Al-Mustaqbal University
Department of Techniques of Fuel and Energy Engineering
Second stage
Subject: Properties of Engineering Materials- UOMU027044
Lecturer Aseel S. Hamzah
2nd term – Lect **8**

Iron-carbon cooling curve, phases, reactions, and multi phases

1. Cooling curve

The melting temperature of any pure material at constant pressure is single temperature, and equilibrium of liquid and solid phases at this temperature. When cooled, the temperature of the molten material will steadily decrease until the melting point is reached. At this point the material will start to crystallize and solidified.

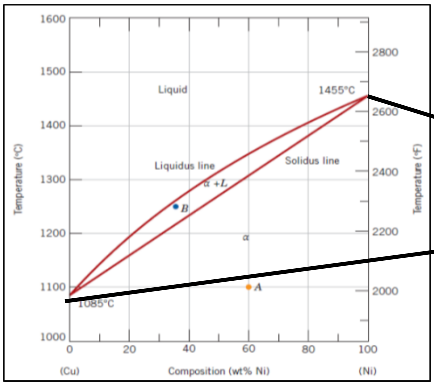


Figure 1 phase diagram

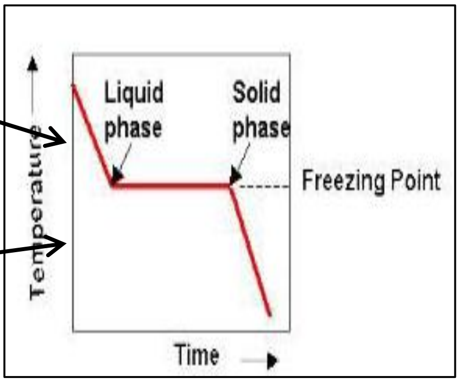


Figure 2 Cooling curve for pure material

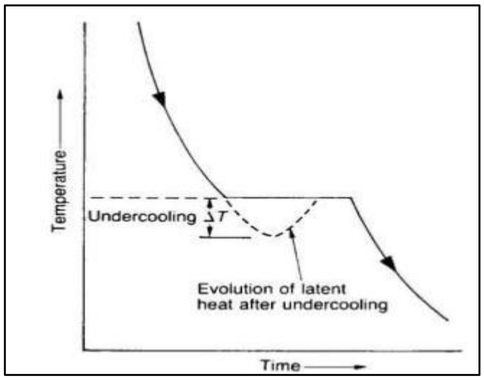


Figure 3 undercooling

Most systems consisting of two or more components exhibit a temperature range has two different temperatures, liquidus temperature (T_L) and solidus temperature (T_S) which are needed to describe the change from liquid to solid.

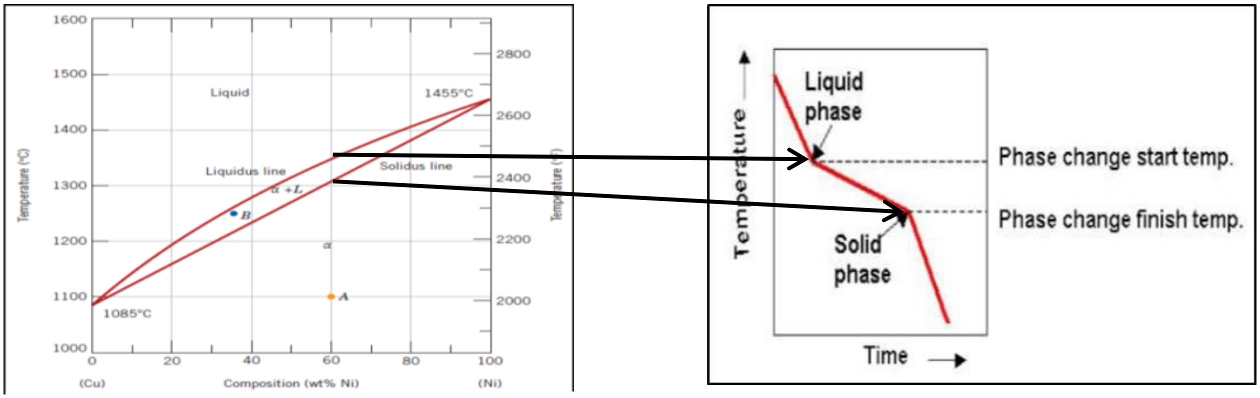
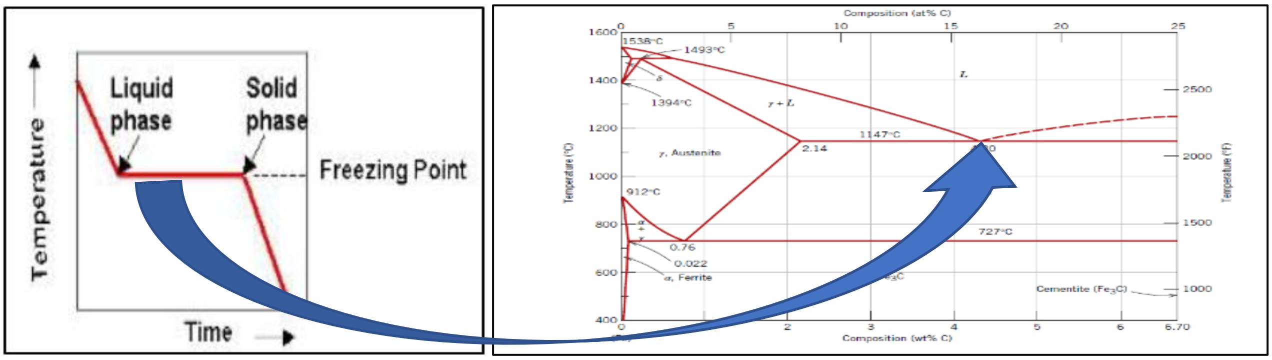


Figure 4 Cooling curve for alloy

Email (ASEEL.SAFI.HAMZAH@uomus.edu.iq)

- Liquidus temperature: the temperature above which the system is entirely liquid.
- Solidus temperature: the temperature below which the system is completely solid.
- Solidification begins when reached liquidus temperature.
- Eutectic alloy solidified at single temperature (eutectic temperature).



2. Iron-carbon cooling curve

Isothermal and continuous-cooling transformation diagrams introduced parameter of **time**, and experimentally determined, by using specified composition and variables of temperature and time. These diagrams allow prediction of the microstructure.

2.1 Isothermal cooling transformation

Conditions of **constant** temperature are termed **isothermal** that referred to isothermal transformation diagrams or sometimes as "time-temperature-transformation" diagram (T-T-T).

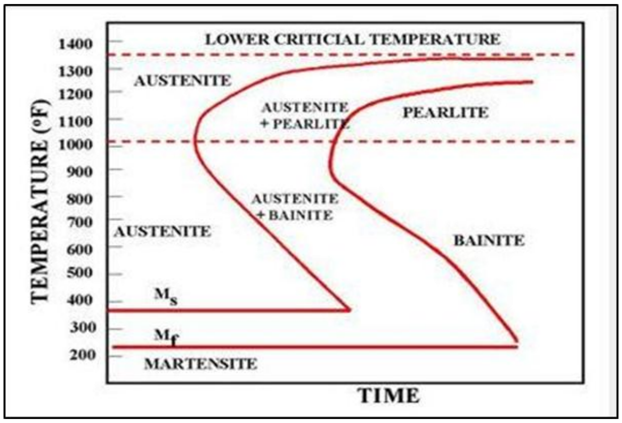
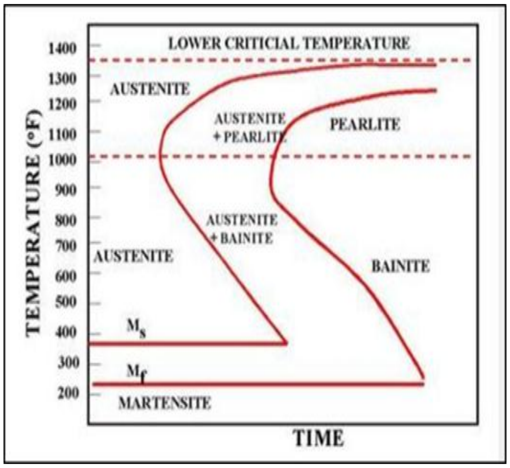


Figure 5 T-T-T diagram

2.2 Determine TTT Diagrams

Salt bath technique combined with metallography and hardness measurements utilized to determine TTT diagrams. In molten salt bath technique used two salt baths and one water bath:

- Salt bath I is maintained at austenetising temperature (780˚C for eutectoid steel).
- Removed from bath I and put in bath II
- Salt bath II is maintained at specified temperature.
- The samples kept for different period of time (t1, t2, t3, t4 ,tn)
- The samples are removed and quenched in cold water bath (bath III).



The **microstructure** of each sample is studied using metallographic techniques.

1% transformation to pearlite represents → **start** of transformation

99% transformation to pearlite represents time → **final** of transformation

1% martensite considered temperature of bath II as martensite start temperature (**M$_S$**).

99 % martensite considered temperature of bath II as martensite finish temperature (**M$_F$**).

The shape of diagram like either S or like C.

2.3 C**ontinuous-cooling transformation**(CCT)

- Most heat treatments for steels involve the continuous cooling.
- The time required for a reaction to begin and end is delayed in continuous cooling.
- Isothermal curves are shifted to longer times and lower temperatures, as indicated in the figure for iron–carbon alloy of eutectoid composition.

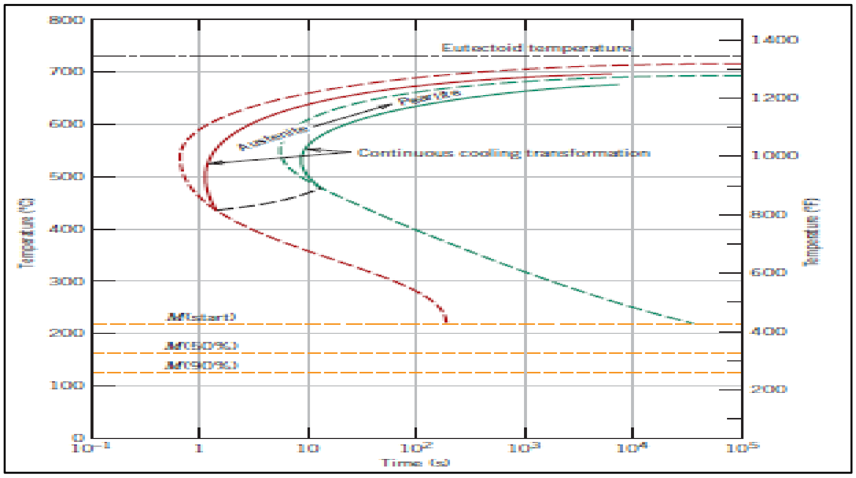


Figure 6 Superimposition of isothermal and continuous-cooling transformation diagrams for eutectoid iron–carbon alloy.

- The rate of temperature change, depending on the cooling environment.
- Two cooling curves fast and slow rates produce fine and coarse pearlite.

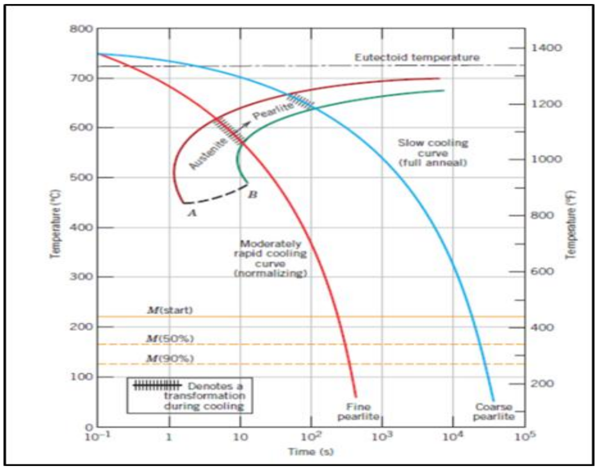


Figure 7 rapid and slow cooling curves superimposed on a continuous-cooling transformation diagram for eutectoid iron–carbon alloy.

- bainite will not form in continuously cooled.
- Unreacted austenite transform into martensite upon crossing the M(start) line.
- Martensitic transformation temperatures, M(start), M(50%), and M(90%) **lines occur** at **identical** temperatures for both isothermal and continuous-cooling transformation.
- **Critical quenching rate** represents minimum rate of quenching that produces a totally martensitic. just misses the nose at which the pearlite transformation begins, as illustrated

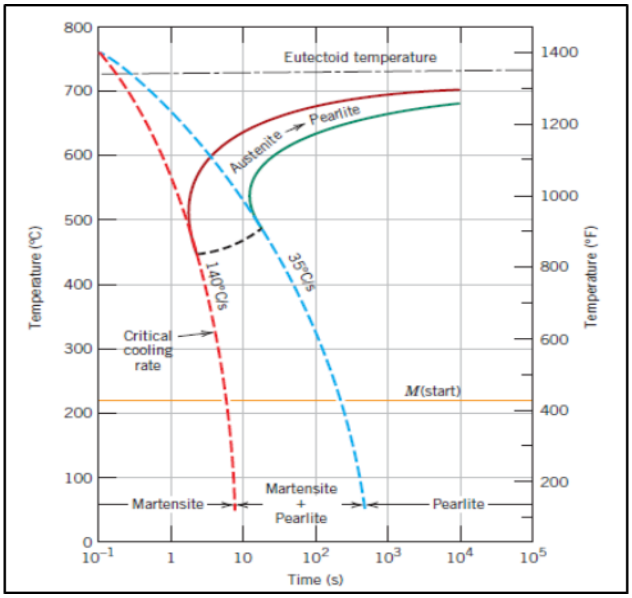


Figure 8 Continuous-cooling transformation for eutectoid iron–carbon alloy

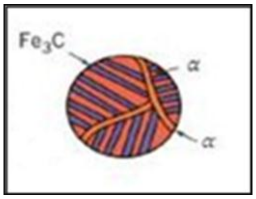
- Low cooling rates produce pearlitic structure.
- **Carbon and other alloying elements shift** the curve to longer times, thus decreasing the critical cooling rate.
- Alloying steels formed totally martensite in relatively thick cross sections.
- Steel alloys containing less than 0.25 wt% carbon are not heat treated to form martensite **because quenching rates too rapid**.
- Alloying elements(Cr ,Ni ,Mo, Mn ,Si, W)effective in **enhancement** heat-treatable of steels.

Email (ASEEL.SAFI.HAMZAH@uomus.edu.iq)

3. Mechanical Behavior of Iron–Carbon Alloys

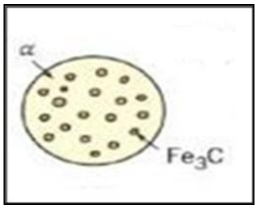
The mechanical behavior of iron–carbon alloys depend on **microstructures**, fine and coarse pearlite, spheroidite, bainite, and martensite according to mechanical property–microstructure relationships.

3.1 Pearlite



- Pearlite consist of (harder and brittle) cementite and (soft) ferrite.
- Increasing fraction of Fe_3C result in decrease of ductility and toughness.
- Fine pearlite is harder and stronger than coarse pearlite.
- Cementite reinforce the ferrite.

Spheroidite



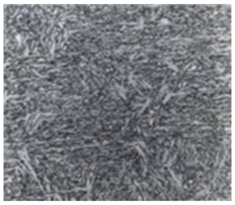
- The cementite phase has spheroidite microstructures.
- spheroidite, soft , weak and ductile material, less strength and hardness
- plastic deformation is not constrained.

Bainite

- It have finer structure (smaller α-ferrite and Fe_3C particles).
- Stronger and harder than pearlitic steels.
- Exhibit a desirable combination of strength and ductility.

Martensite

- Martensite is the hardest , strongest and most brittle; negligible ductility.
- The strength and hardness of martensite **not related to microstructure**.
- The properties attributed to the effect of **interstitial carbon atoms** in hindering dislocation motion.



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Tempered martensite

Martensite is **brittle**, cannot be used for most applications; and **internal stresses** introduced during quenching have **weakening effect**. The ductility and toughness of martensite may be enhanced and internal stresses relieved by heat treatment known as **tempering**.

Tempering is accomplished by **heating a martensitic steel to a temperature below the eutectoid temperature for a specified time period**, between 250°C and 650°C. Transformation reaction of martensite to tempered martensite is:

$$\text{Martensite (BCT, single phase)} \rightarrow \text{tempered martensite } (\alpha + \text{Fe}_3\text{C phases})$$

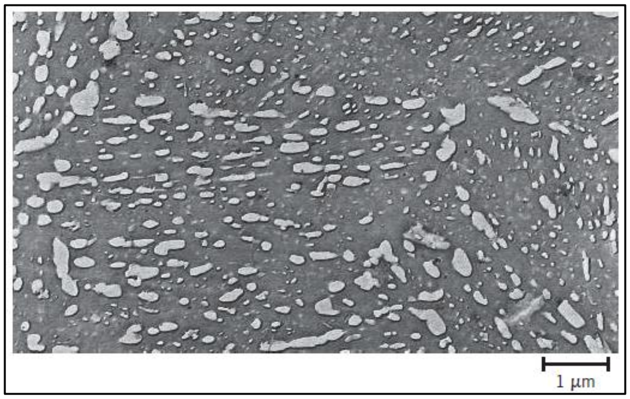

Figure 9 Electron micrograph of tempered martensite.