HEAT TREATMENT PROCESSES AND STRUCTURES

4.1 General

The common heat treatment processes include:

(a) Annealing

(b) Normalizing

(c) Hardening

(d) Tempering

4.2 Annealing process

(a) The annealing process is a situation whereby a metal which is not in an equilibrium structure is caused to attain, as far as possible he equilibrium state. The prior condition may be a hardened condition by way of mechanical working or heat-treatment. With annealing, the following do occur:

(i) The removal of any internal or residual stress without causing any appreciable structural change. This is also known as stress-relief process.

(ii) Recrystallization to form new strain-free grains. If annealing is done at a high temperature or for prolonged soaking at normal temperature, the recrystallized grains may suffer grain growth. The production of recrystallized grains with or without grain growth is known as full annealing.

(b) In full annealing, the annealing temperature are as follows for:

(a) Hypo-eutectoid steels: 30ºC – 50ºC above the upper critical point (A_3 - point).

(ii) Hypo-eutectoid steels: 30ºC – 50ºC above the upper critical point (A_1 - point).

(iii)Cast iron: between 800ºC – 900ºC.

The soaking time depends on the annealing temperature, composition and the amount of internal stress stored in the material and seating size. As a general guide, for the hypo-eutectoid steels, the soaking time is usually one hour for every 25mm section size. It is longer for the hyper-eutectoid steels so as to form spheroidized carbides. It is much longer for cast irons where decomposition of carbides into graphite is required.

(c) cooling from the annealing temperature is done very slowly (usually at a rate less than 30ºC/hour and commonly in the furnace). This slow cooling rate must be done down to substantially below the A_1 point, at least, 550ºC. Below this, slow cooling is not necessary, and any suitable cooling rate is all that is needed.

(d) Partial annealing will occur when steel is heated to below A_3 point and annealing is done within the critical range. This annealing process is known as inter-critical annealing.

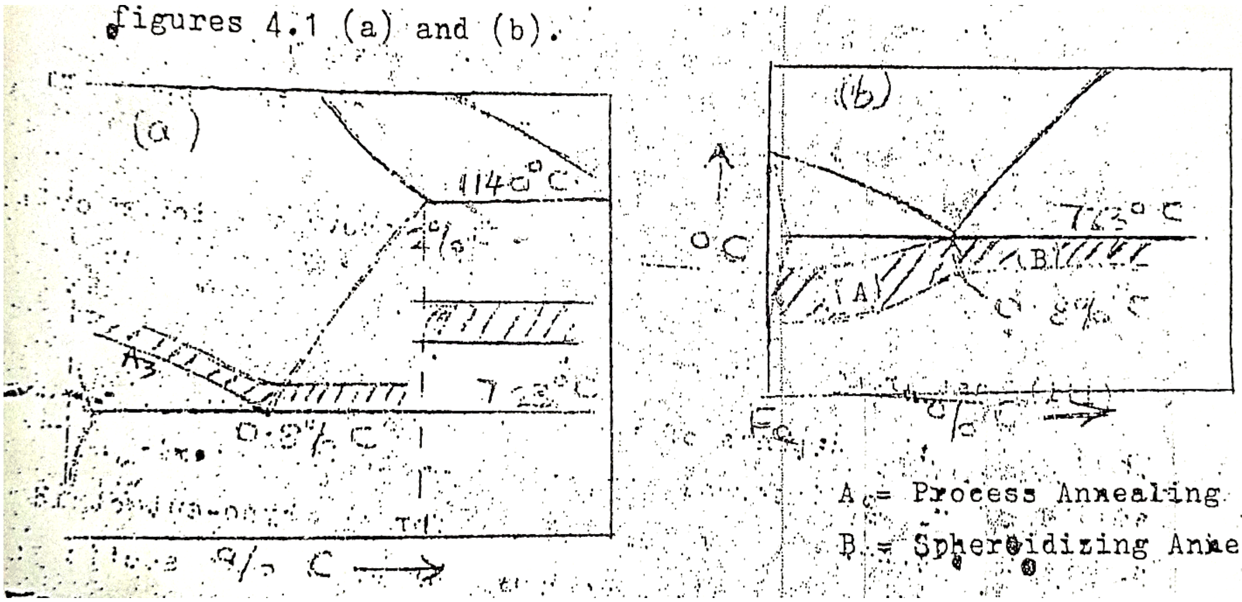
(e) when annealing is done below the critical range, this is called sub-critical annealing process. For the low carbon steels, sub-critical annealing is often referred to as process annealing. Basically, because it is commonly applied to steels being subjected to mechanical working processes (such as repeated cold working in wire drawing, extrusion e.t.c). Process annealing is required in between cold working operations to soften the work piece for the subsequent cold working. For the higher carbon steels, with considerable pearlite structure, the sub-critical annealing results in spheroidization of carbides. Hence it is called spheroidizing annealing.

(i) Process annealing is done between 350 and 650ºC, and

(ii) Spheroidizing annealing is done between 550 and 700ºC, i.e. close to the lower critical point.

Cooling rate is not relevant in the case of sub-critical annealing.

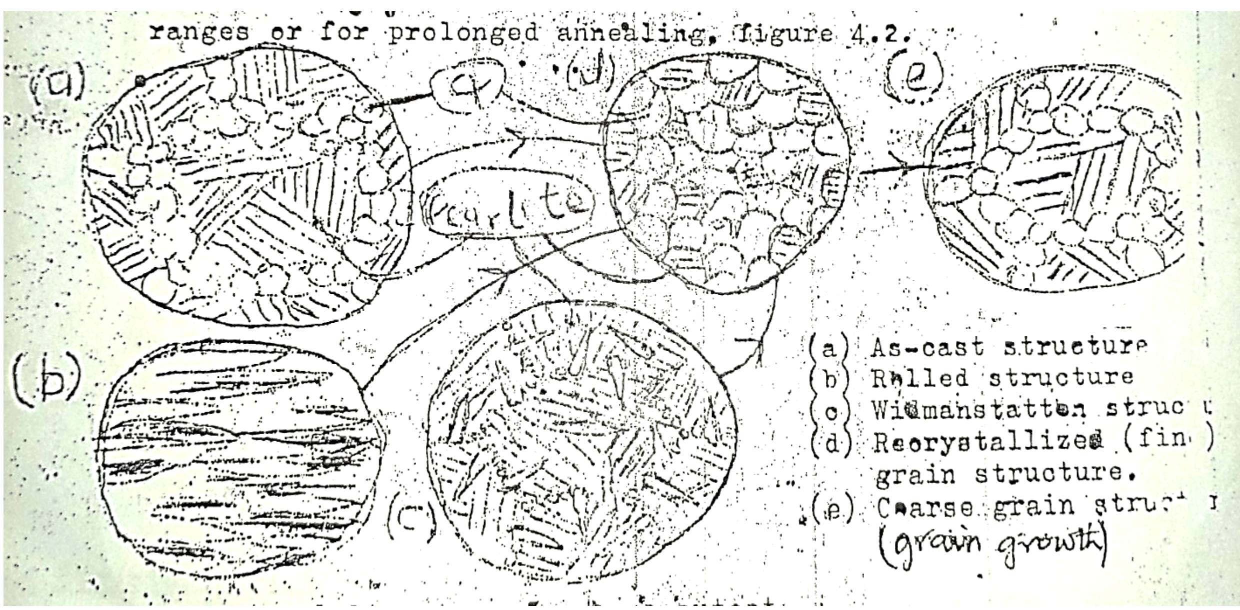
(f) The temperature ranges for the various annealing processes are shown in figure 4.1 (a) and



Annealing structures are shown for different types of steels and cast irons in figures 4.2 to 4.4 for full annealing.

It is seen in the figures that in case of annealing:

(b) **hypo-eutectoid steels**: fine structure of recrystallized ferrite and pearlite grains are formed at low annealing temperatures range. However, large grains will form at higher temperature ranges or for prolonged annealing. Figure 4.2



(a) as-cast structure

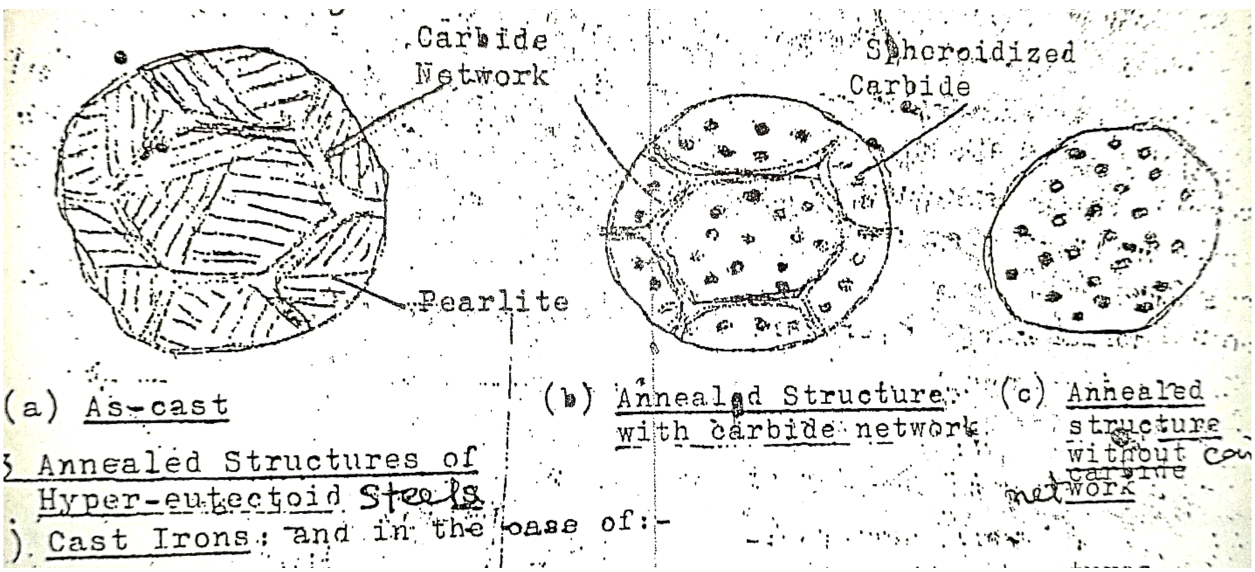
(b) Rolled structure

(c) Weldment structure

(d) Recrystallization (fine) grain structure

(e) Coarse grain structure (grain growth).

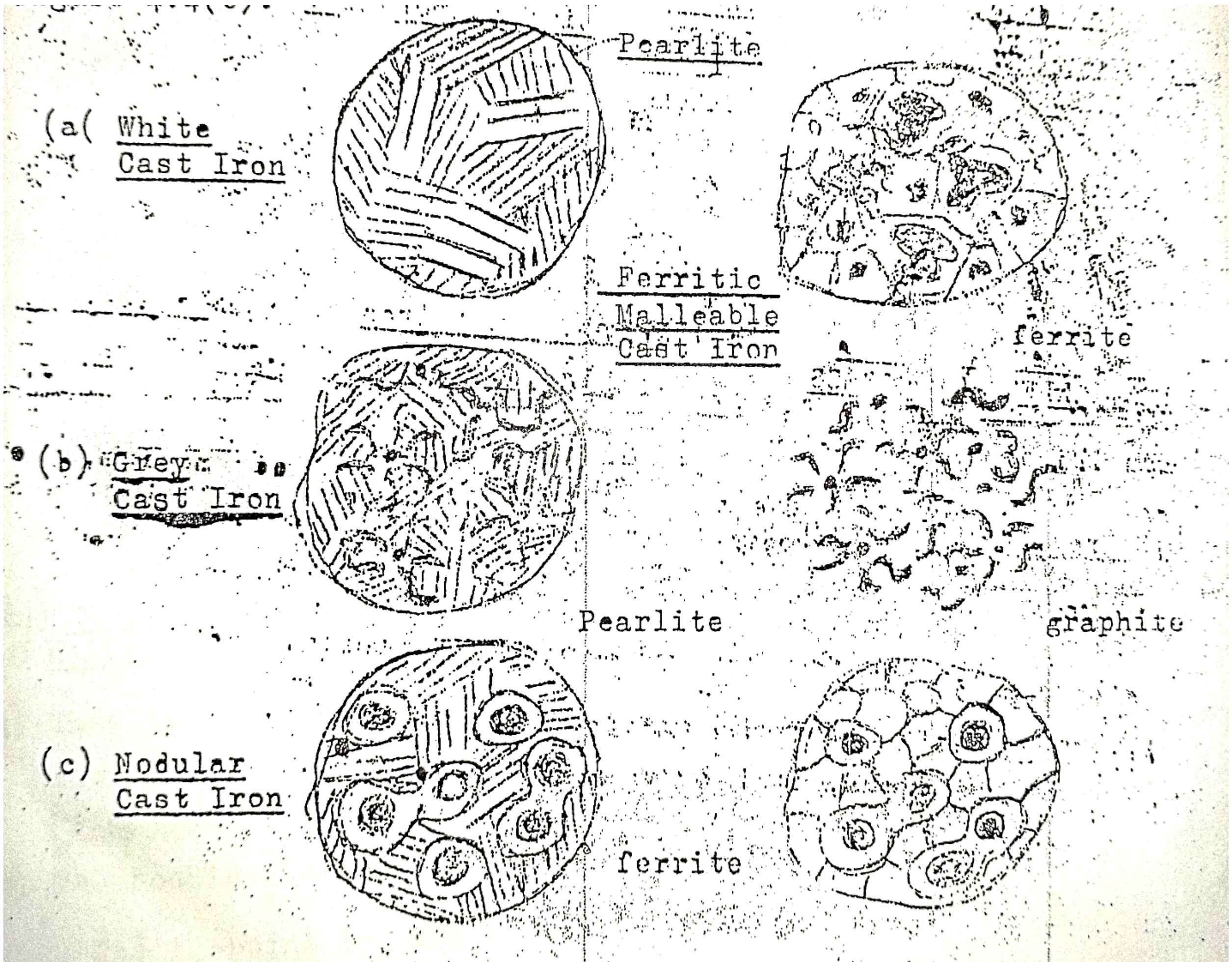
(ii) Hyper-Eutectoid Steels: Spheroidized carbides are formed in a matrix of ferrite, figure 4.3. Special techniques are employed to spheroidize the carbide network in the as-cast structure after annealing and this has not been treated.



(iii) Cast Irons: and in the case of:

1. **White cast iron:** the pearlite and the ledeburite structures are converted into graphite nodules with ragged appearance that occurs after a prolonged heating and at high temperature. This is particularly true of metallic cast irons for which the presence of silicon helps the early decomposition of cementite. The annealed structure is graphite nodules in ferrite matrix.

2. **Grey Cast Iron:** The pearlite structure breaks down and dissolves into the graphite flakes (seedlings of graphite are also produced) in a matrix of ferrite. Figure 4.4 (b).
3. **Modular Cast Iron**: The pearlite structure breaks down are dissolves into the graphite nodules and also, forms graphite seedlings in a matrix of ferrite, Figure 4.4 (e).



4.4 Annealed Structures of Cast Irons

4.3 Normalizing

(a) this is the heat treatment process whereby a steel or cast iron is heated to a temperature for the necessary homogenization to occur and then cooled in air. It is a process commonly adopted to produce grain refinement in cast steels or a preliminary heat-treatment prior to hardening of castings and annealing of hyper-eutectoid steels.

(b) in the hypo-eutectoid steels, there is an increase in the amount of pearlite and finest of the pearlite structure, after normalizing.

(c) The austenizing temperature is about 30ºC above the upper critical point, for steels and between 800 and 900oC for cast irons.

(d) The normalizing temperatures are shown in figure 4.5

(e) The normalizing structures are shown in figures 4.6 for steels and cast irons wherefore:

(i) Steels: Fine grain structures are produced. Figure (a)

(ii) Cast irons: graphite structures form in a matrix of pearlite for grey, nodular and malleable cast irons. (b1, b2 and b3 respectively).

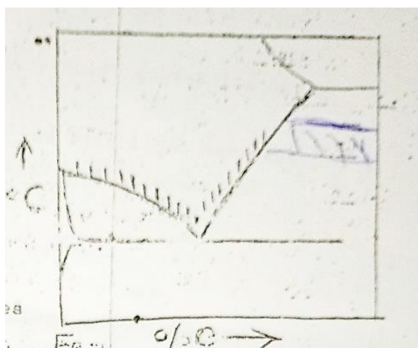
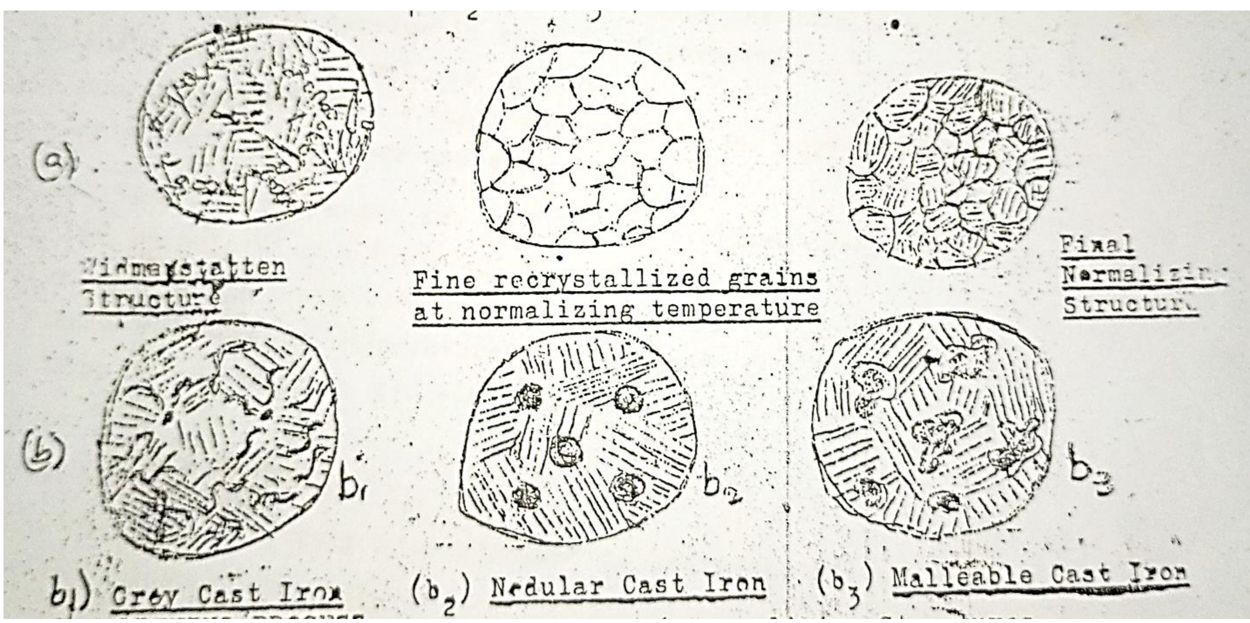


Fig. 4.5 Normalizing



4.4 Hardening Process

(a) This is the heat treatment process whereby a steel or cast iron is cooled, usually rapidly by quenching in a liquid medium, from hardening temperature, to produce a martensite structure.

(b) The soaking temperature is about 30°C above the:

- (i) A_3-point for the hypo-eutectoid steel, and
- (ii) A_1-point for the hyper-eutectoid steels, or cast irons, it is between 800 and 900°C.

(c) Quenching operation must be carefully performed since it is accompanied by a high level of thermal and transformation stresses. These stresses are responsible for the cracking of some components on hardening. In some steels and in thin-section components, interrupted quenching processes may have to be adopted to avoid cracks.

(d) Austenite is invariably retained in practically all hardenable steels. This is because it is not possible to fully attain 100% austenite transformation during quenching of these steels.

(e) Hardened steels and cast irons are not in stable conditions in the as-quenched condition, because of the presence of:

- (i) high internal stresses which may result in failure in service and dimensional instability.
- (ii) retained austenite, which results in structural and property instability
- (iii) extremely hard and brittle martensite, which causes the metal to be hard though not tough (brittle).

Tempering operation is performed on steels and cast irons hardened by quenching to produce stability of properties, dimensions and structures.

5.0 Tempering process

(a) Tempering is a heat treatment process to achieve one or many of:

(i) Relieving of internal stresses, which are particularly high in the as-quenched steels and cast irons.

(ii) attaining structural stability, and hence the attainment of reliability in service in respect of properties and dimensions as well as safety.

(iii) producing toughness without necessarily any appreciable reduction in hardness and strength.

(a) tempering temperature ranges are as follows, for plane carbon steels;

(i) low temperatures – 150 – 250ºC

(ii) Temper brittleness temperature – 200 – 350ºC

(iii) Normal temper temperatures – 350 – 500ºC

(iv) High temperatures – 450 – 600ºC.

5.1 Low temperature tempering

(a) at these temperatures, only stress relief is achieved, and the hardened steel of cast iron suffers:

(i) a slight reduction in the o/a ratio of the martensite lattice parameter for the BCC tetragonal structure.

(ii) segregation of carbon atoms to suitable site for the formation of carbide. This is an intermediate phase before the formation of the stable cementite.

(b) There is no appreciable reduction in hardness or strength.

5.2 Temper Brittleness Tempering Temperatures

Within this temperature range, the following occur:

(i) Further reduction in the c/a ratio for the martensite lattice, causing it to be more cubic.

(ii) More participation of the epsilon carbides in the martensite lattice plates.

(iii) More stress relief in the martensite.

(iv) Transformation of retained austenite to bainite, and this is considered to be responsible for some loss in toughness in carbon steels. The actual cause is not certain.

(v) There is a slight reduction in the hardness of plane carbon steels with a negotiable change in strength.

5.3 Normal Tempering Temperature

(a) The stable cementite form in the martensite plates causing a considerable relaxation in martensite plates and full stress relief.

(b) all retained austenite is transformed into bainite,

(c) The combination of the above results is appreciable less in hardness and strength of the material. However, there is corresponding increase in toughness.

(d) The tempered structure is tempered martensite which is the precipitation of stable cementite in an extremely fine super-saturated
plates of ferrite. (not the traditional ferrite), and lower bainite.

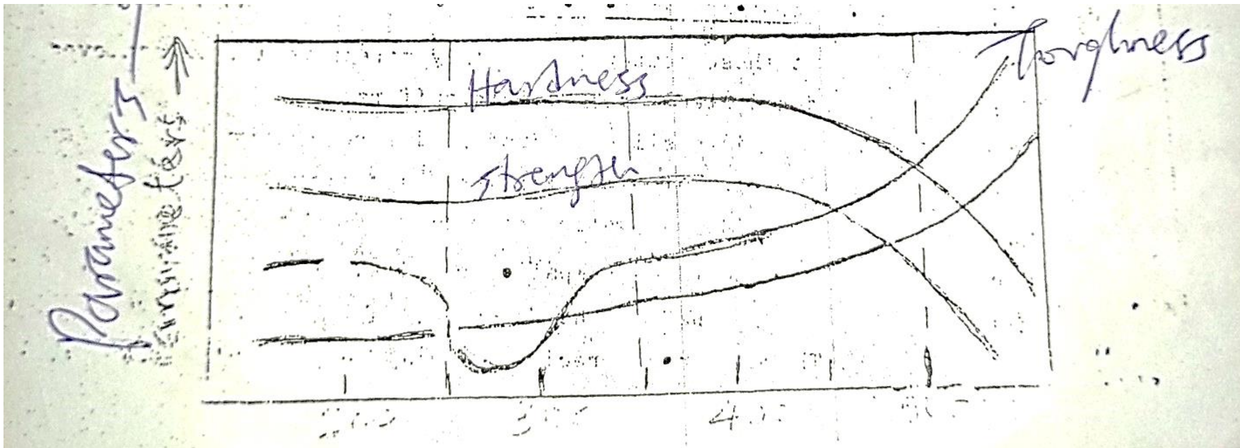
5.4 High Temperature Tempering

(a) The cementite precipitates are larger and are spheroidized, because there is considerably less super-saturation of carbon in the martensite plate. The martensite becomes essentially more of stable ferrite structure.

(b) The material suffers a considerable loss of hardness and strength, and the ductility is significantly increased.

5.5 Mechanical Properties of Tempered carbon steels

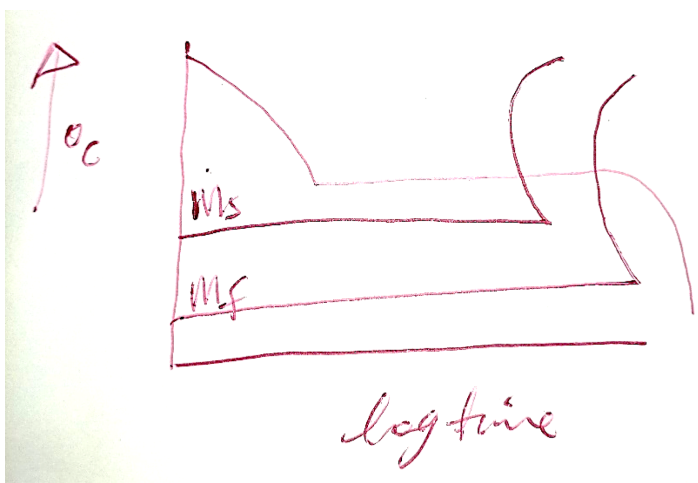
The mechanical properties of tempered carbon steels are summarized in figure 4.7, which is only schematic.



INTERRUPTED QUENCHING PROCESS

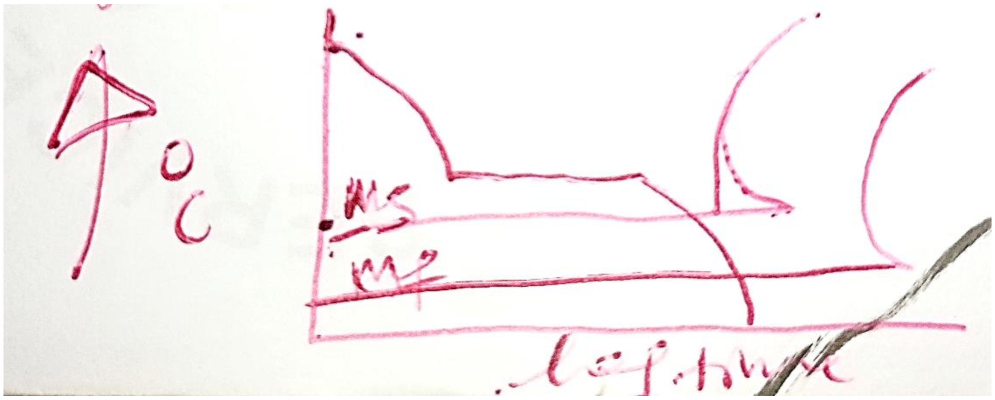
These are processes normally apply during quenching takes care of the problem met at quenching. It may involve quenching in the furnace or liquid. Common quenching process include:

(1) **Austempering**: in this process, the steel is first quenched from the austenite temperature into a molten salt bath which is maintained at a temperature high above the Ms Temperature. This is maintained until all the austenite is transformed to lower bainite.



(2) **Martempering:** This is similar to austempering in that the cooling is interrupted just above the Ms and hold for some time. Cooling is resumed before austenite start transforming to

bainite and at a much slower rate. The holding time is shorter here. The structure formed is called tempered martensite.



Annealing	Normalizing
1. The final structure is ferrite 2. Cooled in furnace	1. Final structure is pearlite 2. Cooled in air