COURSE : PHYSICAL METALLURGY 2

Prepared by Pr. Zakaria Boumerzoug

Lecture 1: Introduction to Phase Diagram Fe-C.

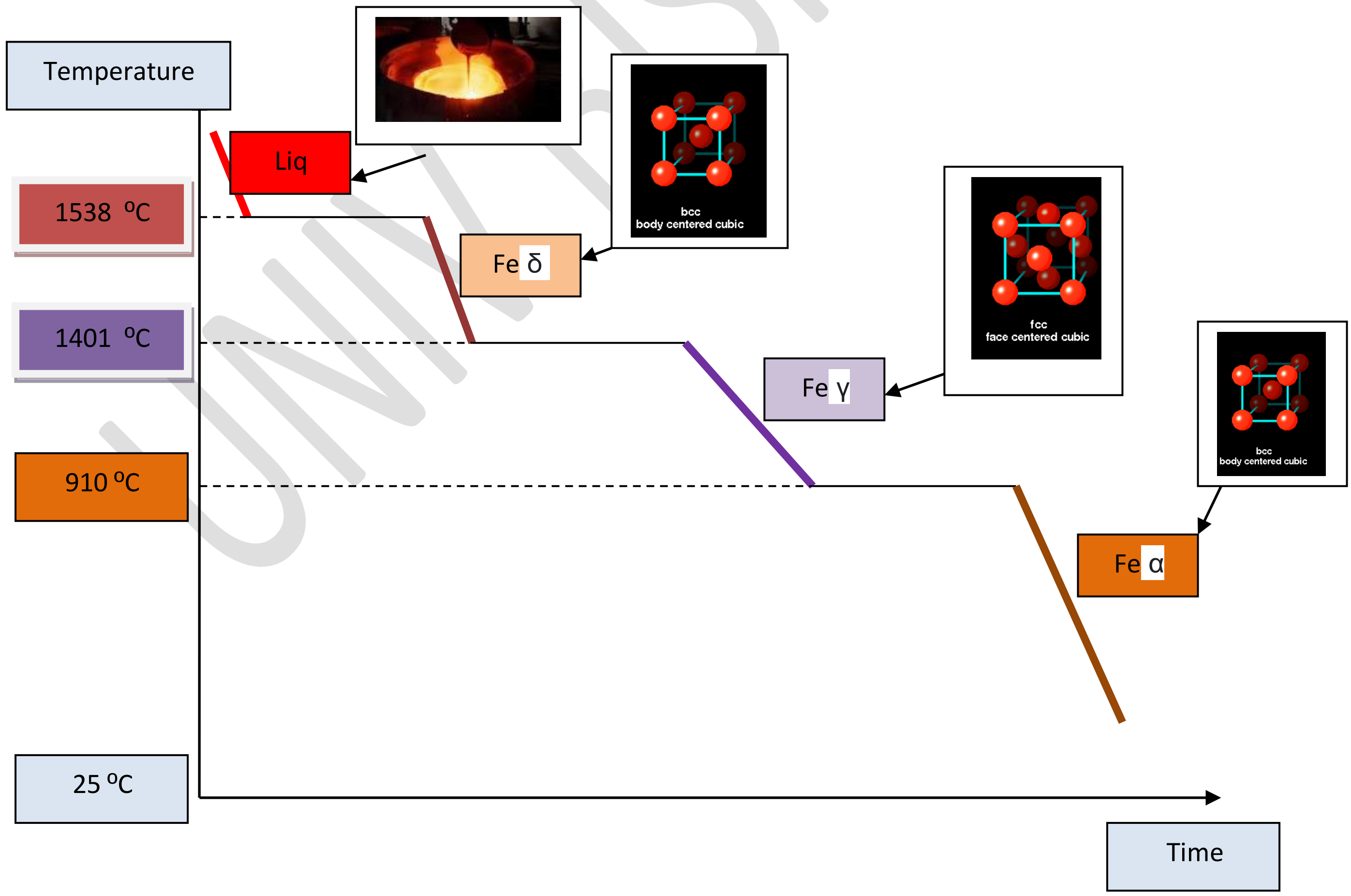
Iron :

-Iron is a metal

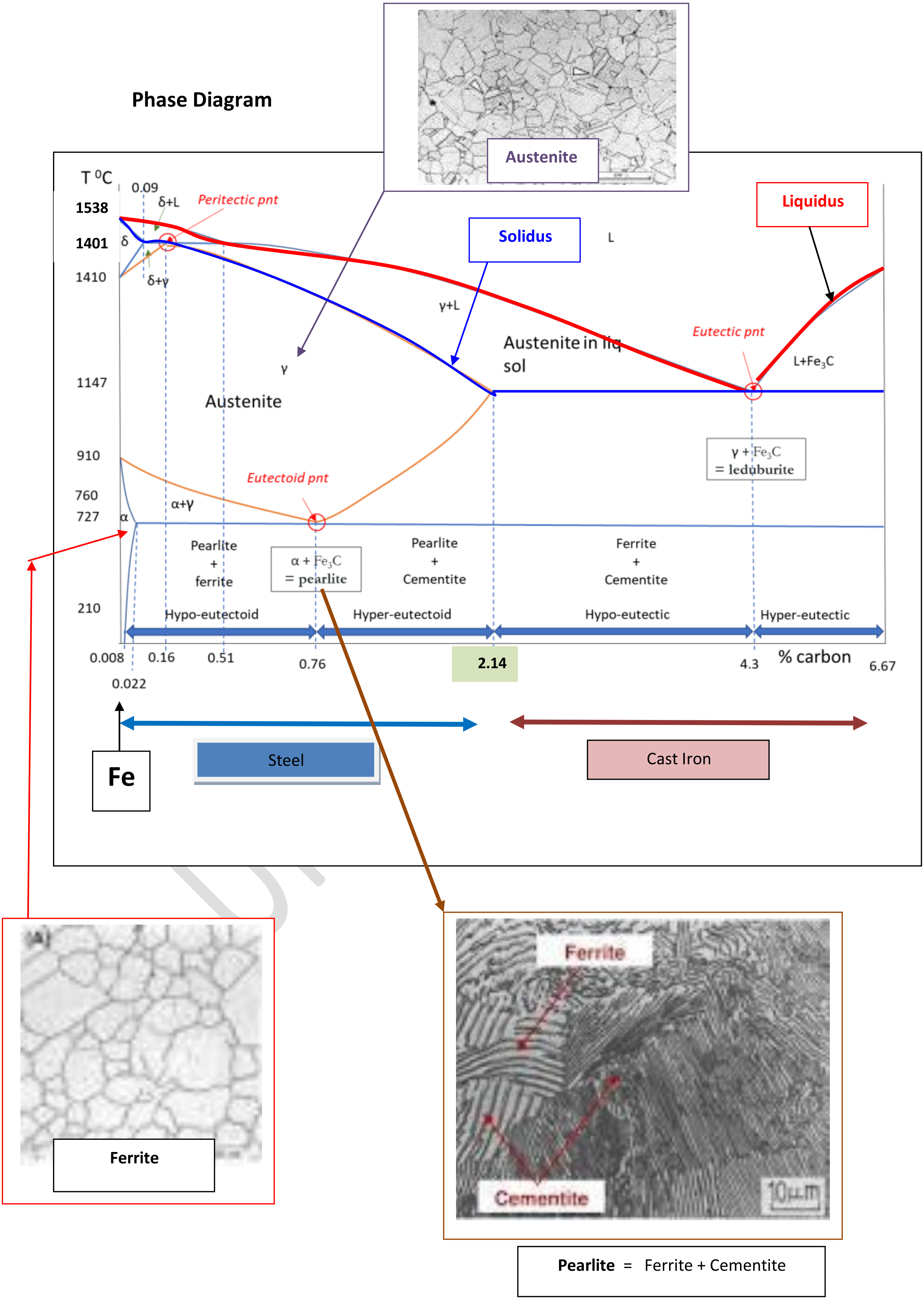
- It has an atomic weight of 56

-It is the most-used and cheapest metal.

The structure : Three **allotropic** forms of iron exist, depending on temperature: **alpha iron (α-Fe)**, **gamma iron (γ-Fe)**, and **delta iron (δ-Fe)**.



Phase Diagram



Definitions of phases :

Definition 1 : α-ferrite -solid solution of C in Fe (BCC)

Definition 2 : γ-austenite -solid solution of C in FCC Fe

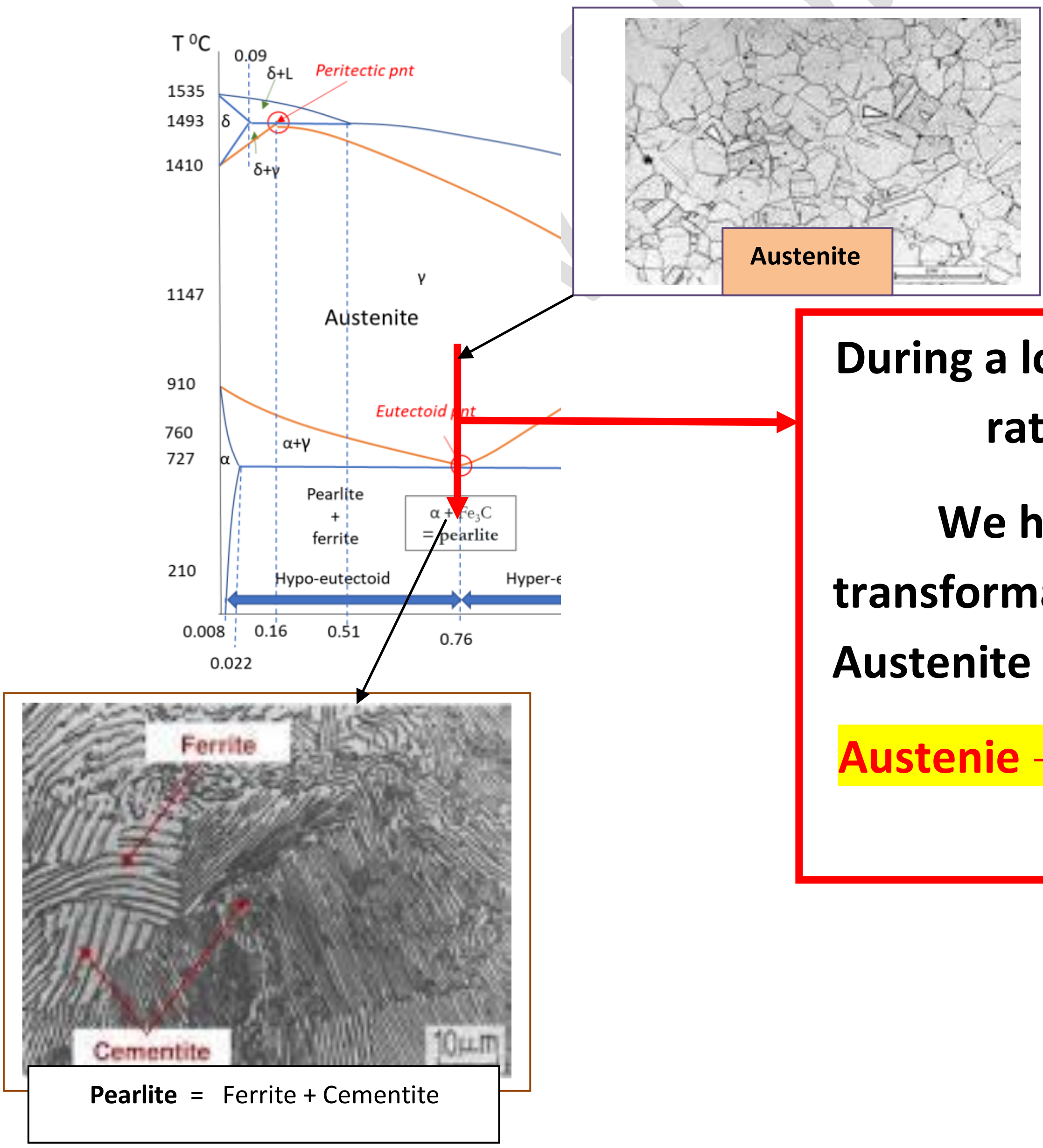
Definitin 3 : δ-ferrite solid solution of C in BCC Fe

Definition 4 : Fe3C (iron carbide or cementite)

Definition 5 : Maximum solubility in BCC α-ferrite is limited (max. 0.022 wt% at 727 °C)

Definition 6 : Maximum solubility in FCC austenite is 2.14 wt% at 1147 °C-FCC has larger interstitial positions.

Phase transformation at solid state :



During a low cooling rate :

We have a transformation from Austenite to Pearlite

Austenie → Pearlite

Lecture 2: Some phase transformations in Fe-Fe_3C

/(Reference : https://mech.poriyaan.in/topic/iron-iron-carbide-equilibrium-diagram-30655)

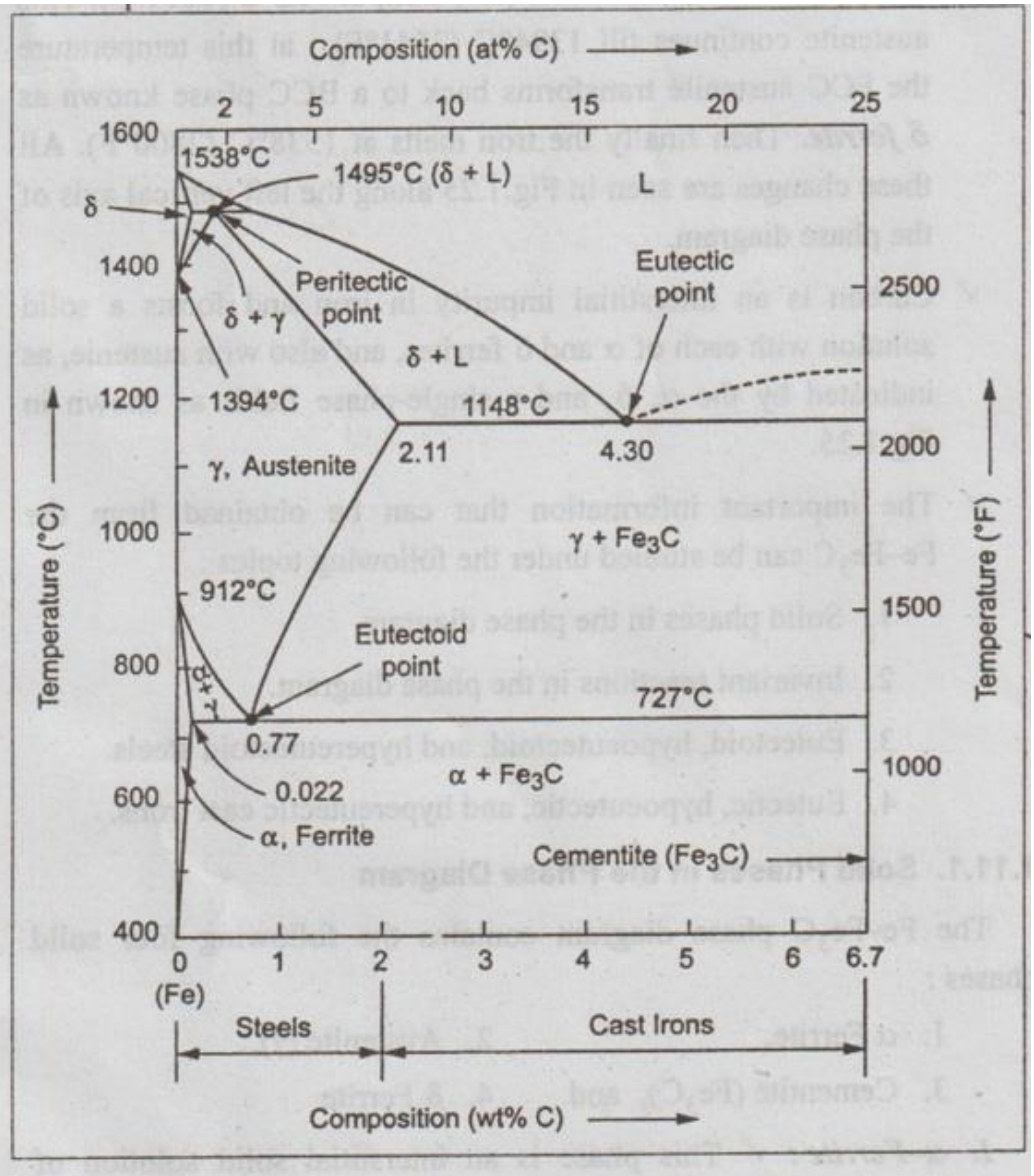


Fig. 1.25. The iron-iron carbide phase diagram

1- Pearlitic transformation

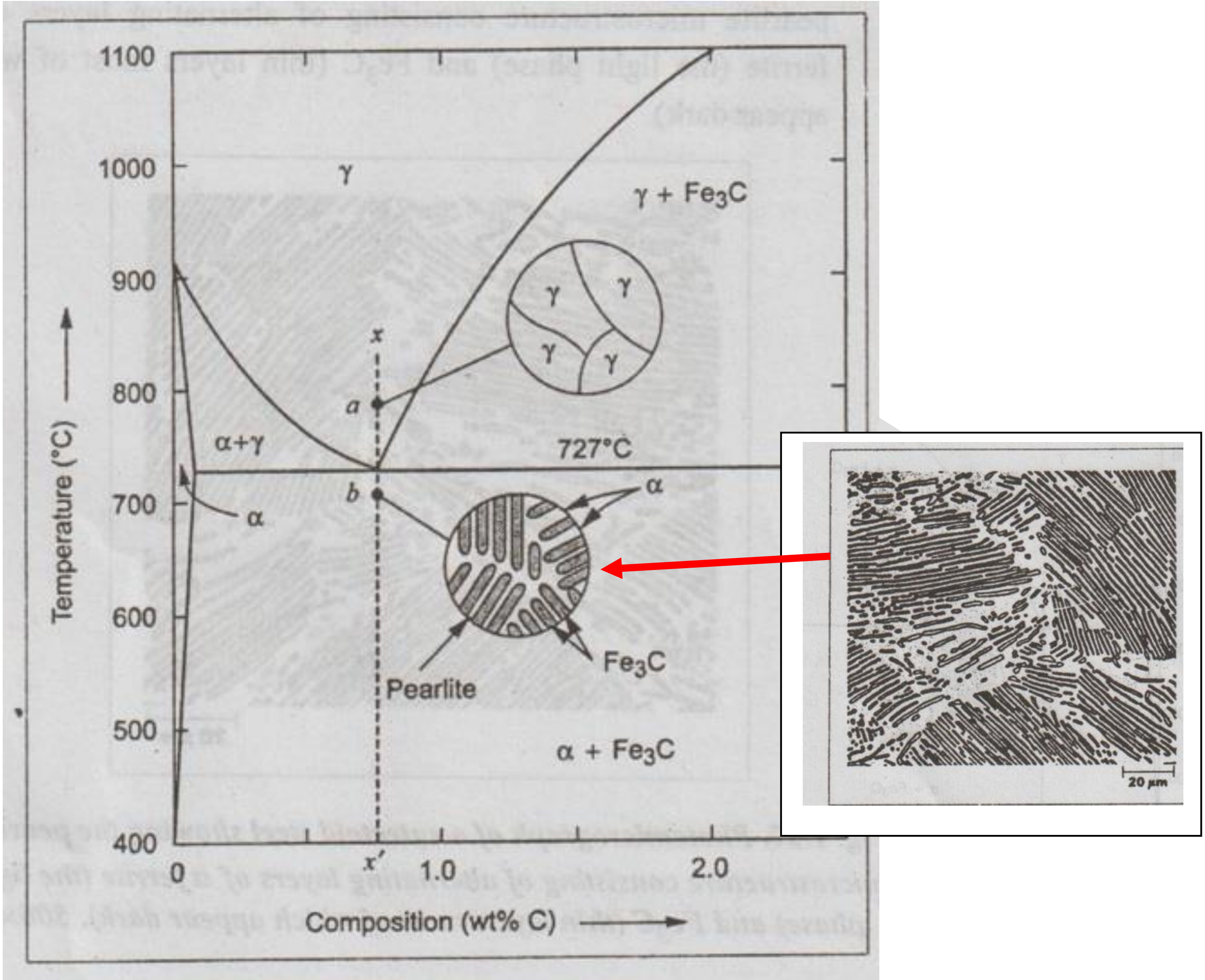
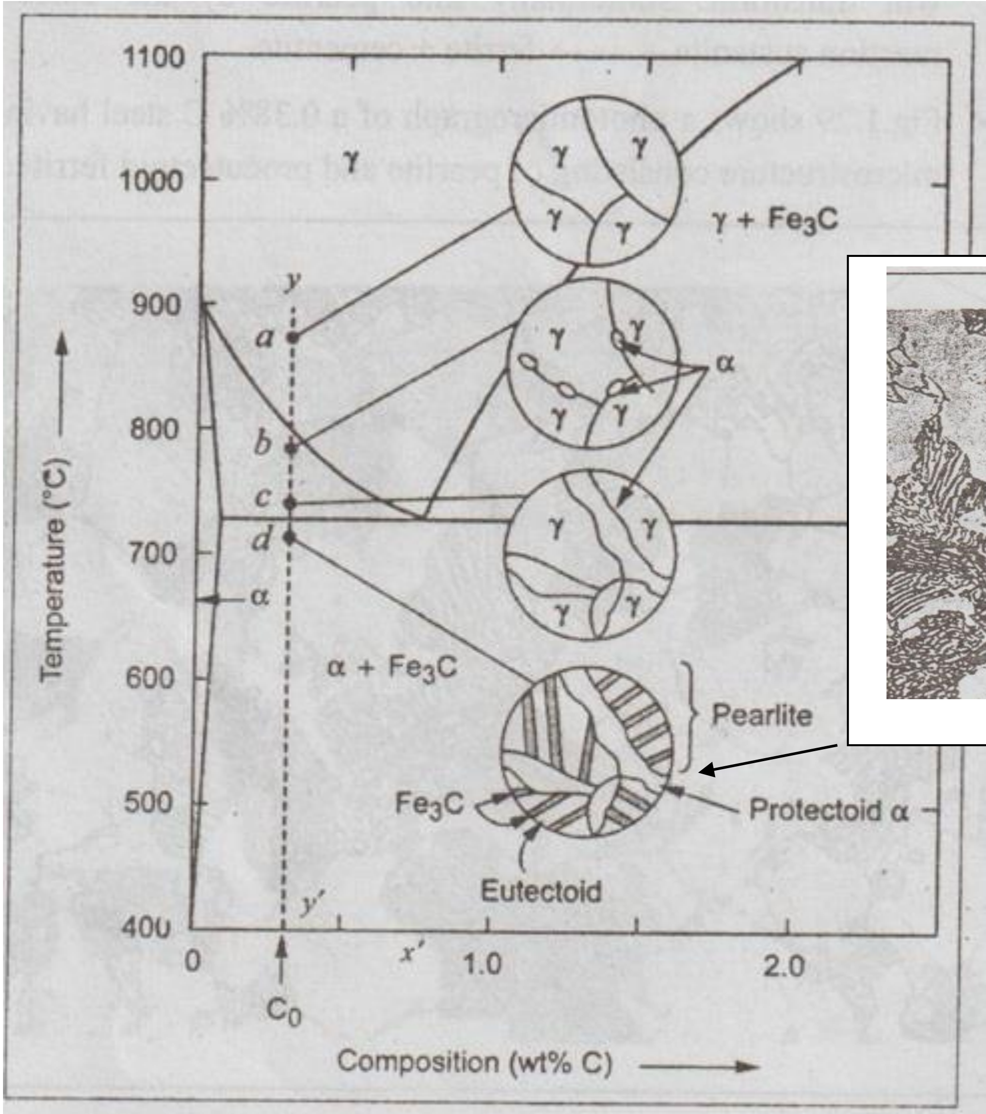


Fig. 1.26. Transformation of a eutectoid steel (0.8% C) with slow cooling

2- Slow cooling of Hypoeutectoid Steel



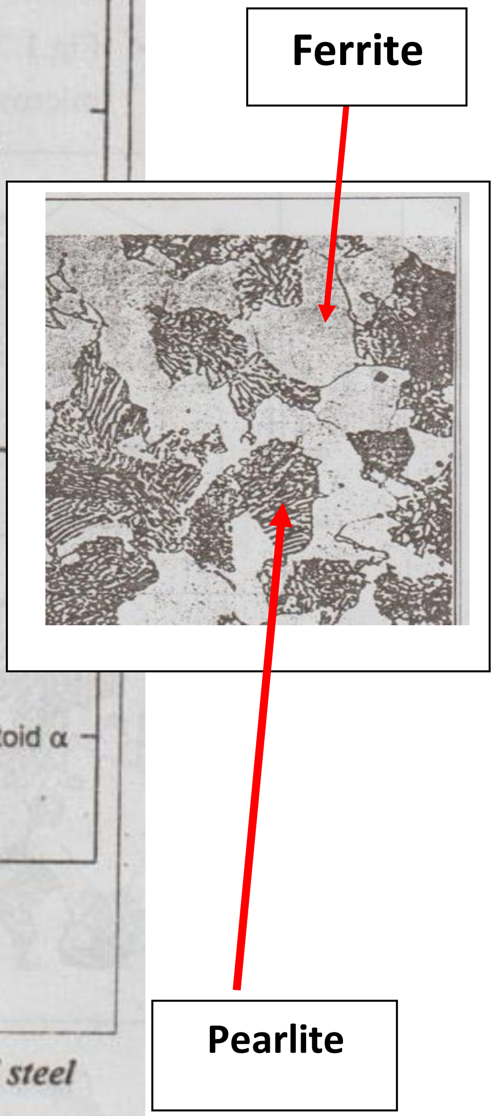


Fig. 1.28. Transformation of 0.38% C hypoeutectoid steel with slow cooling

3- Slow cooling of an Hypereutectoid steel

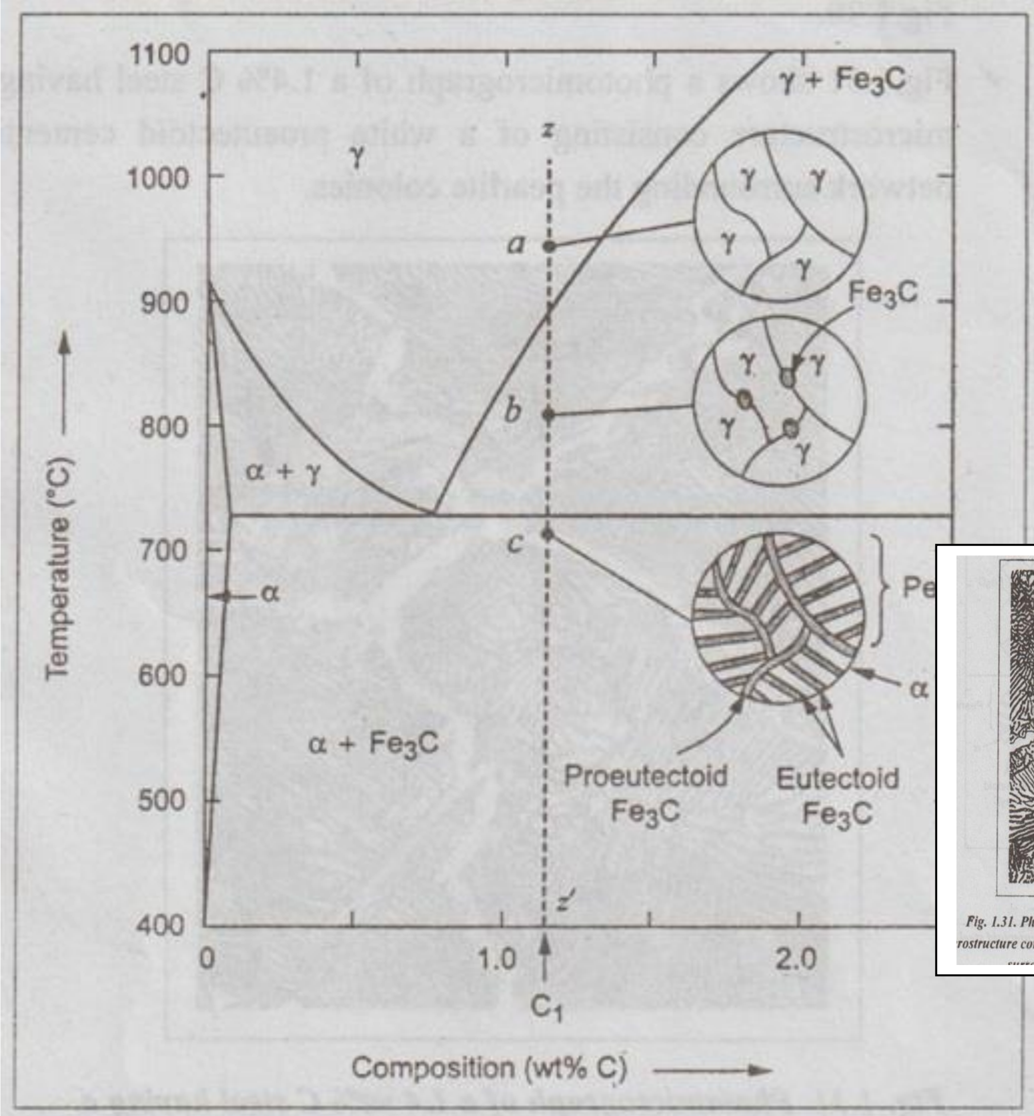


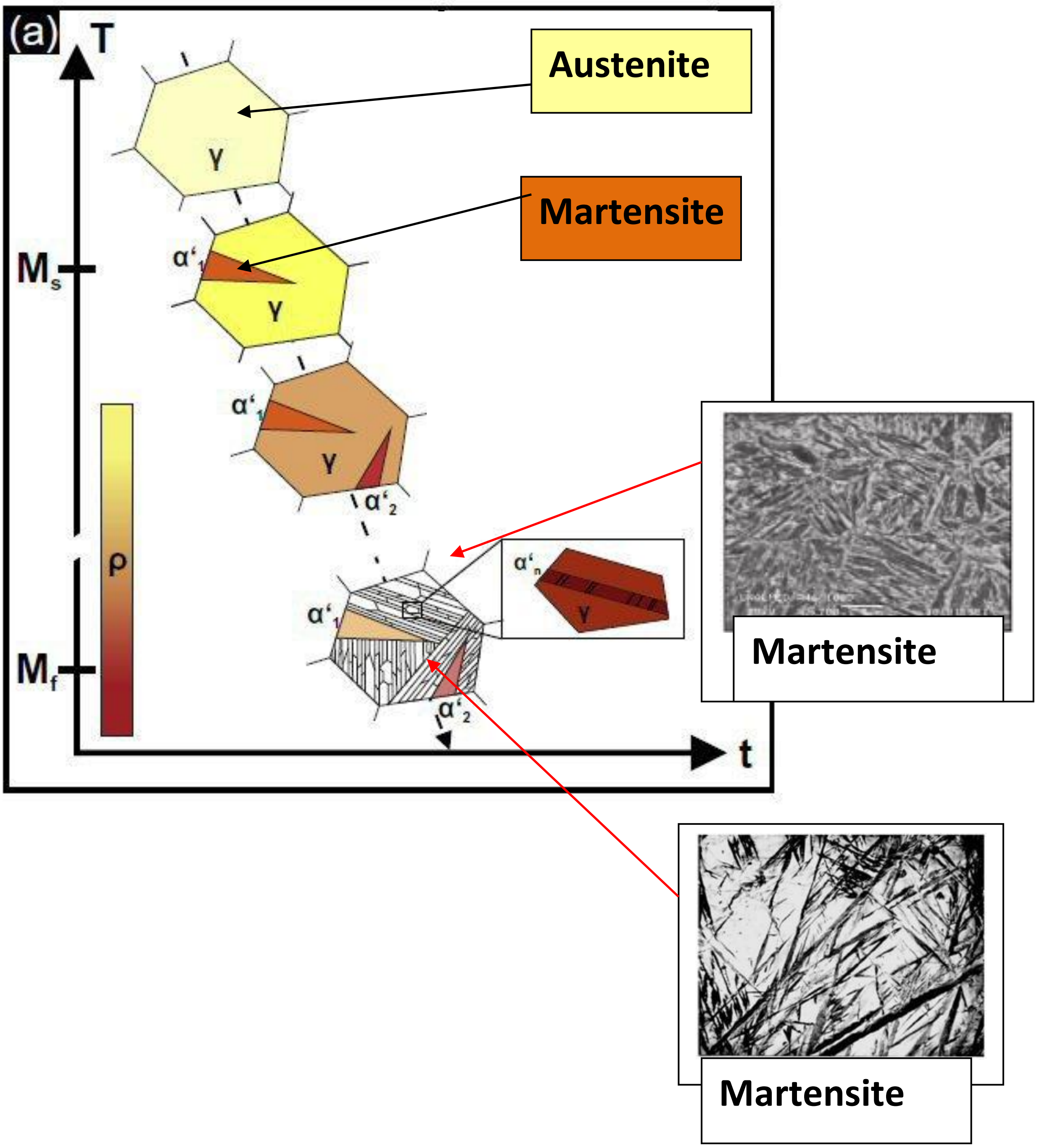
Fig. 1.30. Transformation of a 1.2% C hypereutectoid steel with slow cooling

Fig. 1.31. Photomicrograph of a 1.4 wt% C steel having a rostructure consisting of a white proeutectoid cementite network

Lecture 3 Martensitic transformation

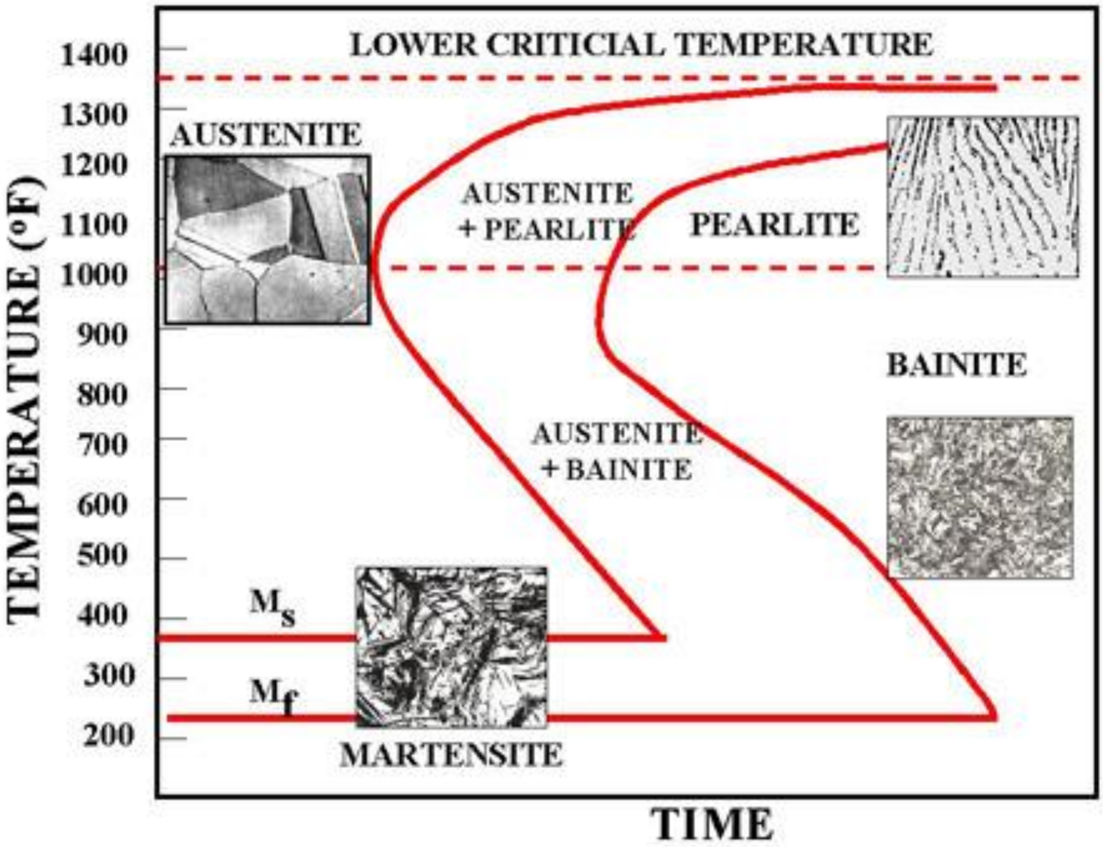
During rapid cooling (quenching) of austenite, a martensitic transformation begins at the martensite start temperature (M_s).

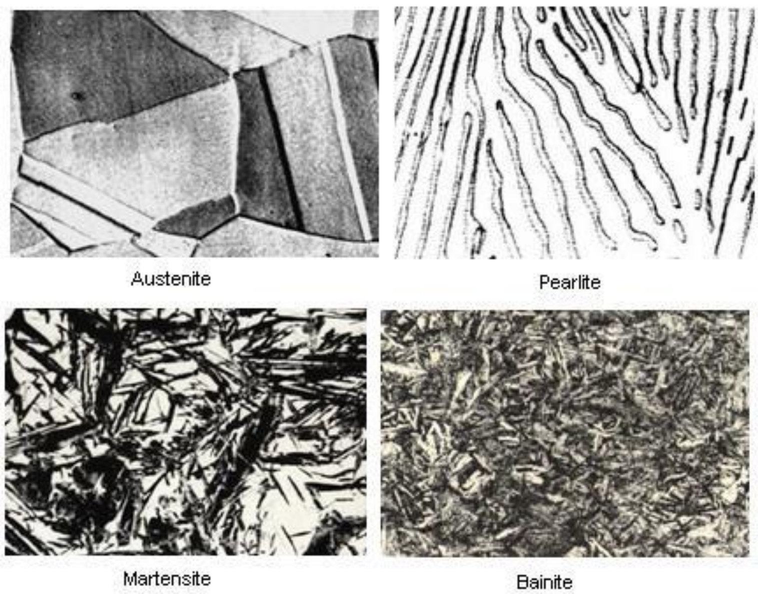
L. Morsdorf et al./Acta Materialia 95 (2015) 366–377



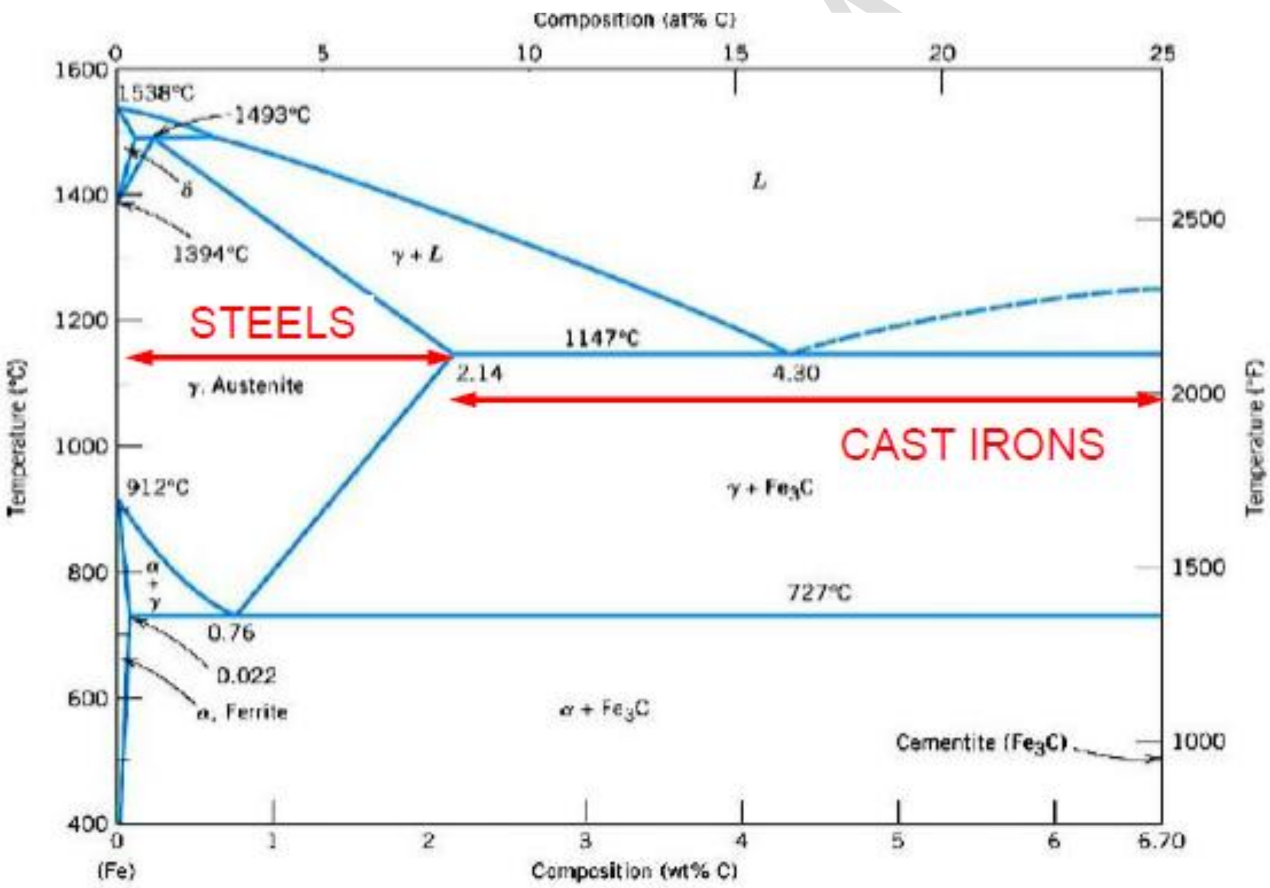
Lecture 4 : Diagram TTT

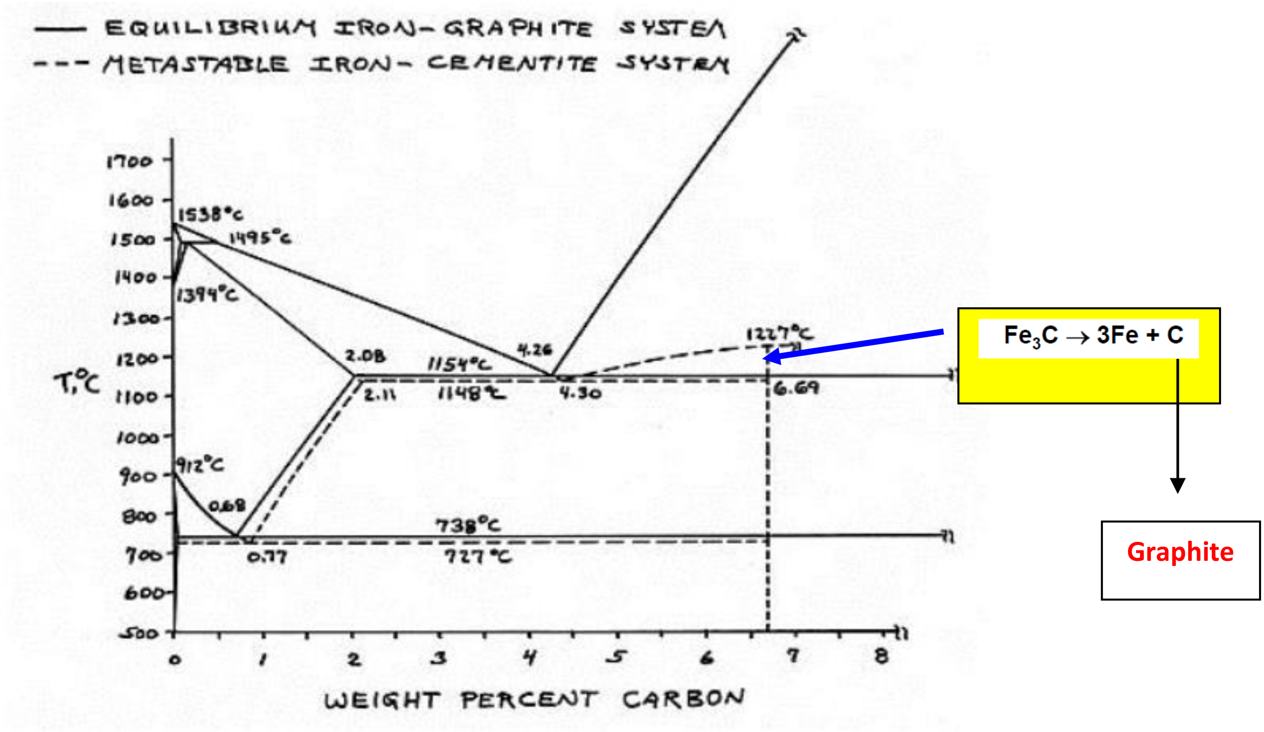
(Reference : https://www.metallurgyfordummies.com/time-temperature-transformation-ttt-diagram.html)

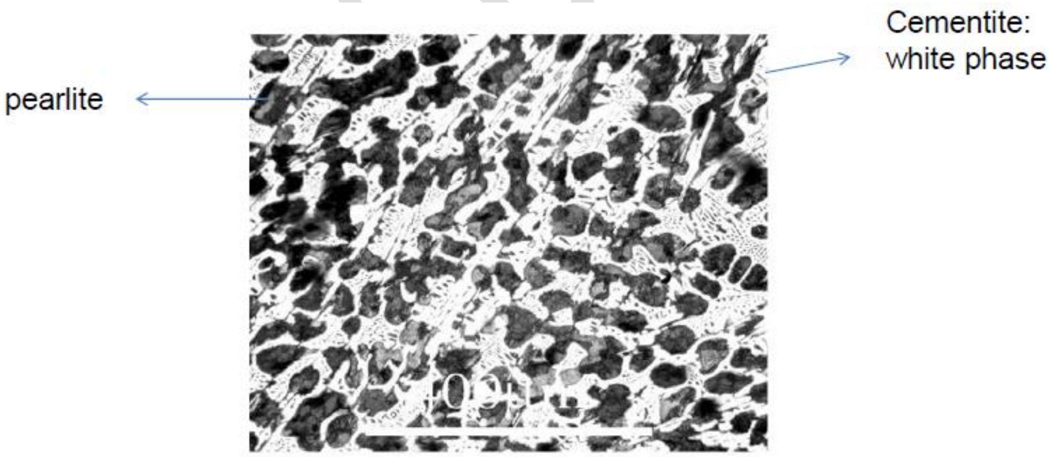


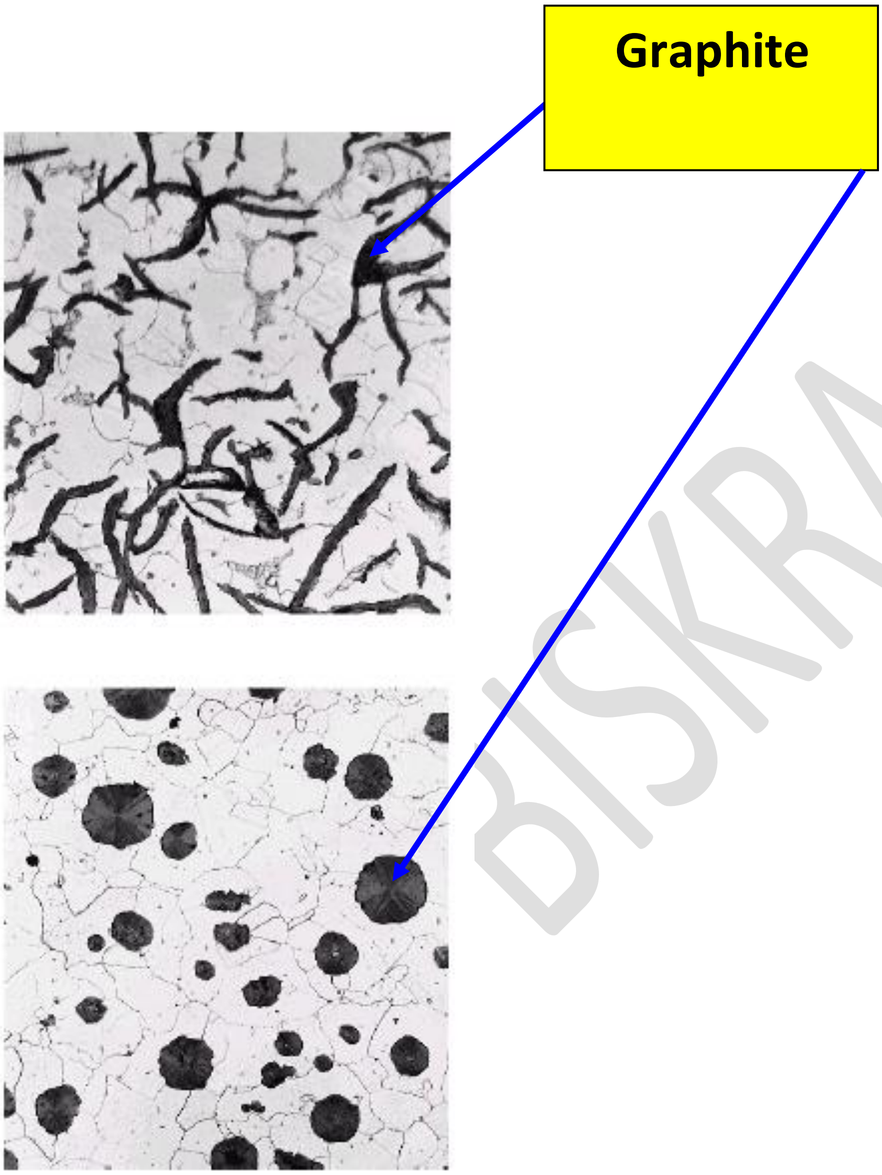


Lecture 5 Cast Iron



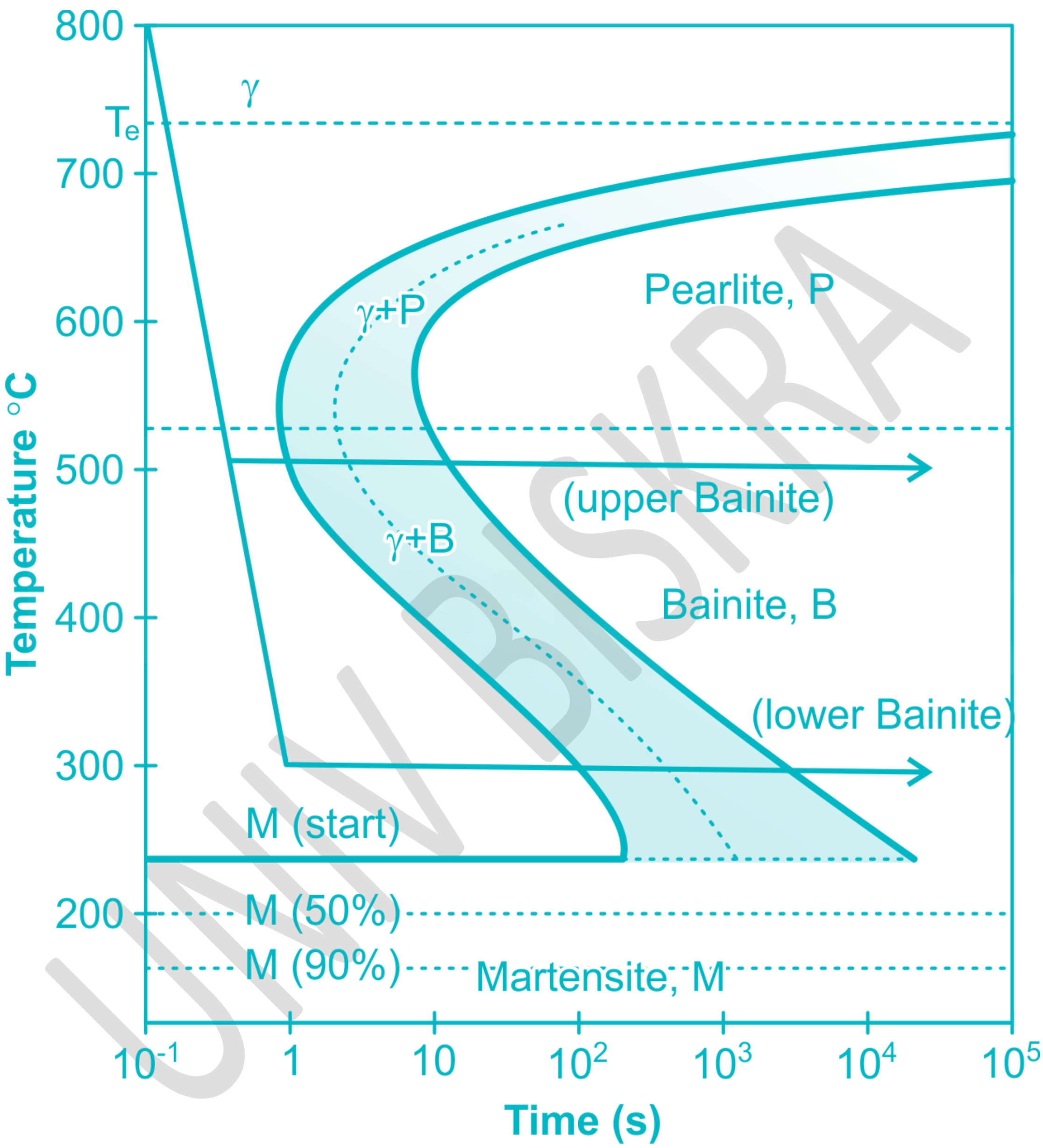

— EQUILIBRIUM IRON-GRAPHITE SYSTEM
--- METASTABLE IRON-CEMENTITE SYSTEM
T, °C
1538°C
1495°C
1394°C
2.08
1154°C
4.26
1227°C
2.11
1148°C
4.30
6.69
912°C
0.68
738°C
0.77
727°C
WEIGHT PERCENT CARBON
Fe$_3$C → 3Fe + C
Graphite

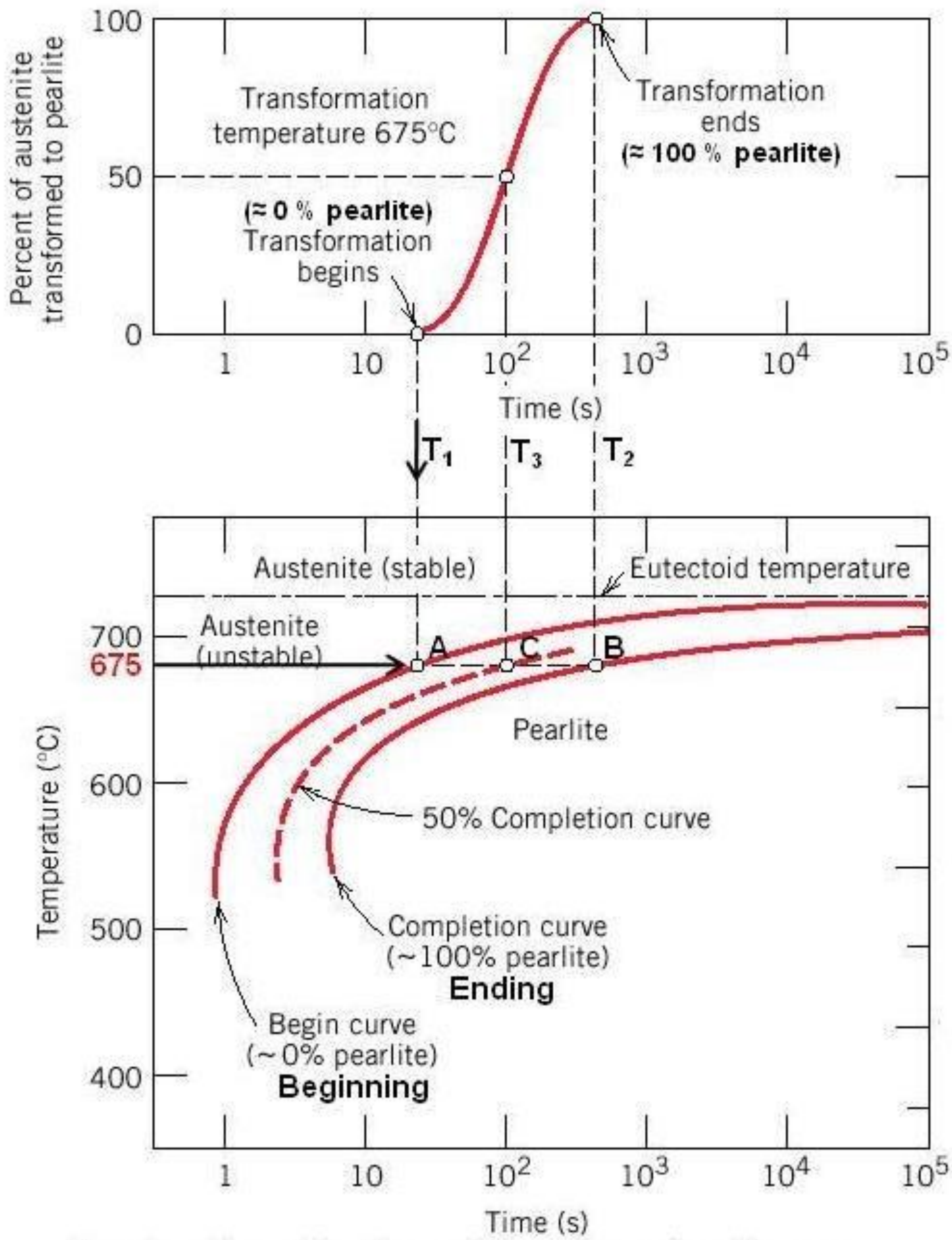

pearlite
Cementite:
white phase


Graphite

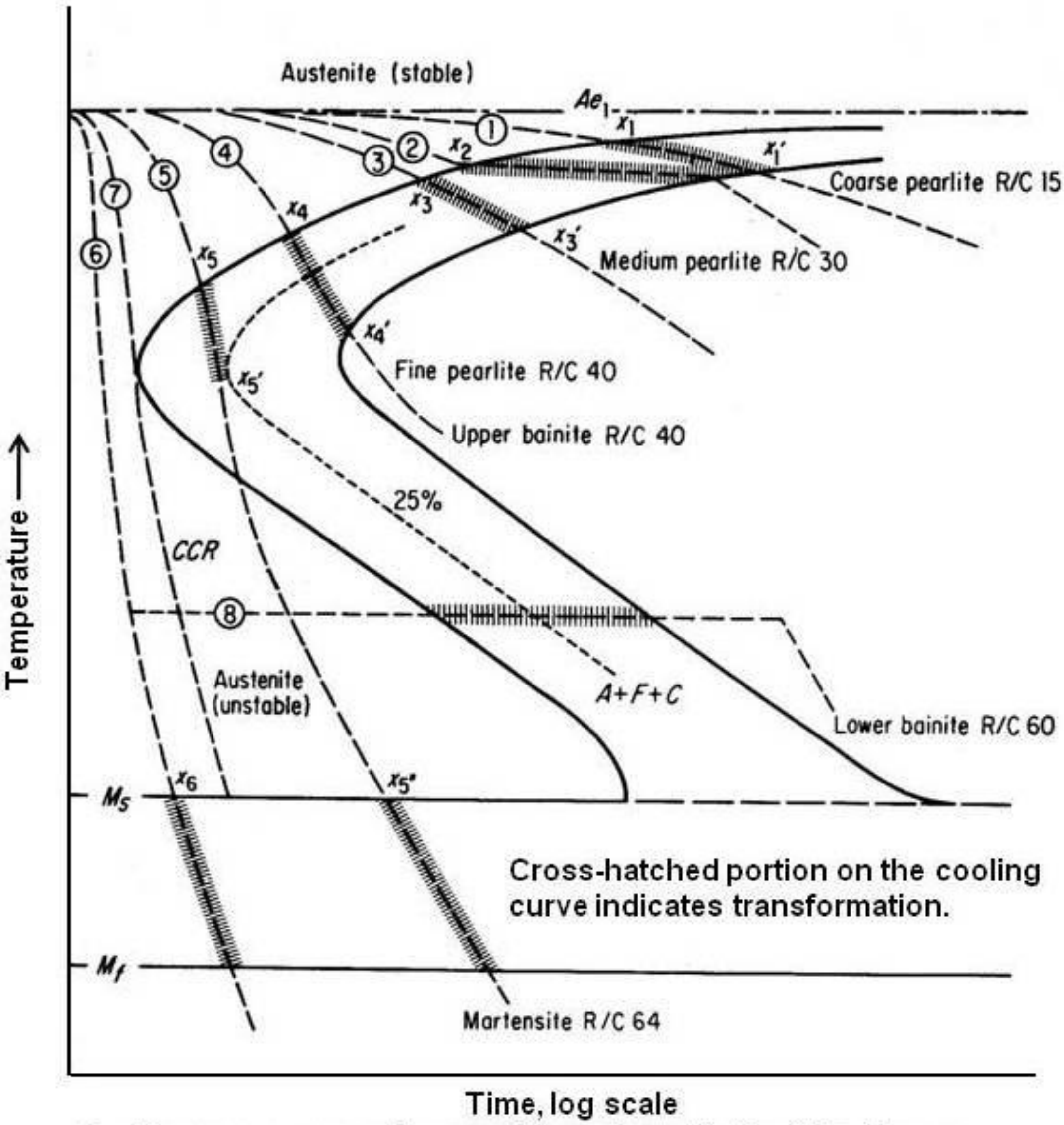
Lecture 6 TTT Diagram

https://www.metallurgyfordummies.com/fe-fe3c-t-t-t-diagram.html

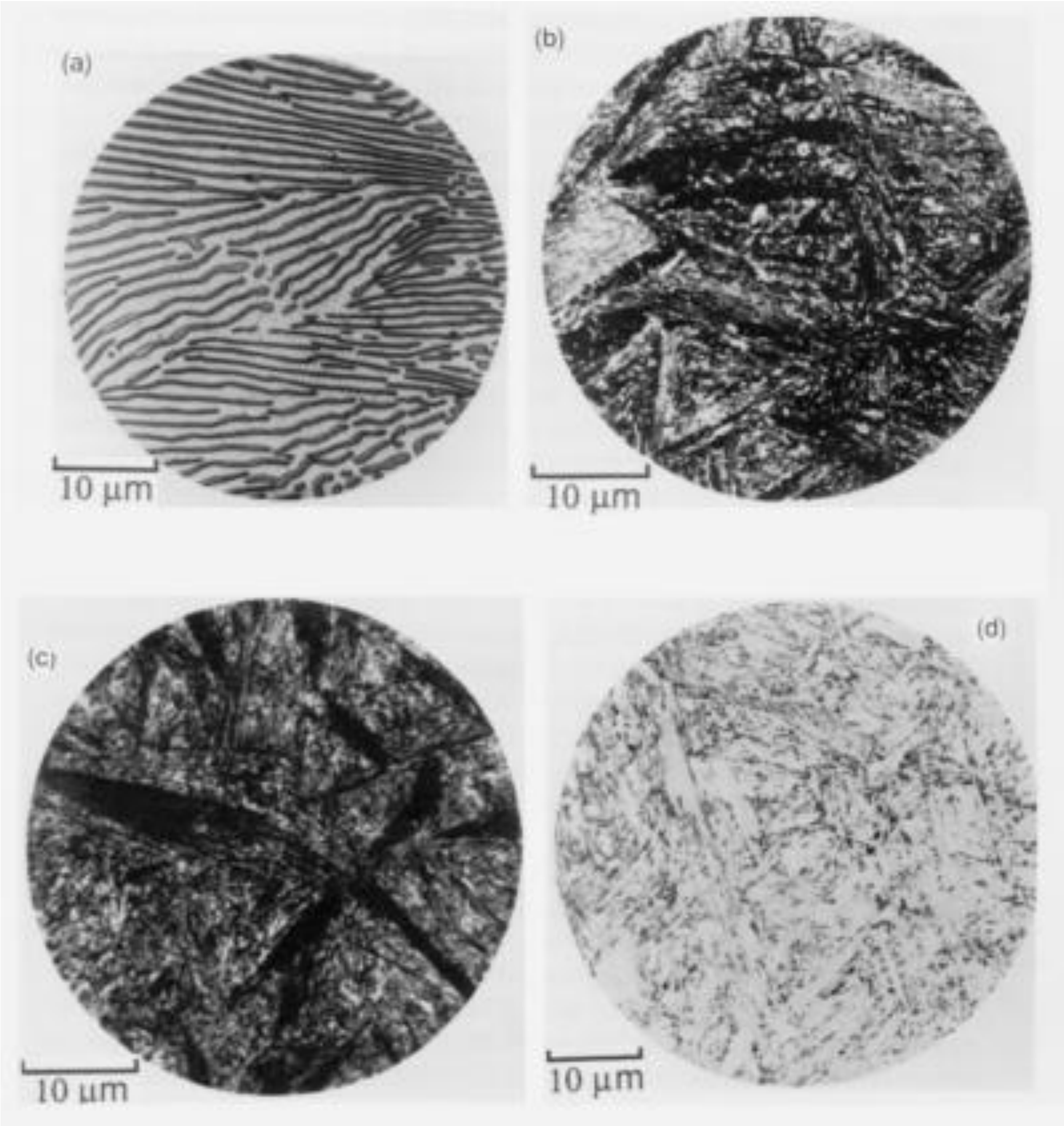




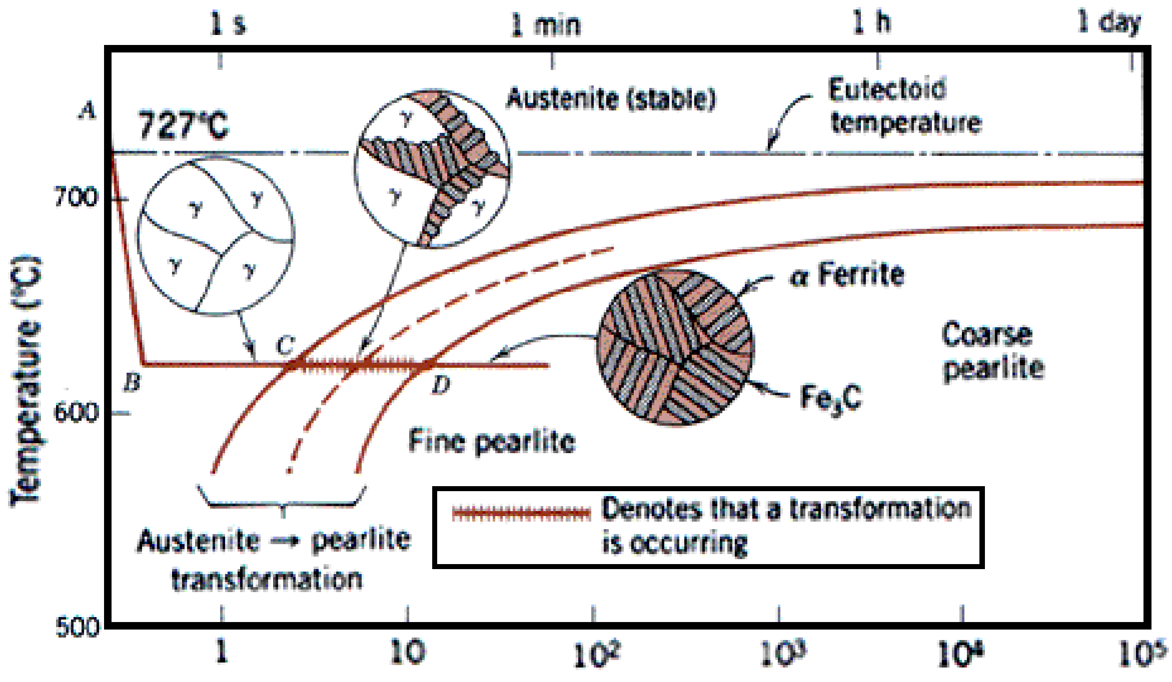
Construction of Isothermal Transformation Diagram



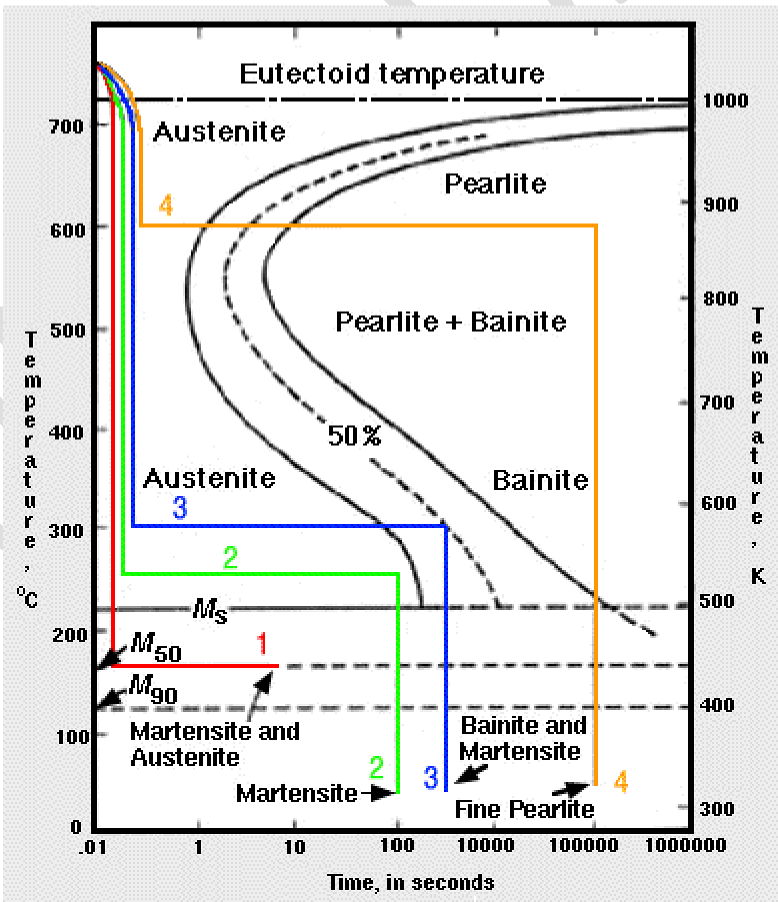
Cooling curves superimposed on a hypothetical I-T diagram



Microstructures in a eutectoid steel. (a) Pearlite formed at 720 oC, (b) bainite formed at 290 ^{o}C, (c) bainite formed at 180 ^{o}C, and (d) martensite



1 s
1 min
1 h
1 day
A
727°C
Austenite (stable)
Eutectoid temperature
700
α Ferrite
Coarse pearlite
C
B
D
600
Fe$_3$C
Fine pearlite
Temperature (°C)
Denotes that a transformation is occurring
Austenite → pearlite transformation
500
1
10
10^2
10^3
10^4
10^5

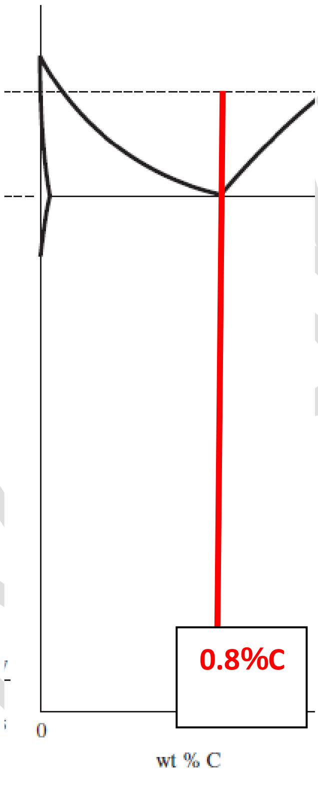


Eutectoid temperature
1000
700
Austenite
4
Pearlite
600
900
800
500
Pearlite + Bainite
Temperature, °C
700
Temperature, K
400
50 %
Austenite
Bainite
3
600
300
2
M_S
500
200
M_{50}
1
M_{90}
400
100
Martensite and Austenite
Bainite and Martensite
2
3
4
Martensite
Fine Pearlite
300
0
.01
1
10
100
10000
100000
1000000
Time, in seconds

Lecture 07: TTT and CCT Diagrams

I- TTT diagram Eutectoid, Hypoeutectoid and Hypereutectoid steel

1- TTT Diagram for Eutectoid Steel :



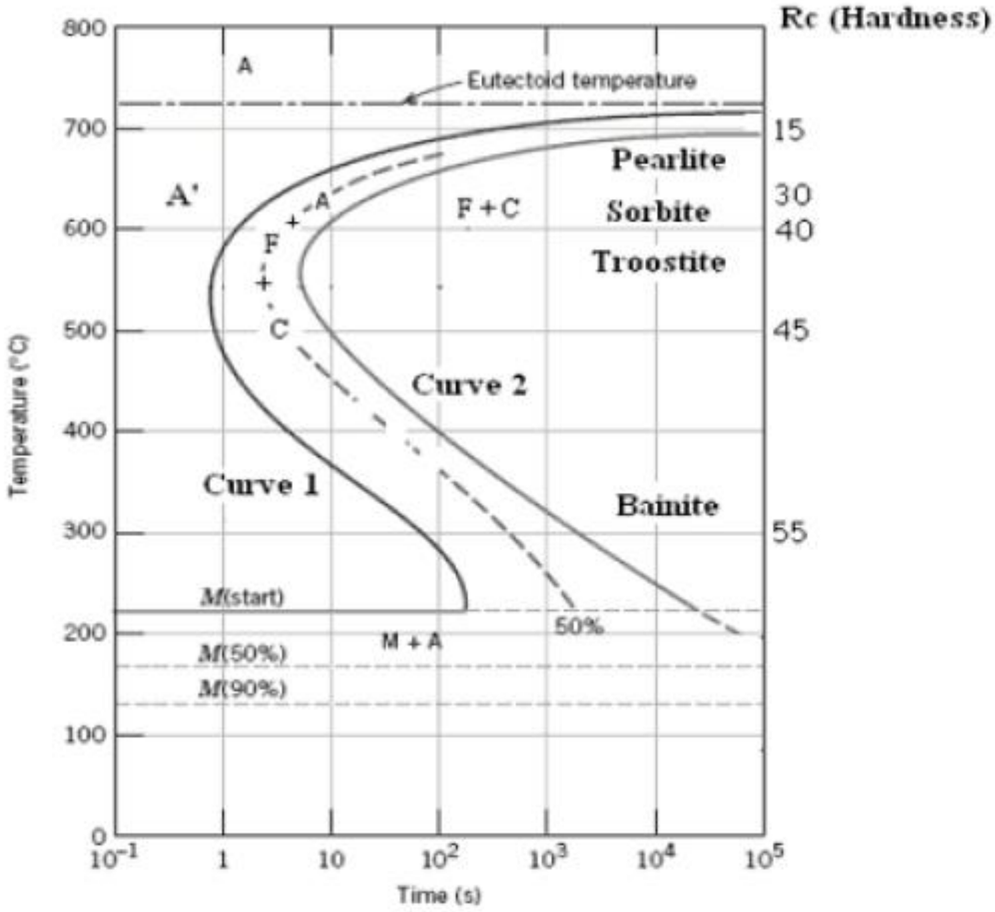
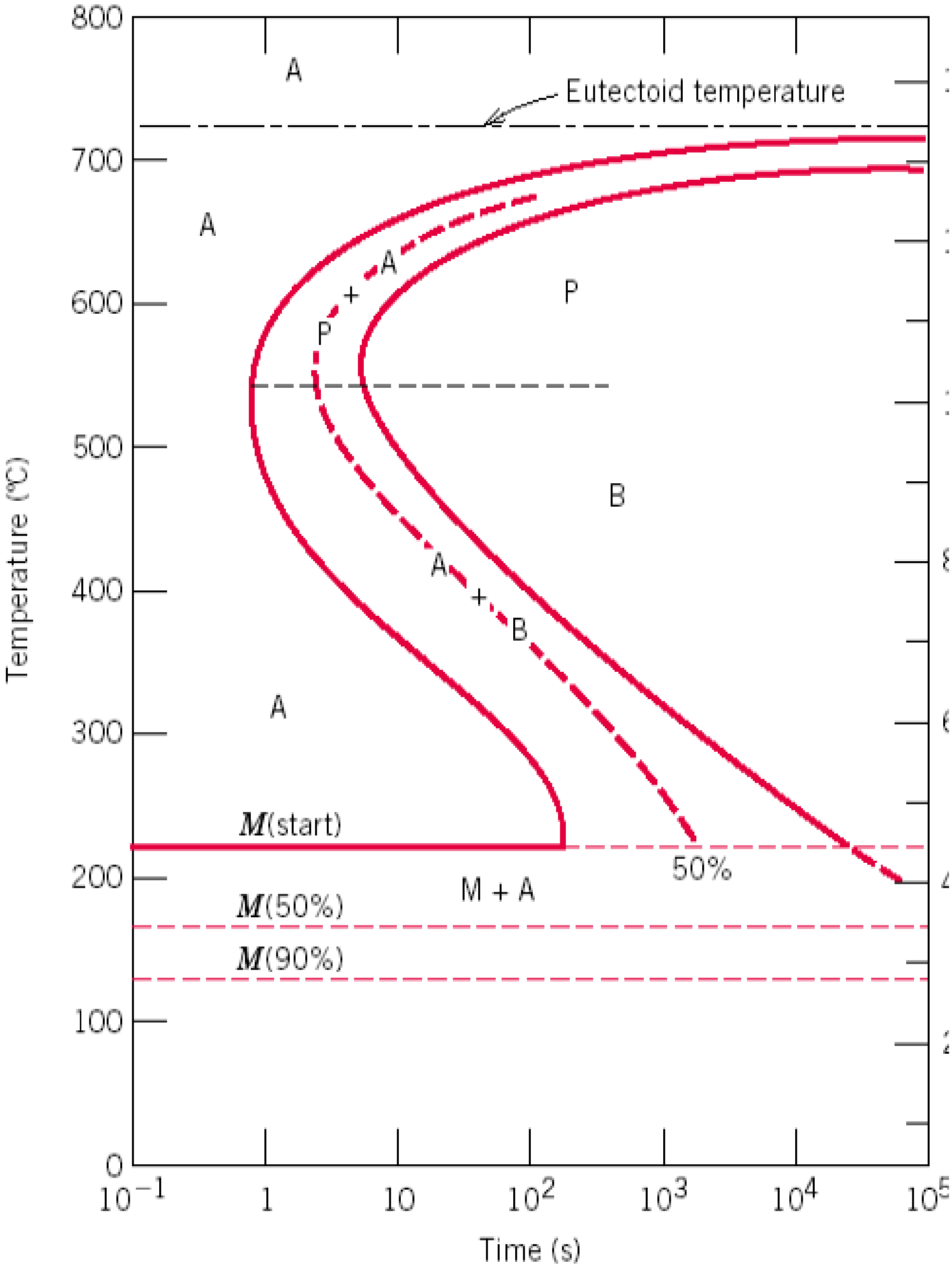
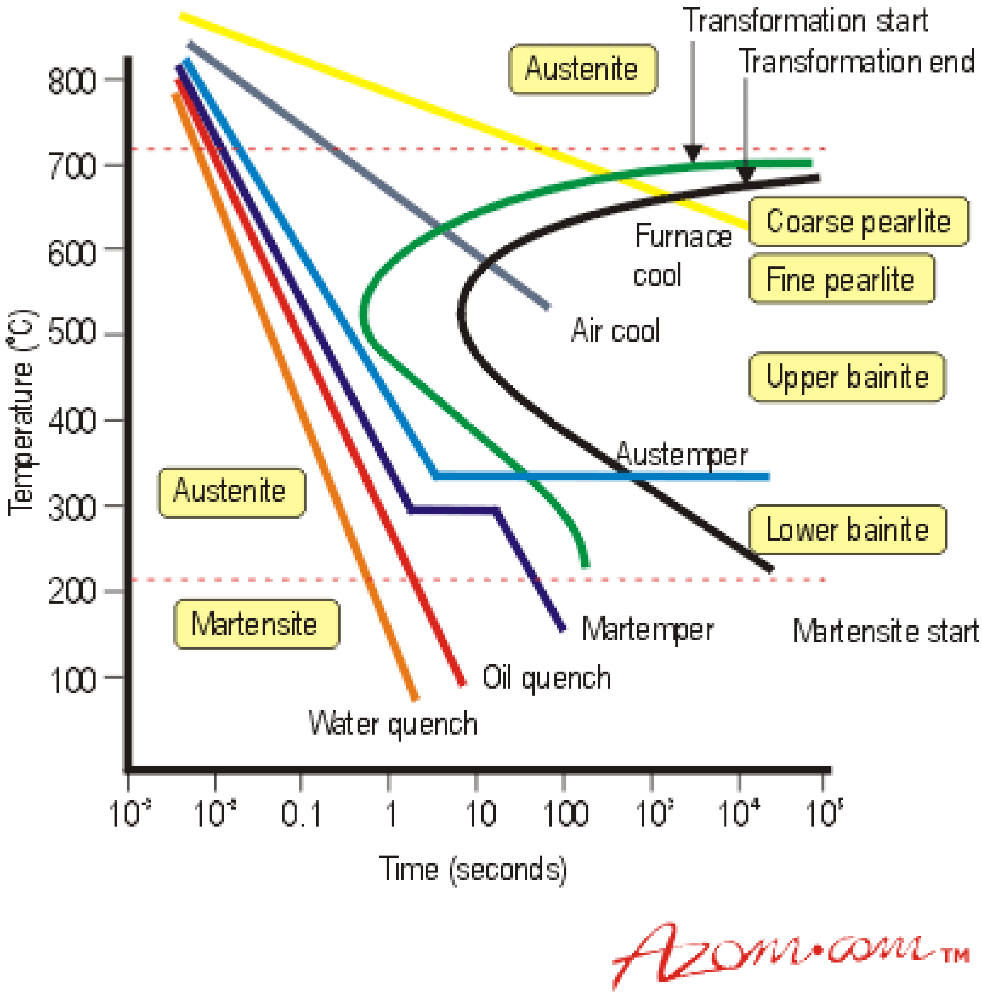


Fig 2.3: TTT diagram of eutectoid steel



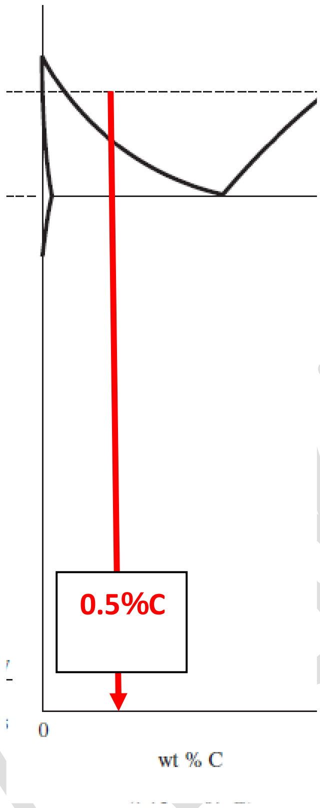
800
700
600
500
400
300
200
100
0
Temperature (°C)
A
Eutectoid temperature
A
A
+
P
P
B
A
+
B
A
M(start)
50%
M + A
M(50%)
M(90%)
10^{-1}
1
10
10^2
10^3
10^4
10^5
Time (s)

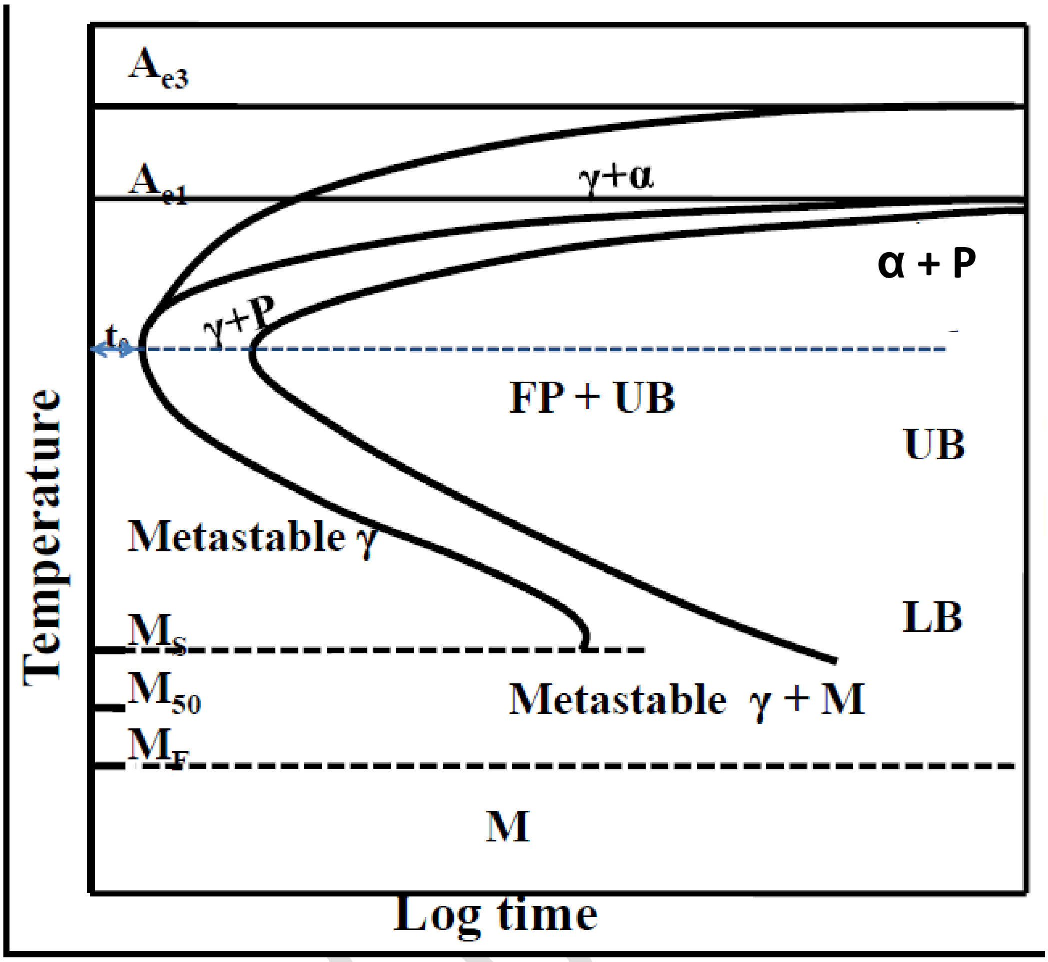


The TTT diagram for AISI 1080 steel (0.79%C, 0.76%Mn) austenitised at 900°C.

Ref: https://www.azom.com/article.aspx?ArticleID=313

2-TTT diagram of Hypoeutectoid steel





A_{e3}
A_{e1}
γ+α
α + P
γ+P
t_0
FP + UB
UB
Metastable γ
LB
M_s
M_{50}
M_F
Metastable γ + M
M
Temperature
Log time

3-TTT diagram of Hypereutectoid steel

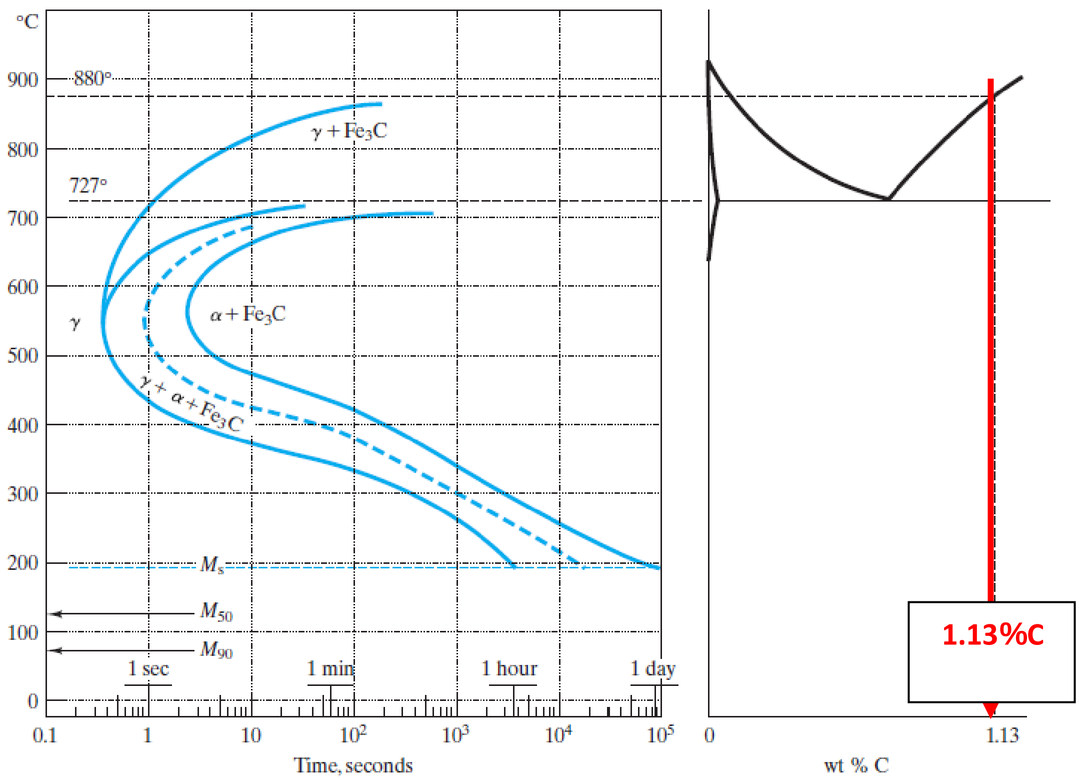
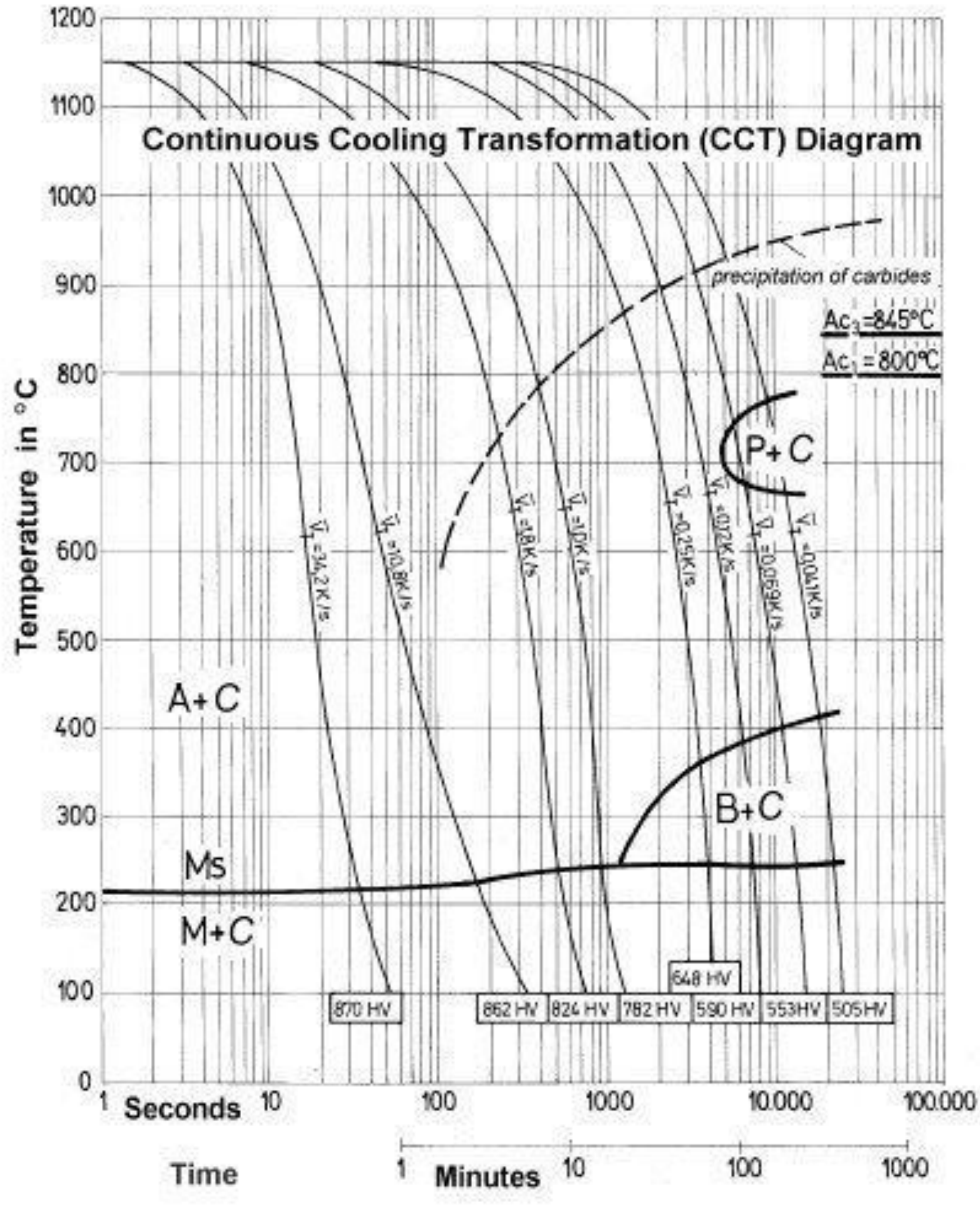


FIGURE 10.15 *TTT diagram for a hypereutectoid composition (1.13 wt % C) compared with the* Fe–Fe_3C *phase diagram. Microstructural development for the slow cooling of this alloy was shown in Figure 9.39. (TTT diagram after* Atlas of Isothermal Transformation and Cooling Transformation Diagrams, *American Society for Metals, Metals Park, OH, 1977.)*

II- Continuous cooling transformation (CCT) diagram

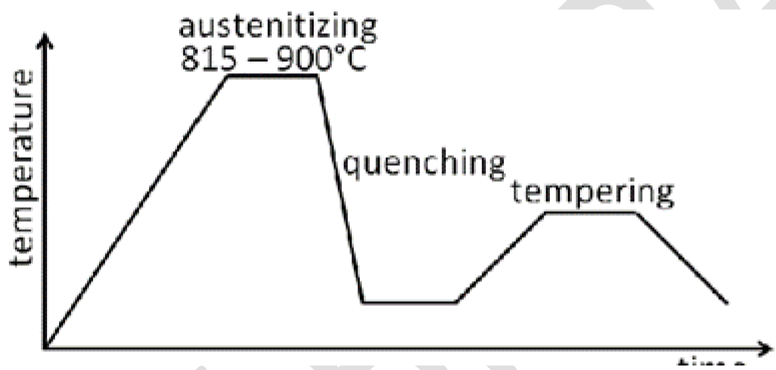
Continuous cooling transformation (CCT) diagrams Measure the extent of transformation as a function of time for a continuously decreasing temperature. In other words a sample is austenitised and then cooled at a predetermined rate and the degree of transformation is measured, for example by dilatometry. Obviously a large number of experiments is required to build up a complete CCT diagram.



https://steelselector.sij.si/help/testing/ttt.html

Lecture 8 Tempering of steel

Tempering is usually performed after quenching. After quenching the steel is hard, brittle and internally stressed. It is applied to improve its mechanical characteristics, as well as to reduce the internal stresses . Tempering is accomplished by controlled heating of the quenched workpiece to a temperature below its "lower critical temperature".



The main types of tempering

Low-temperature tempering

, Low-temperature tempering is used to form tempered martensite at 150-200℃

When tempering is performed, the internal strain in the steel is relieved or eliminated, and the precipitation effect of carbides is promoted, resulting in improved quality.

High-temperature tempering

High temperature tempering is when we use temperatures higher than 500 °C.

- **There is also tempering at medium temperatures. (Between the Low-temperature tempering and High-temperature tempering)**

Effect of temperature of tempering in mechanical proprieties of steel :

Tempering curves, which are plots of hardness against tempering temperature. exist for all commercial steels and are used to select the correct tempering temperature.

As the tempering temperature increases, the hardness decreases.

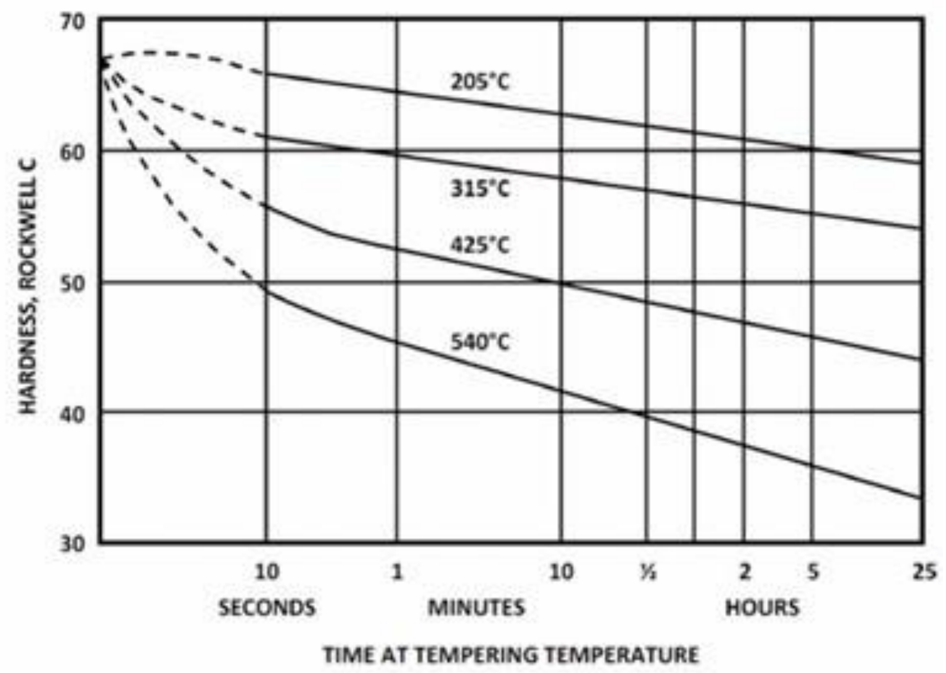
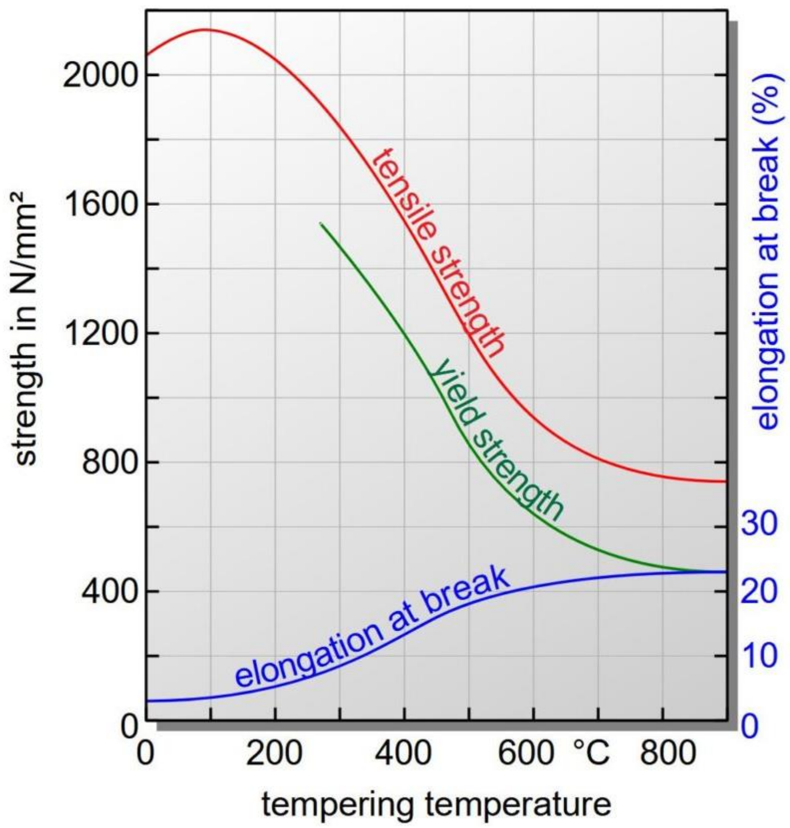


Figure 11 – Effect of time at tempering temperature on the hardness of 0.8% carbon steel [1, 2].

The other mechanical properties are also affected :



Ref : https://www.tec-science.com/material-science/heat-treatment-steel/quenching-and-tempering/

The hardness variation during tempering treatment , the percentage of carbon can also affect the hardness variation :

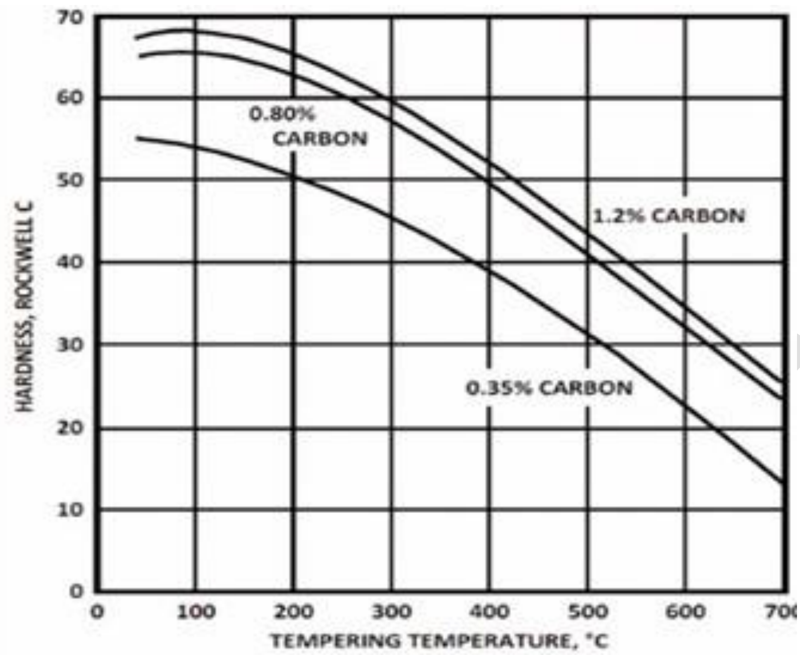


Figure 10 – Effect of tempering temperature on the hardness of carbon steels of different carbon content. Specimens were tempered for 1 hour [1, 2]

Ref : https://www.chengxinspringsteel.co.za/steel-heat-treatment.html

This course is prepared from different sources