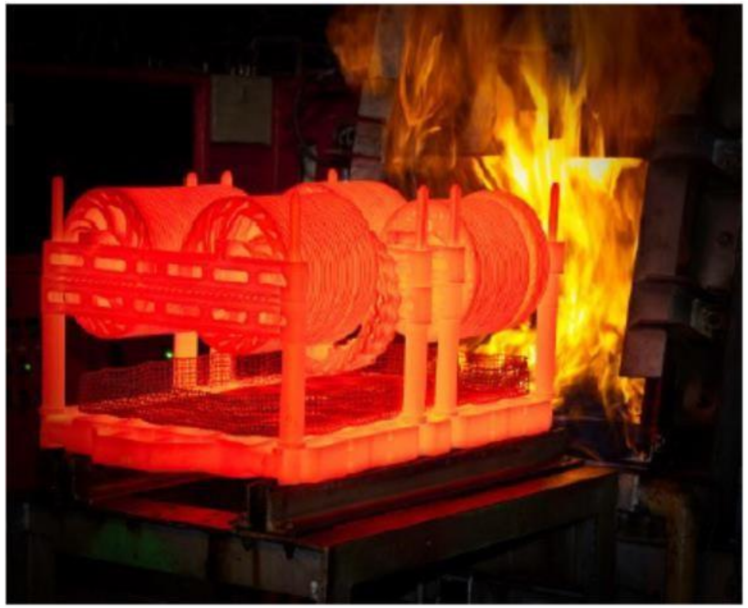
– Electrical resistance heating

– Other (i.e. Laser, electron-beam etc.)

- Quench or cooling equipment

Gas fired furnaces

Electric Atmosphere Furnace



- Once the annealing process is successfully completed, some workpieces are left in the oven to cool in a controlled fashion.
- Once removed from the oven, the workpieces are often quickly cooled off in a process known as quench hardening.
- Typical methods of quench hardening materials involve media such as air, water, oil, or salt. Brine provides faster cooling rates than water.
- This is because when an object is quenched in water, steam bubbles form on the surface of the object reducing the surface area the water is in contact with. The salt in the brine reduces the formation of steam bubbles on the object's surface, meaning there is a larger surface area of the object in contact with the water, providing faster cooling rates.

Home Assignment

1. The complete phase recrystallization and fine grain structure is obtained in casting, forging and rolled parts by

a. recrystallization annealing

b. Normalizing

c. Spheroidizing

d. Austenizing

2. Heating the hypoeutectoid steels to 30^{o}C above the critical temperature line, soaking at that temperature and then cooling to room temperature to form a pearlite and ferrite structure is known as

a. Hardening
b. Normalizing
c. Tempering
d. Annealing

3. Which of the following statements are true for annealing of steels?

1. Steels are heated to 500 ^oC to 700 ^oC
2. Cooling is done slowly and steadily
3. Internal stresses are relieved
4. Ductility of steel is increased.

a. 2, 3 and 4 are true
b. 1, 3 and 4 are true
c. 1, 2 and 4 are true
d. 1, 2 and 3 are true

4. Temperature required for full annealing in hyper-eutectoid steel is

a. 50 ^oC above upper critical temperature(A3)
b. 50 ^oC below upper critical temperature(A3)
c. 50 ^oC above lower critical temperature(A1)
d. 50 ^oC below lower critical temperature(A1)