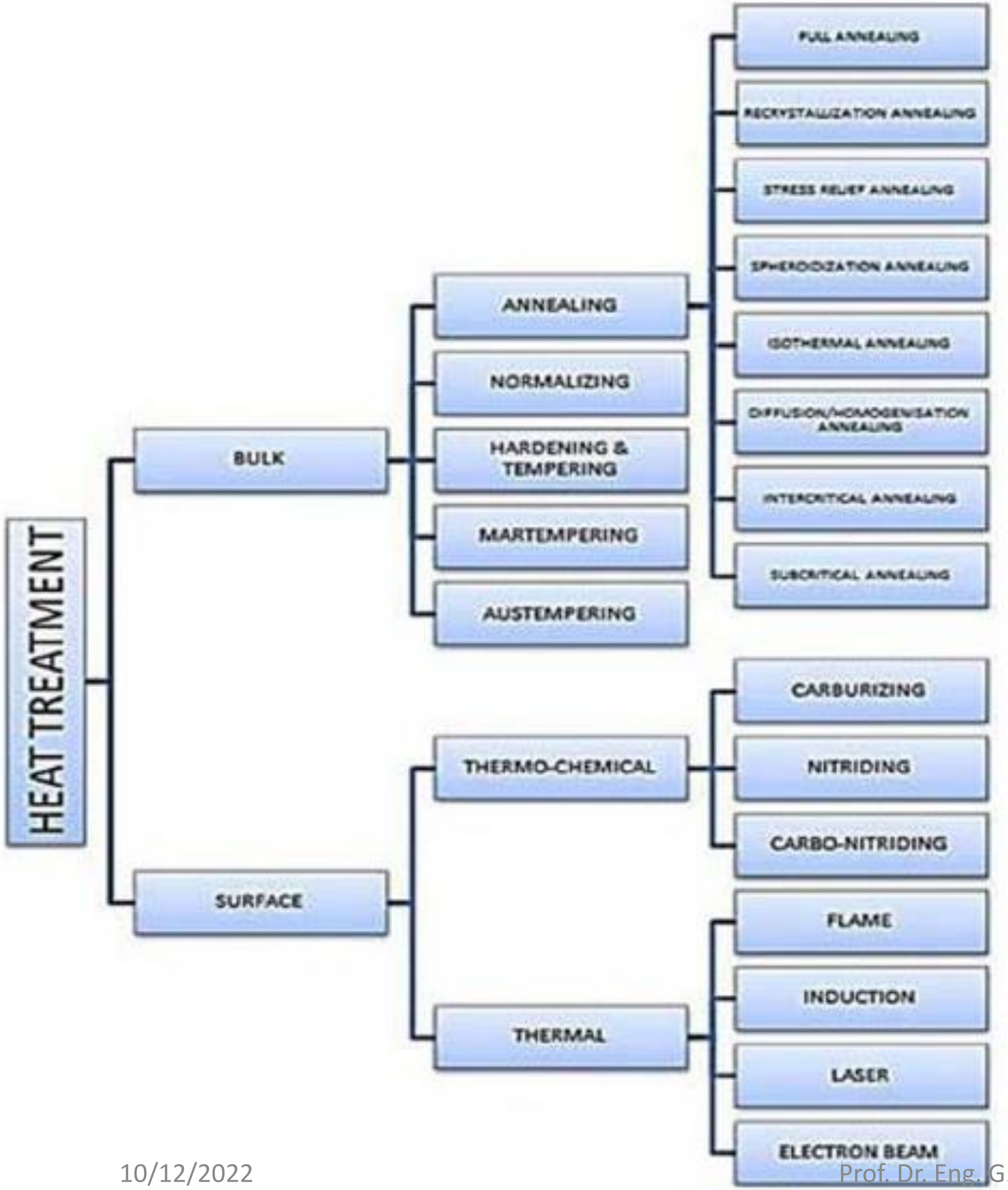
Heat Treatment Technology MME352

Heat Treatment Technology

Pre requisites: diffusion and phase transformations.

1. General principals of heat treatments
2. Heat treatment furnaces
3. **Heat treatment of steel**
4. **Heat treatment of cast iron**
5. **Heat treatment of non ferrous alloys**
6. **Thermo mechanical treatment of ferrous and non ferrous alloys**
7. **Thermo chemical treatment**
8. **Surface hardening**



Annealing: Cool in the furnace (normally 50°C/hr.) i.e., the furnace is switched off.

- **Full annealing** (Above A3)
- **Recrystallization annealing** (Tr = (0.3 – 0.5) Tm.p in K) about 650°C to 680°C,
- **Stress relief annealing**
  1. Slow heating in a furnace at a rate of 100-150°C/h up to 650°C.
  2. Soaking at this temperature for a definite time based on maximum thickness at the rate of 3-4 minutes/mm to attain uniformity of temperature.
  3. Slow cooling of 50-100°C/h to at least 300°C and then cooled in air to room temperature.
- **Spheroidizing annealing** (close to A1 temperature, requiring more than 200 hours.), Pendulum HT.
- **Isothermal annealing**
- **Diffusion / Homogenization annealing** (at 1150°C to 1200°C for 10-20 hours followed by slow cooling)
- **Sub-critical annealing** (below Ac1)
- **Inter-critical annealing** (between Ac1 and Ac3)
- **Patenting**

Heat Treatment Technology

Bulk Heat Treatment

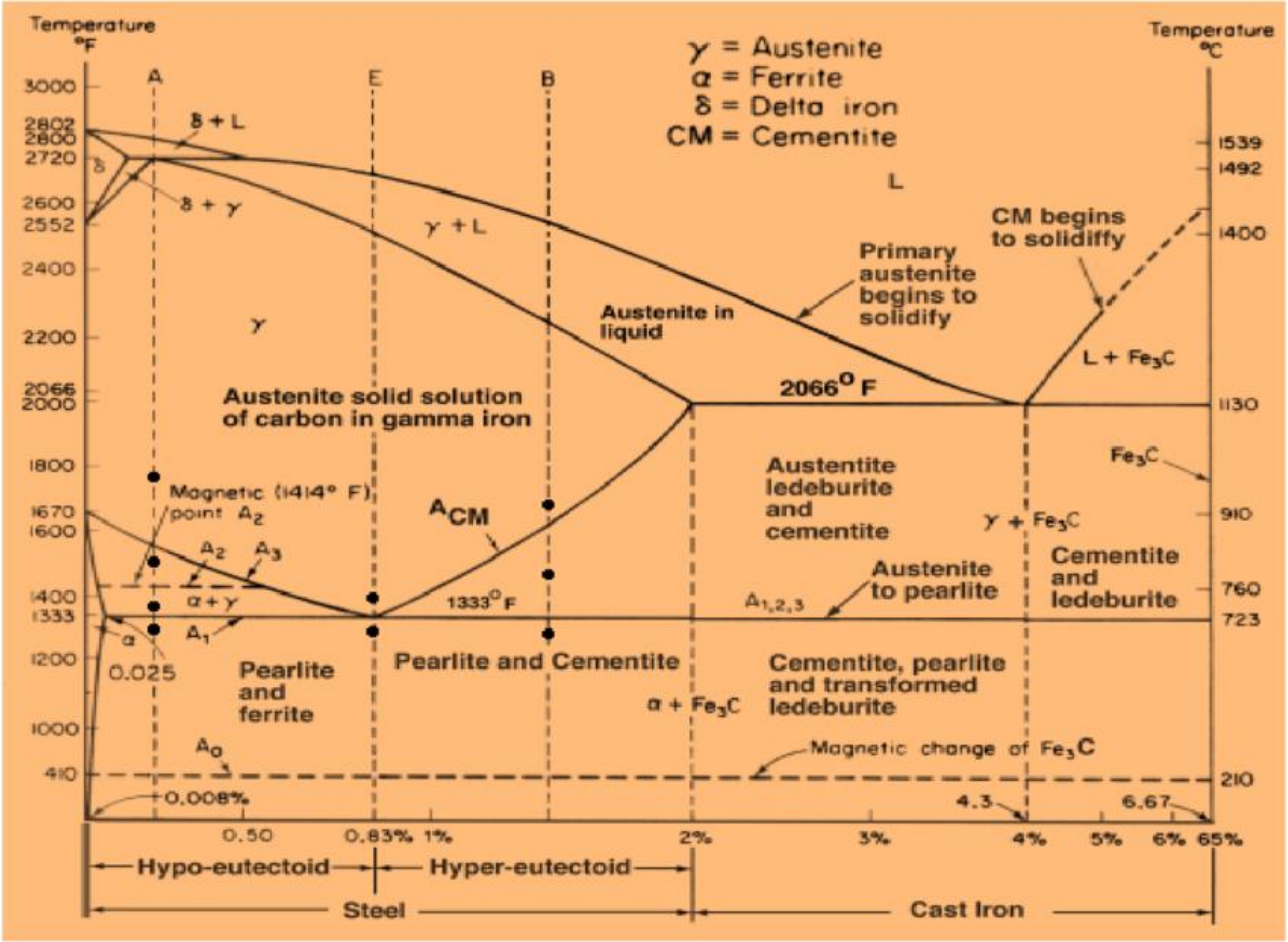
- **Annealing (Ful -, Recrystallization -, Stress relief -, Spheroidizing-, Isothermal-, Diffusion / Homogenization-, Subcritical-, Intercritical-, Patenting- annealing.)**
- **Normalizing**
- **Hardening & Tempering (quench tempering)**
- **Martempering**
- **Austempering**

Surface Heat Treatment

- **Thermochemical (case hardening)**
  - **Carburizing**
  - **Nitriding**
  - **Carbo-nitriding**
- **Thermal (surface hardening)**
  - **Flame**
  - **Induction**
  - **Laser**
  - **Electron beam**

Stable & Metastable Phase Diagram

Constitutional Diagram



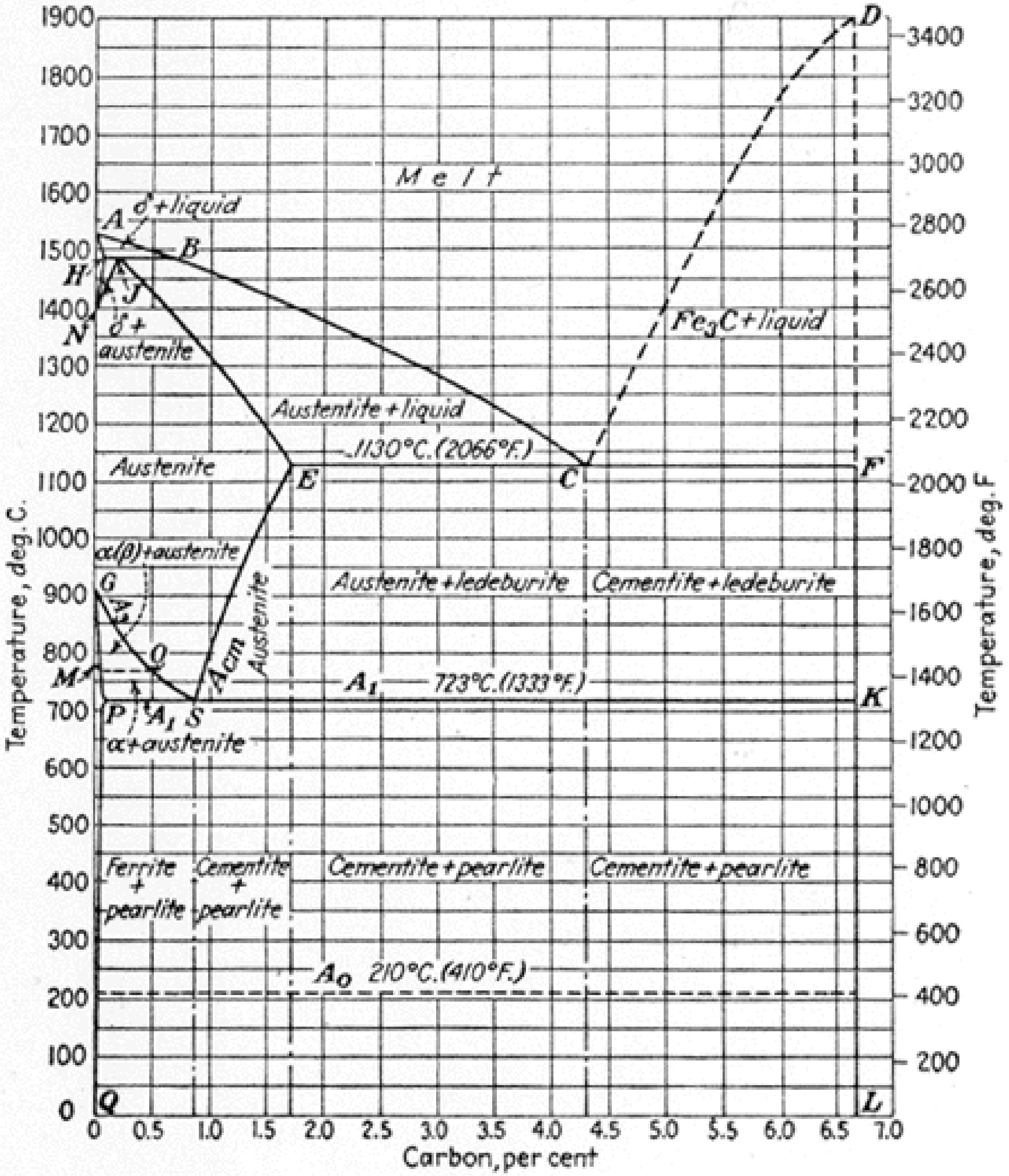
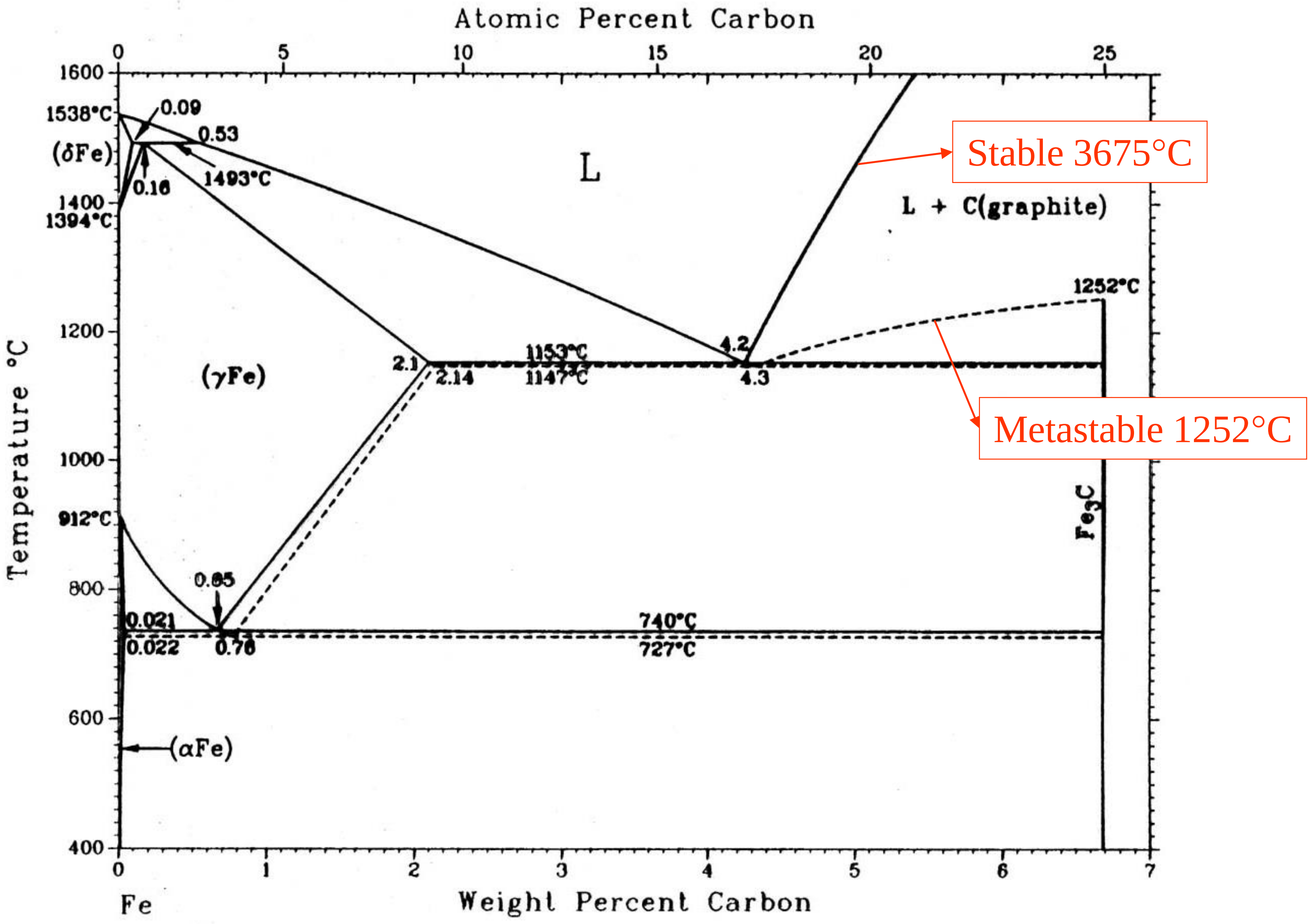


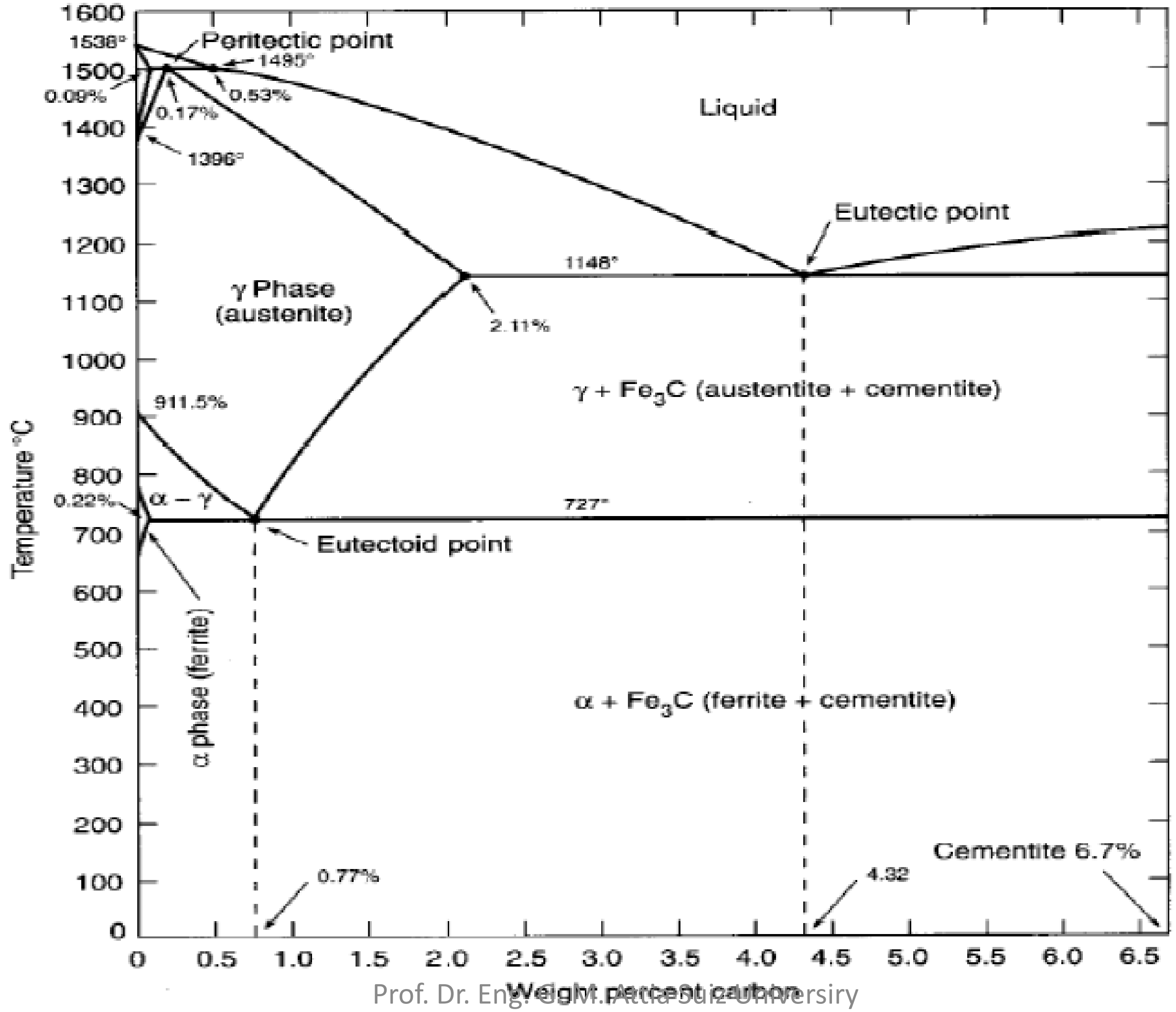
Fig. 13.—The proposed iron–iron carbide diagram.

Diagram letters A, B, C, ….

Fe-C Phase Diagram



Meta-Stable Iron-Iron Carbide Binary Phase Diagram



Meta-Stable Iron-Carbon System

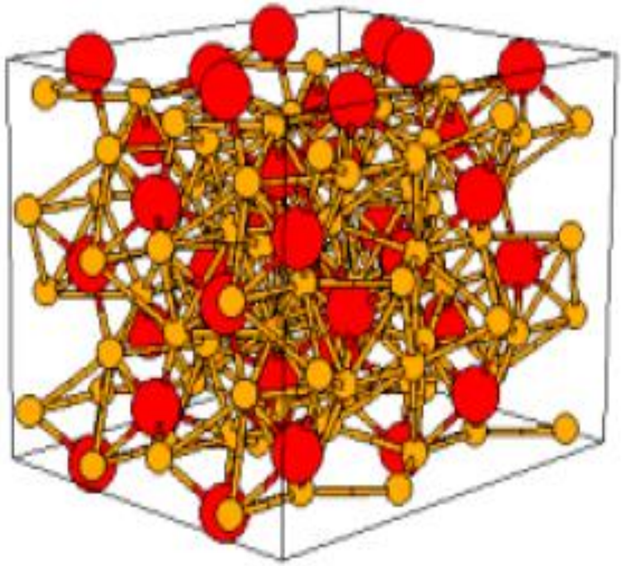
The formation of graphite in the equilibrium iron-carbon system is dependent upon the diffusion of carbon through the iron matrix to form the graphite precipitates.

If the cooling rate is fast, then the carbon is not able to segregate, and iron carbide (Fe_3C) forms in place of graphite.

This meta-stable system is commonly called the iron-iron carbide system.

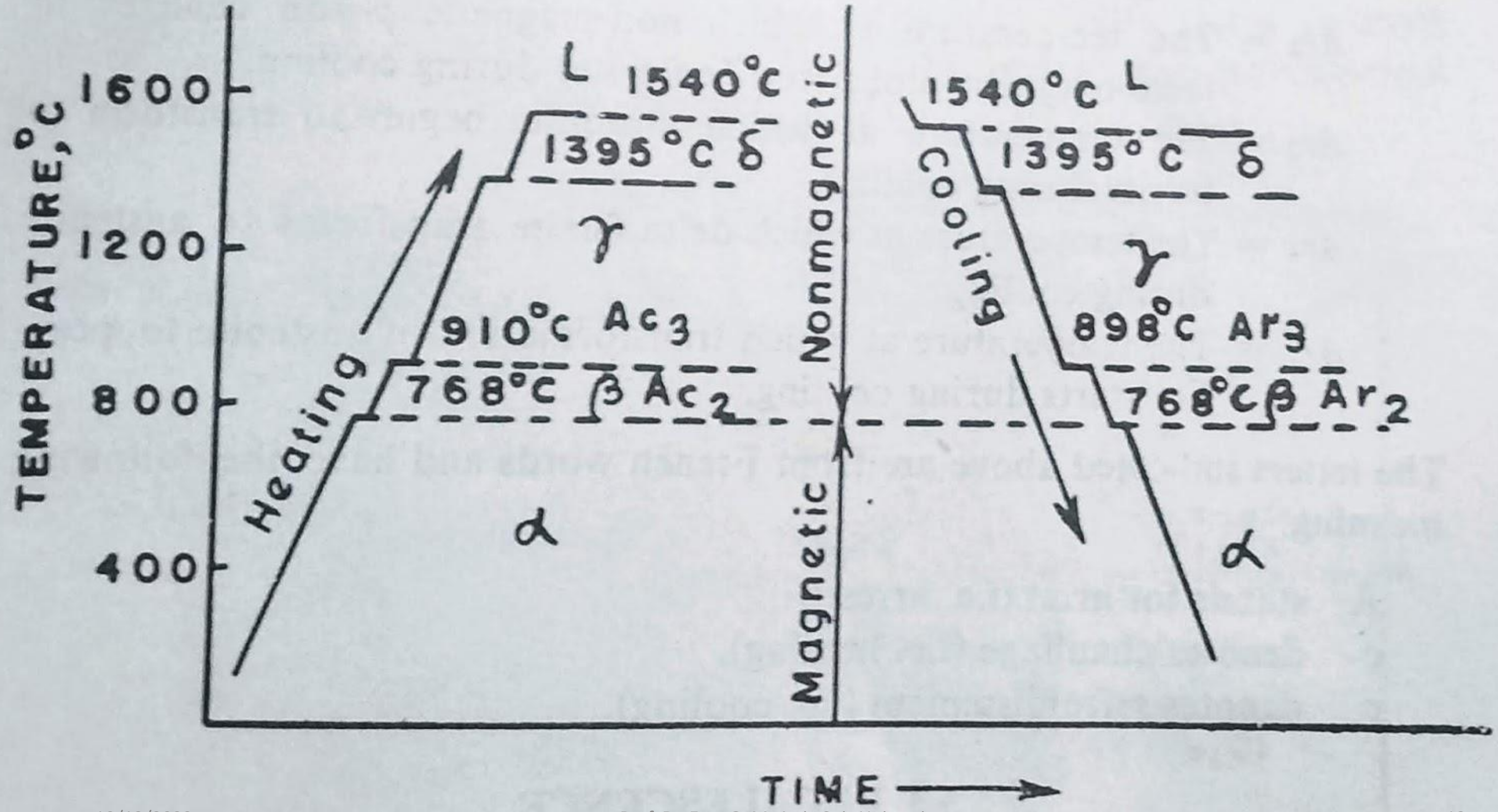
Iron Carbide Phase

- Fe_3C is the chemical composition, and it has orthorhombic crystal structure.
- **Iron carbide breaks down to iron and graphite with sufficient time and temperature.**
- For practical purposes it is considered stable below 450°C.
- Density: 7.66 grams/cm 3 at 20°C
- Very hard and brittle phase
- Commonly called “cementite”
- M.p. 1227°C



Transition temperatures

- **A 0: 210 °C Curie point of Fe_3C**
- **A 1: 723 °C By cooling $\gamma \rightarrow \alpha + Fe_3C$**
- **A 2**, point is the **Curie point** when iron changes from the ferro- to the paramagnetic condition. This temperature is **769°C** for pure iron, but no change in crystal structure is involved.
- **A 3: 910 - 723 °C By cooling $\gamma \rightarrow \alpha + \gamma$**
- **A 4** at which γ-iron transforms to δ-iron, **1390°C** in pure iron, hut this is raised as carbon is added.
- **A 5: 1538 °C**
- **A cm: $\gamma \rightarrow \gamma + Fe_3C_{II}$**
- **Curie temperature:** Temperature above which certain materials lose their permanent magnetic properties. The Curie temperature is named after **Pierre Curie**, who showed that magnetism was lost at a critical temperature.


TEMPERATURE, °C
1600
1200
800
400
L
1540°C
1395°C δ
γ
910°C Ac3
768°C β Ac2
α
Heating
Nonmagnetic
Magnetic
Cooling
1540°C L
1395°C δ
γ
898°C Ar3
768°C β Ar2
α
TIME

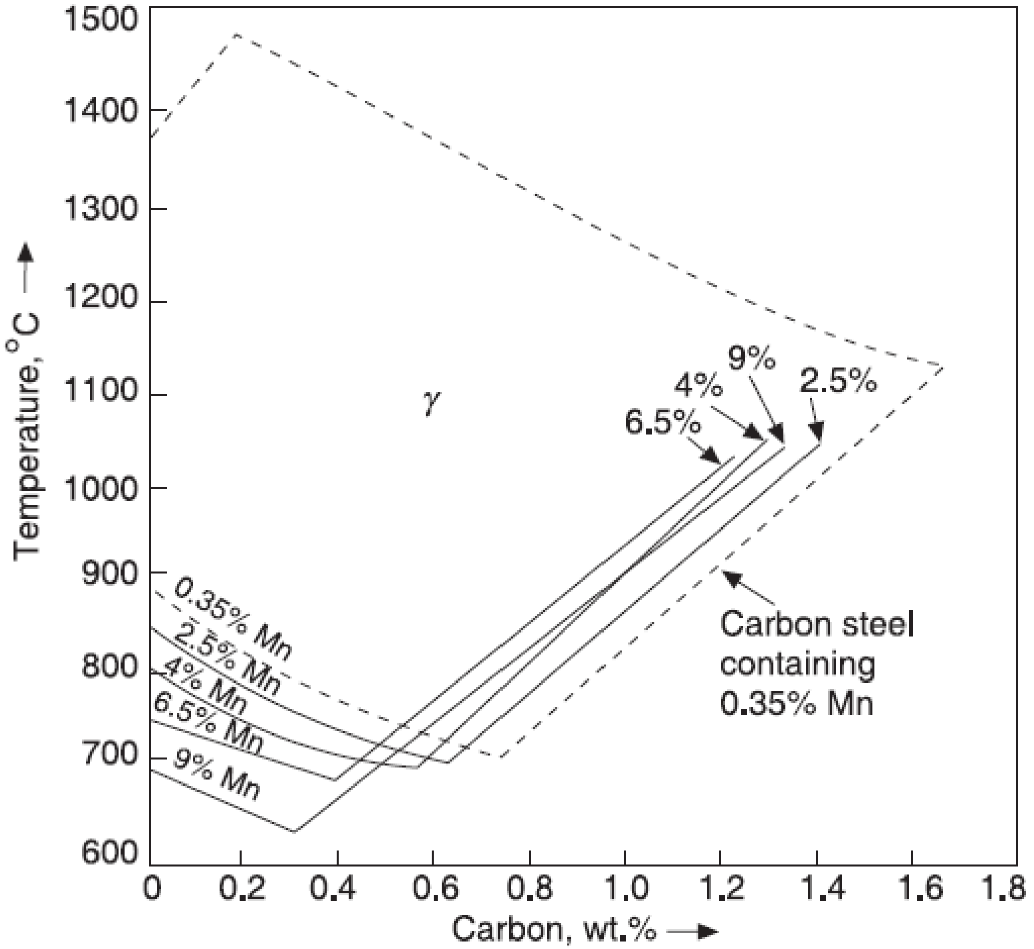


Figure 3.9 Effect of manganese on austenite phase region.

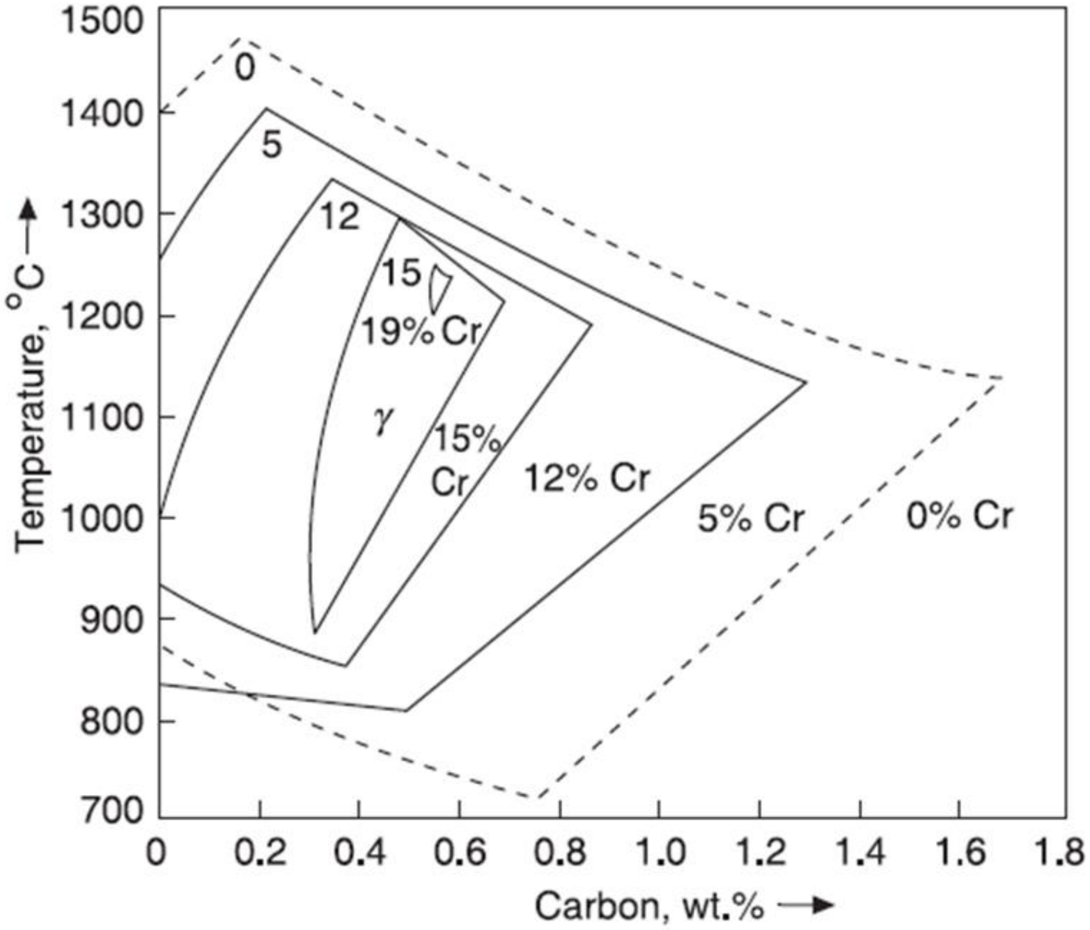


Figure 3.10 Effect of chromium on austenite phase region.

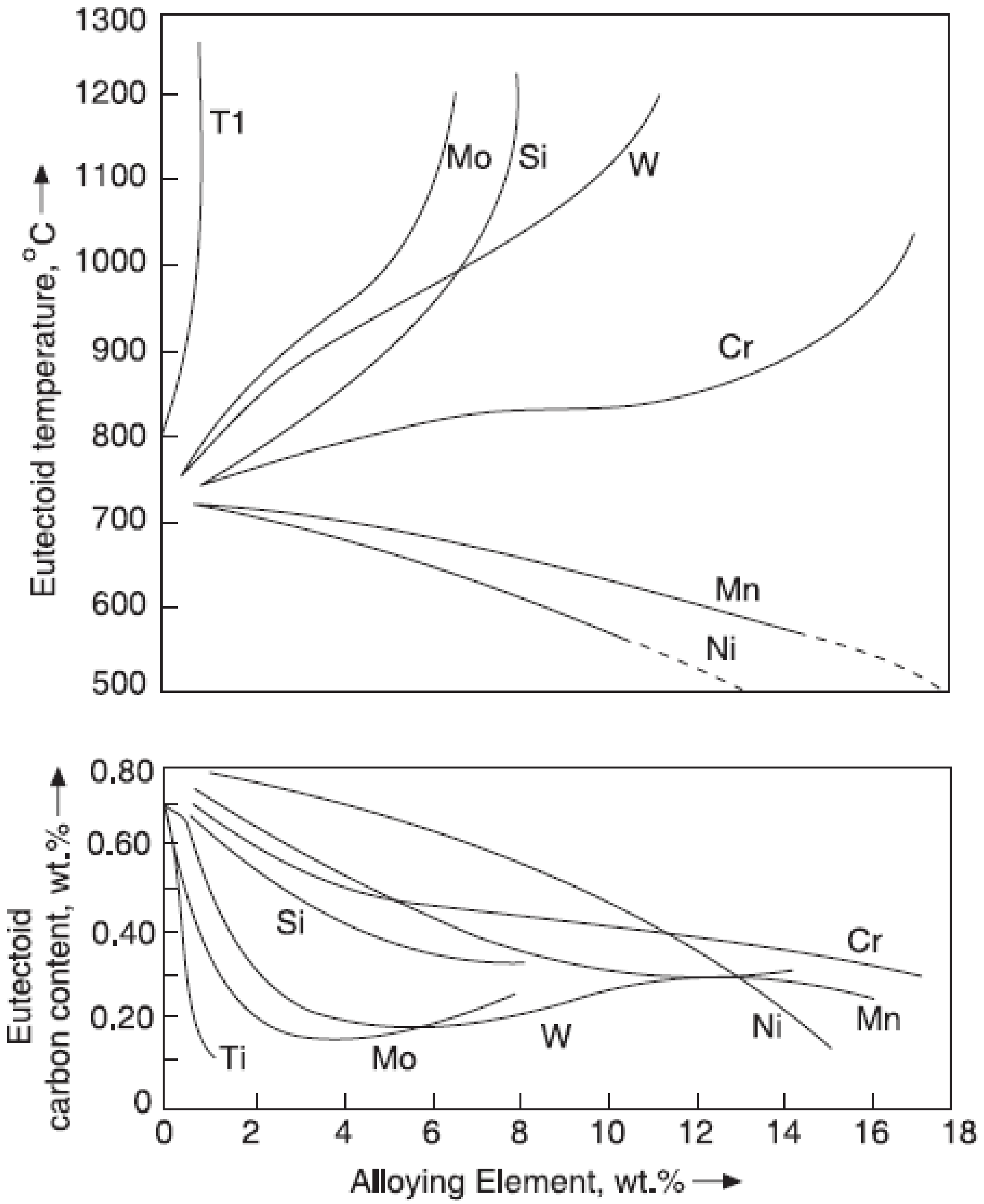


Figure 3.11 Effect of various alloying elements on the eutectoid temperature and composition.

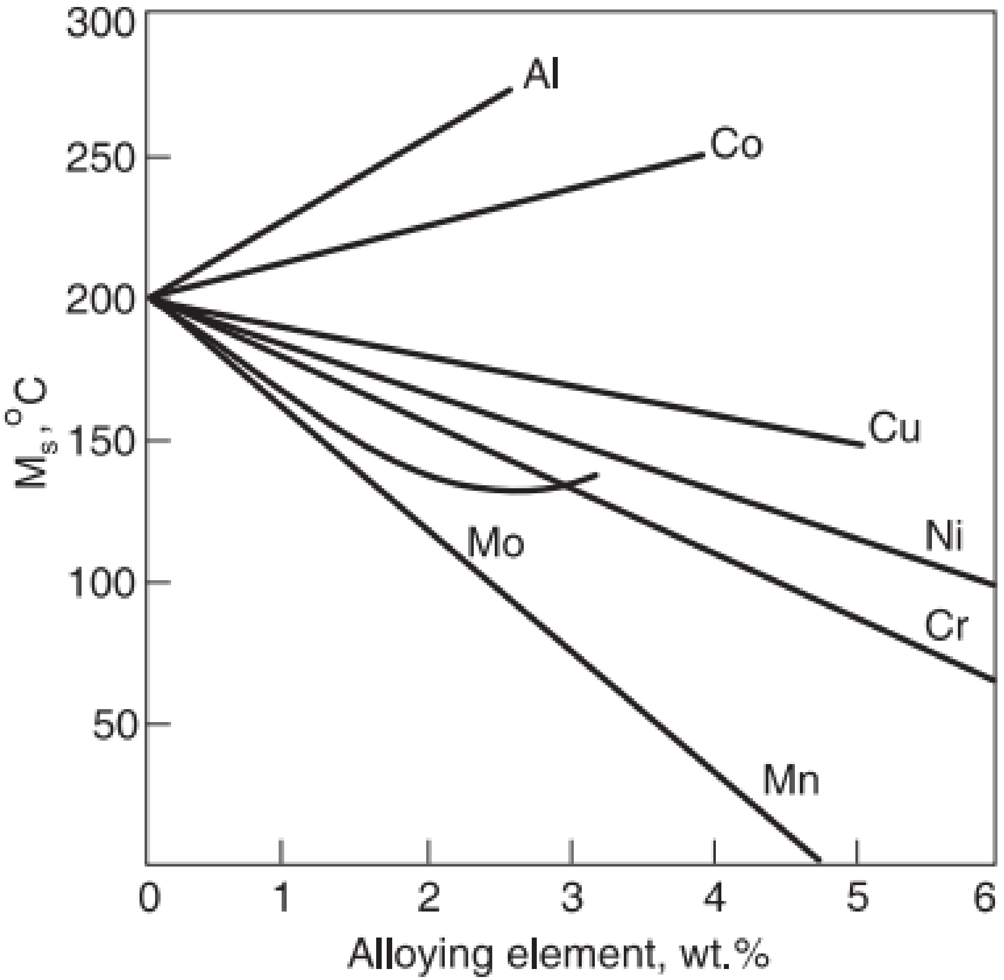


Figure 4.28 **Effect of alloying elements on M_s temperature of a steel containing 1% carbon.**

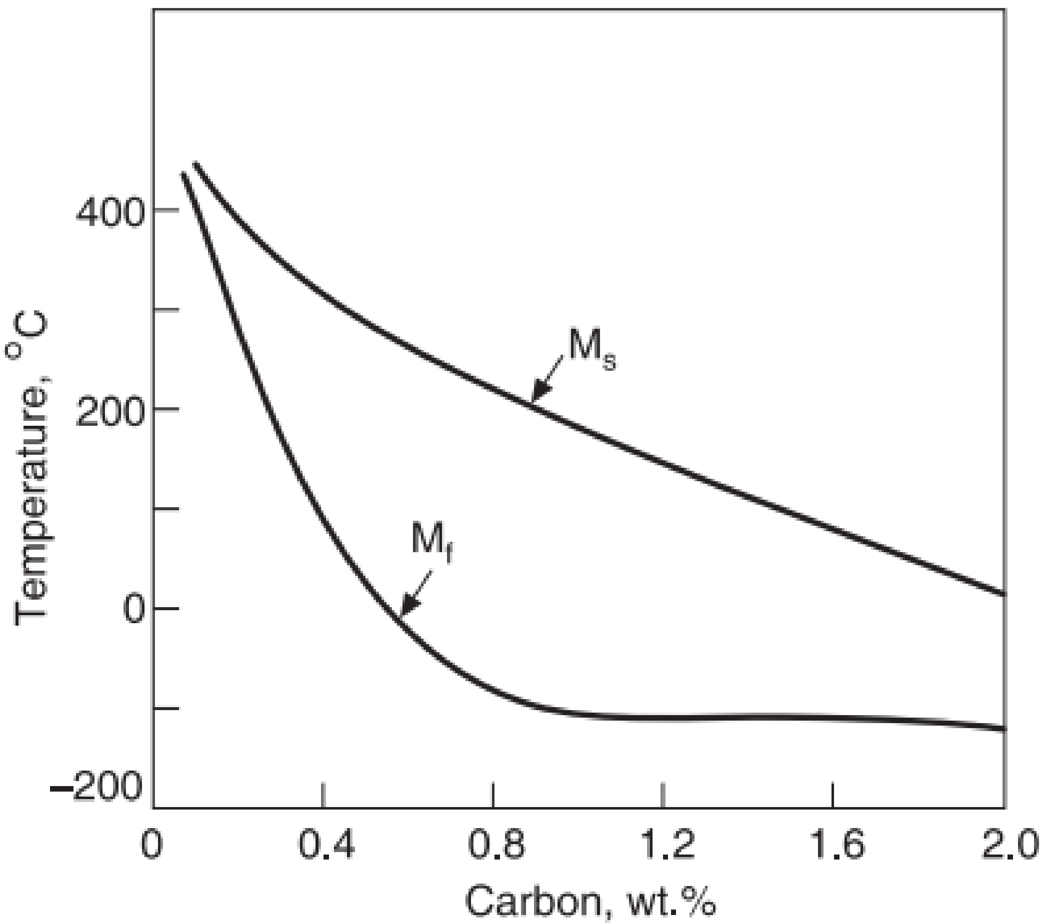
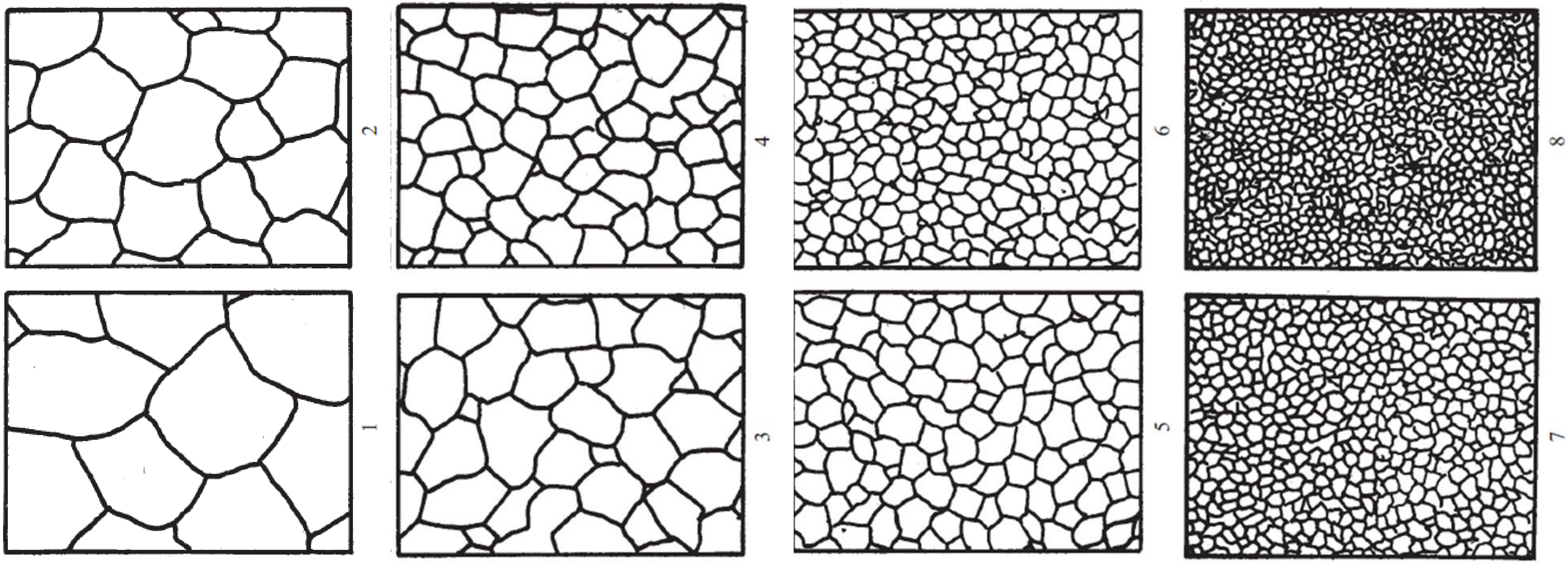


Figure 4.29 **Effect of carbon content on M_s and M_f temperatures of steel.**

Table 4.1 ASTM Grain Size

ASTM No. (Grain size index)	Mean number of grains/in^2 at 100 ×	Grains/mm^2
1	1	16
2	2	32
3	4	64
4	8	128
5	16	256
6	32	512
7	64	1,024
8	128	2,048
9	256	4,096
10	512	8,200


2
4
6
8
1
3
5
7

Transformation Diagrams (CCT & TTT)

- There are two main types of transformation diagram that are helpful in selecting the optimum steel and processing route to achieve a given set of properties.
- These are time-temperature transformation (TTT) and continuous cooling transformation (CCT) diagrams.
- CCT diagrams are generally more appropriate for engineering applications as components are cooled (air cooled, furnace cooled, quenched etc.) from a processing temperature as this is more economic than transferring to a separate furnace for an isothermal treatment.

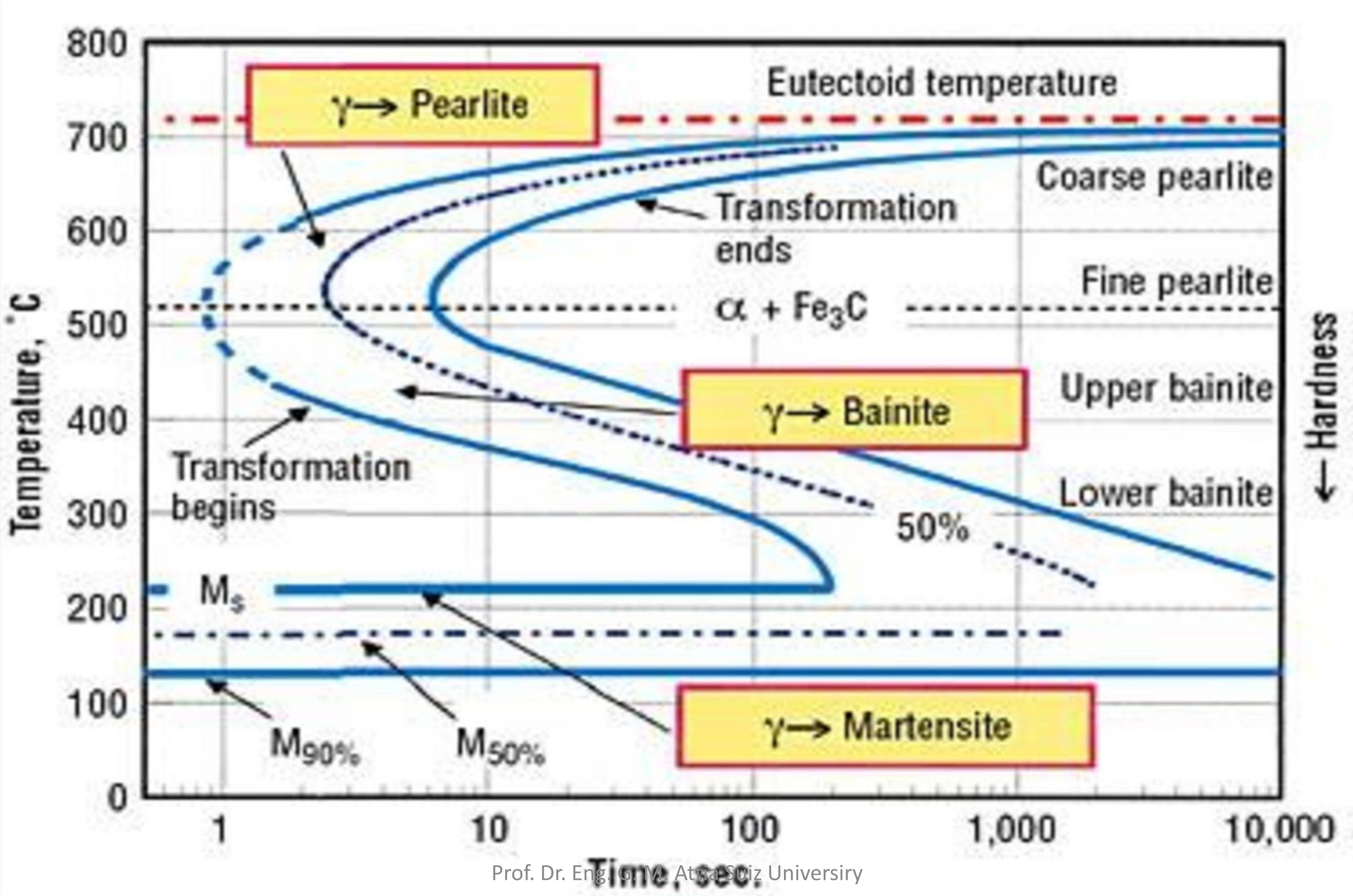
Time-temperature transformation (TTT) diagrams

- Measure the rate of transformation at a constant temperature. In other words a sample is austenitised and then cooled rapidly to a lower temperature and held at that temperature whilst the rate of transformation is measured, for example by dilatometry.
- Obviously a large number of experiments is required to build up a complete TTT diagram.

Continuous cooling transformation (CCT) diagrams

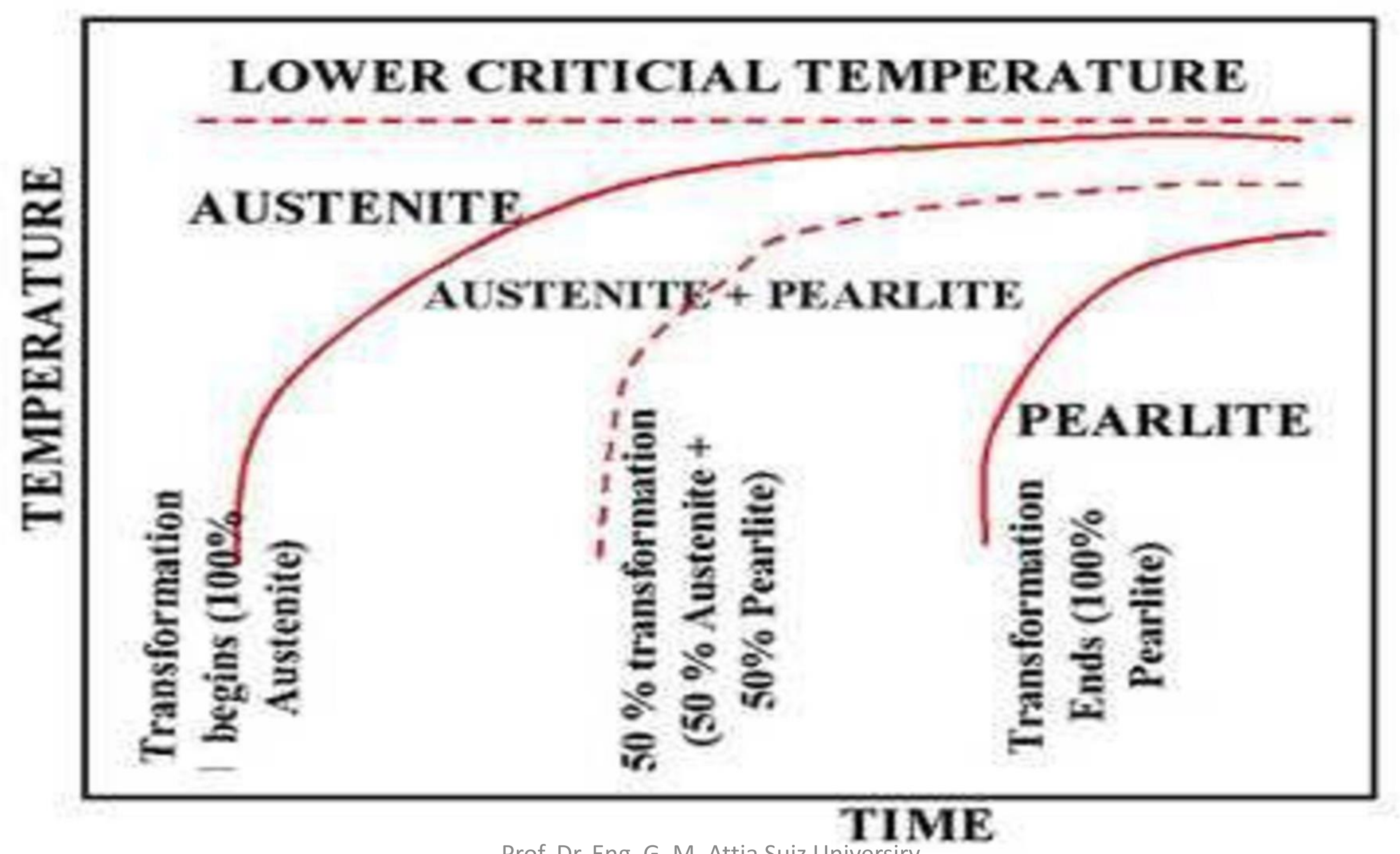
- Measure the extent of transformation as a function of time for a continuously decreasing temperature. In other words a sample is austenitised and then cooled at a predetermined rate and the degree of transformation is measured, for example by dilatometry. Obviously a large number of experiments is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

TTT DIAGRAM

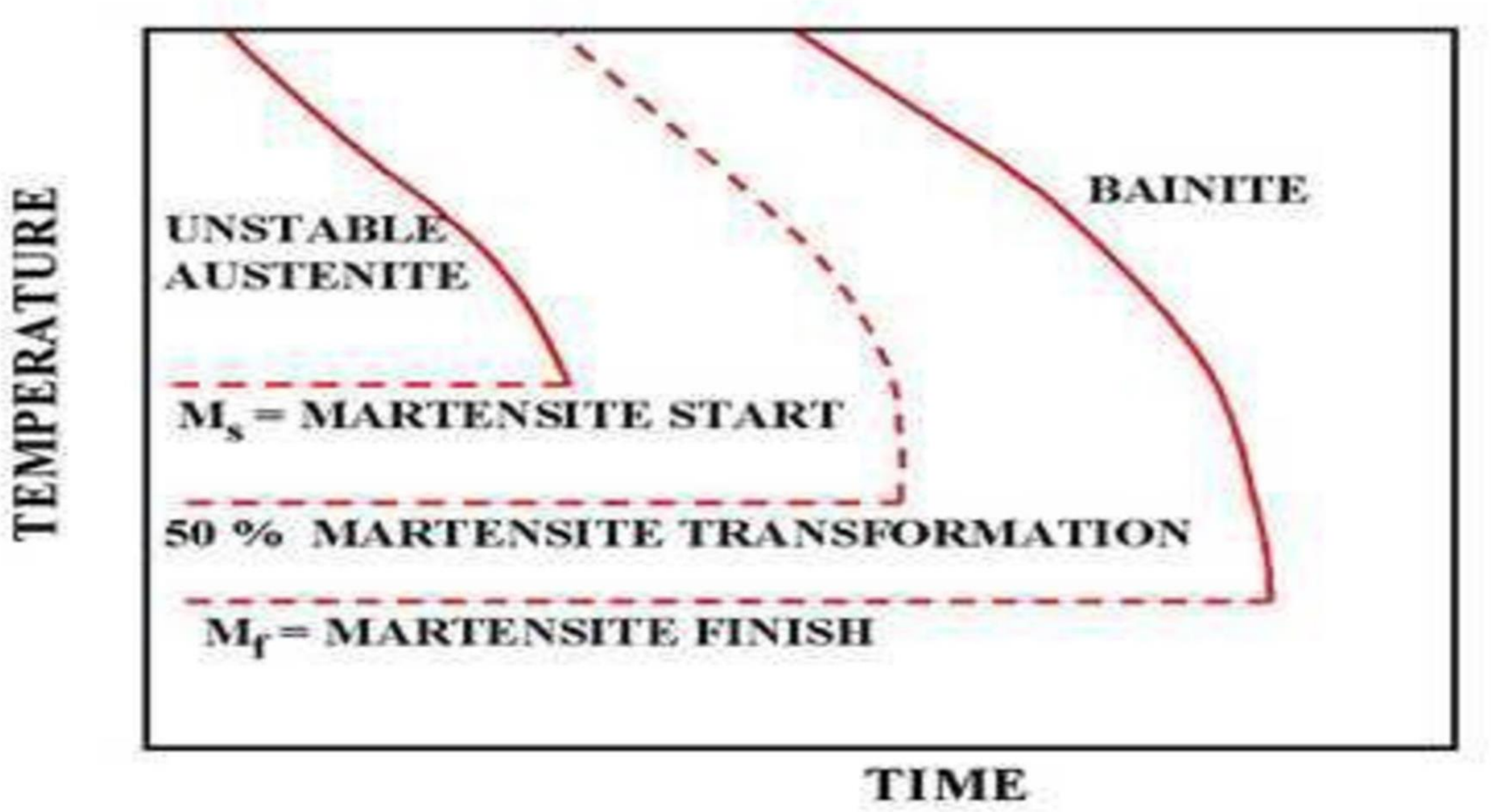


800
700
600
500
400
300
200
100
0
Temperature, °C
γ→ Pearlite
Eutectoid temperature
Coarse pearlite
Transformation
ends
Fine pearlite
α + Fe3C
Upper bainite
γ→ Bainite
Lower bainite
Transformation
begins
50%
Ms
M90%
M50%
γ→ Martensite
← Hardness
1
10
100
1,000
10,000
Time, sec.

Upper half of TTT Diagram (Austenite-Pearlite Transformation Area)



Lower half of TTT Diagram
(Austenite-Martensite and Bainite Transformation Areas)



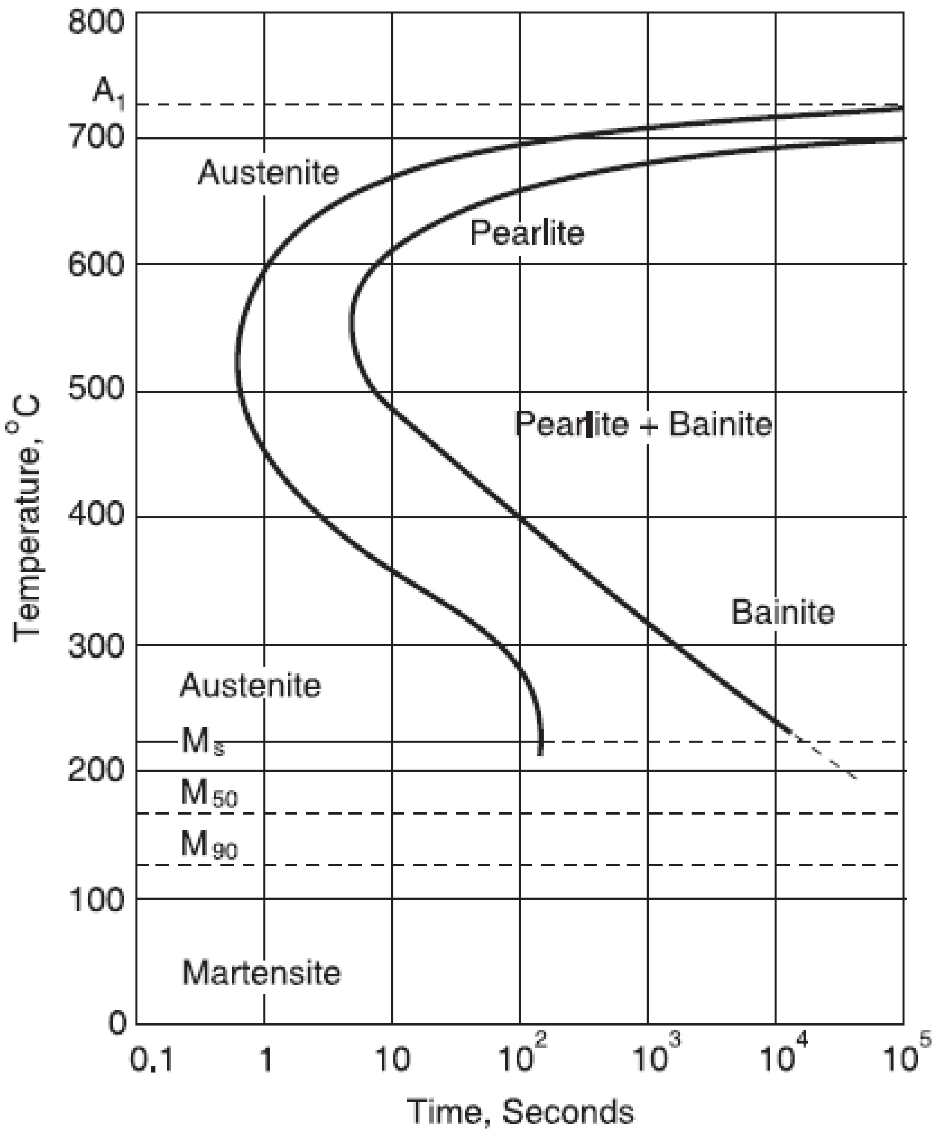


Figure 4.13 TTT diagram for eutectoid steel.

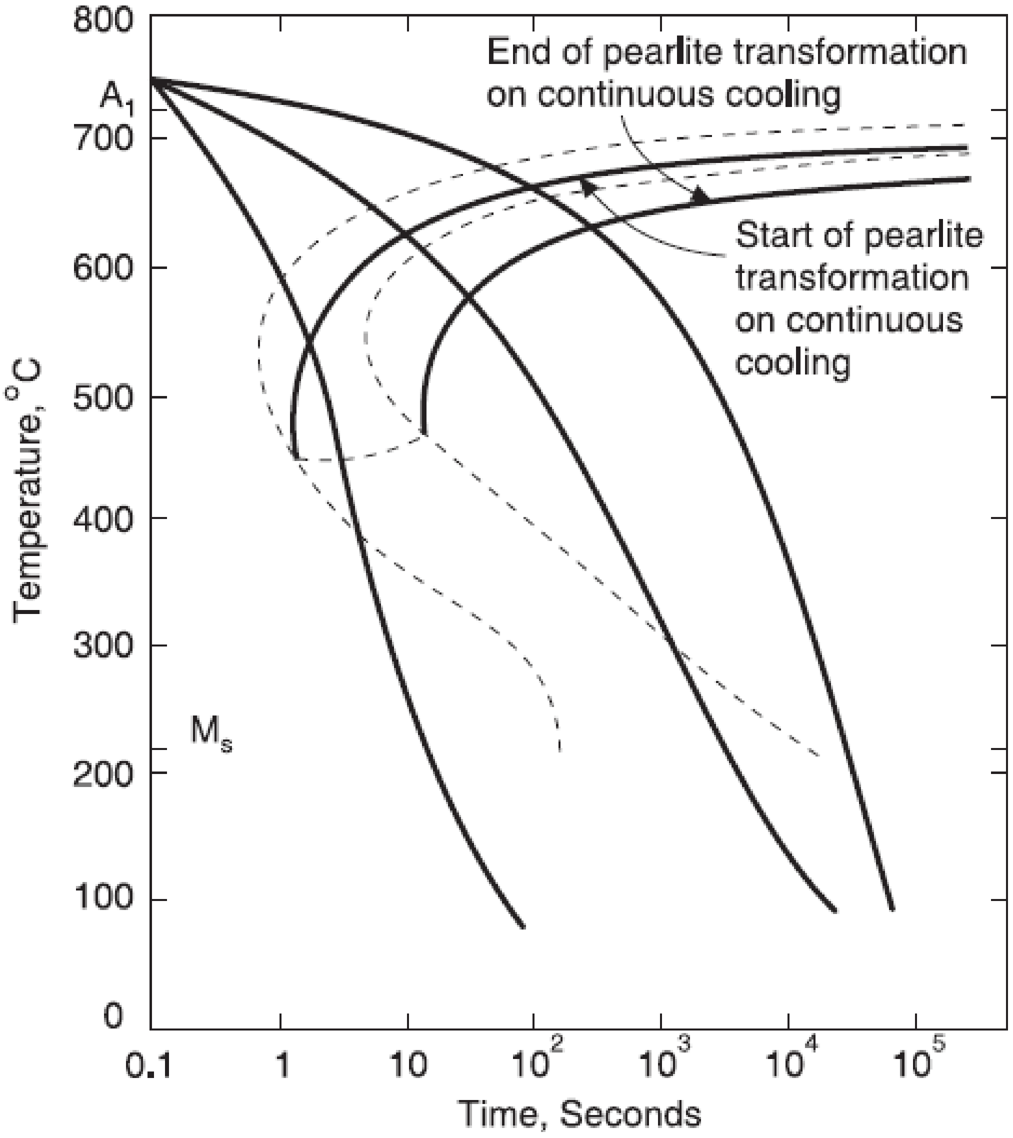


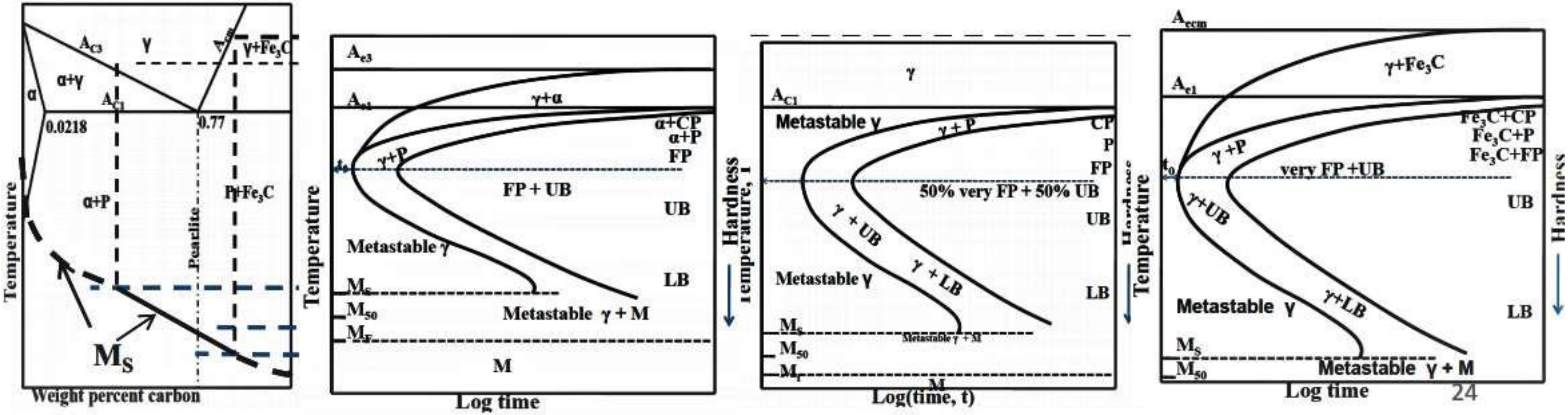
Figure 4.17 CCT diagram for eutectoid steel.

(a) Fe-Fe_3C metastable phase diagram

(b) TTT diagram for hypoeutectoid steel

(c) TTT diagram for eutectoid steel

(d) TTT diagram for hypereutectoid steel



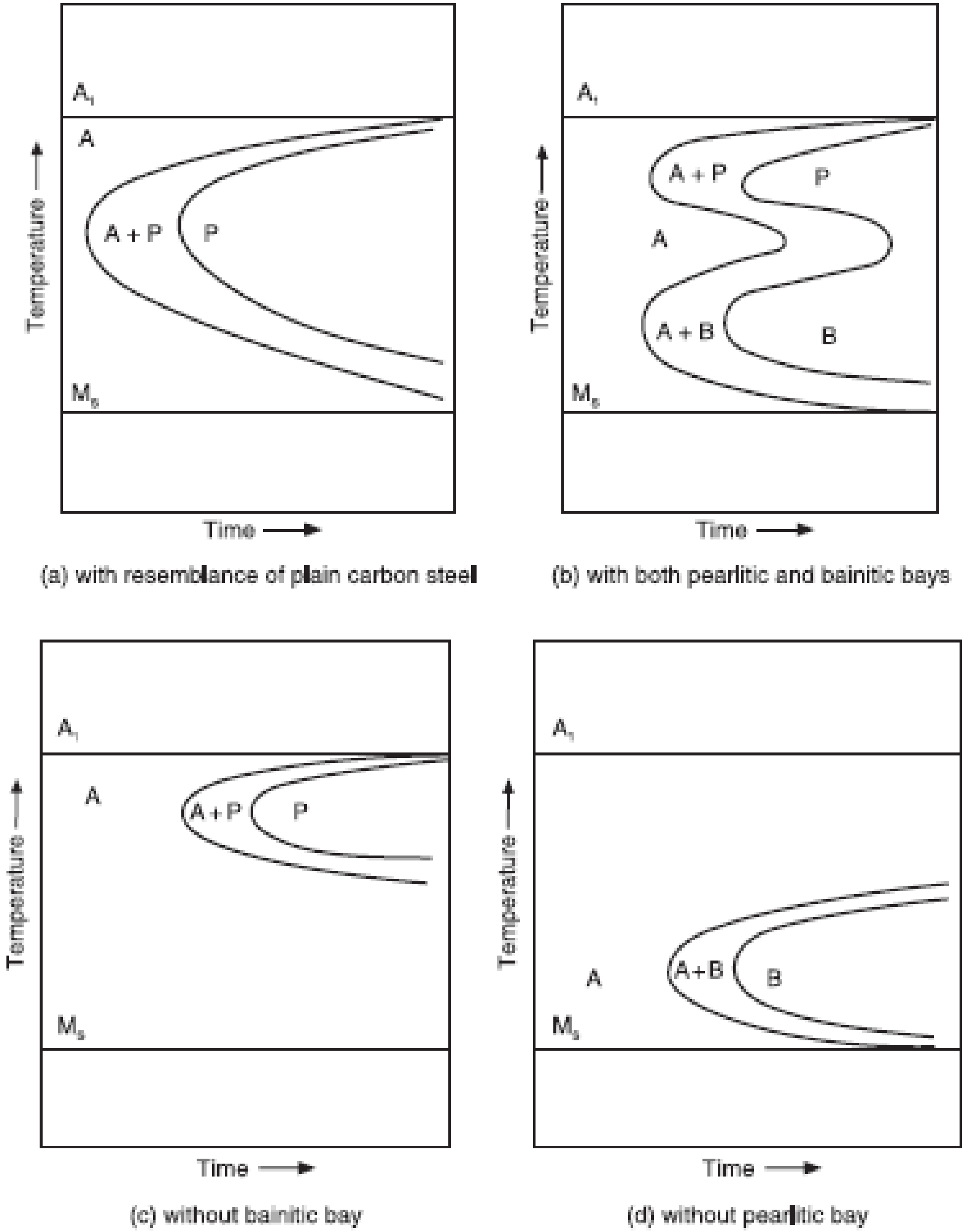
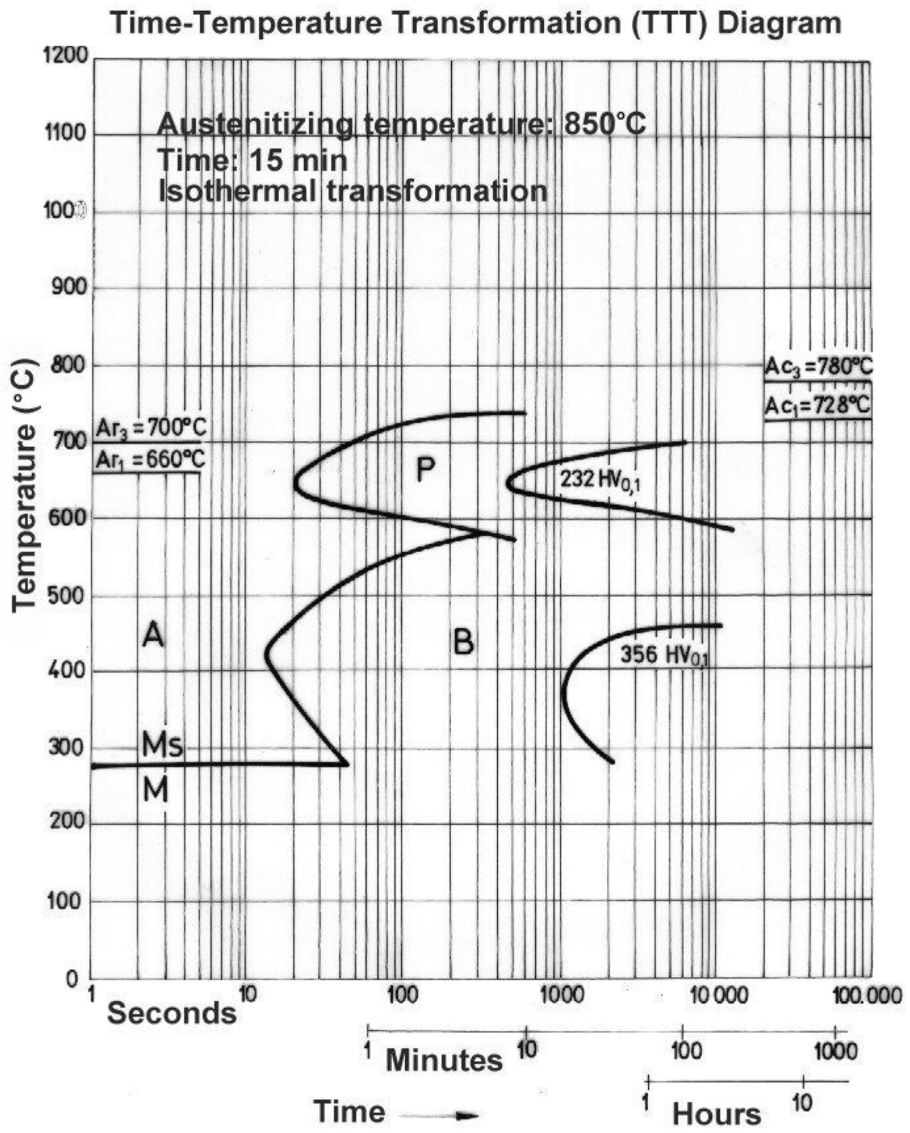
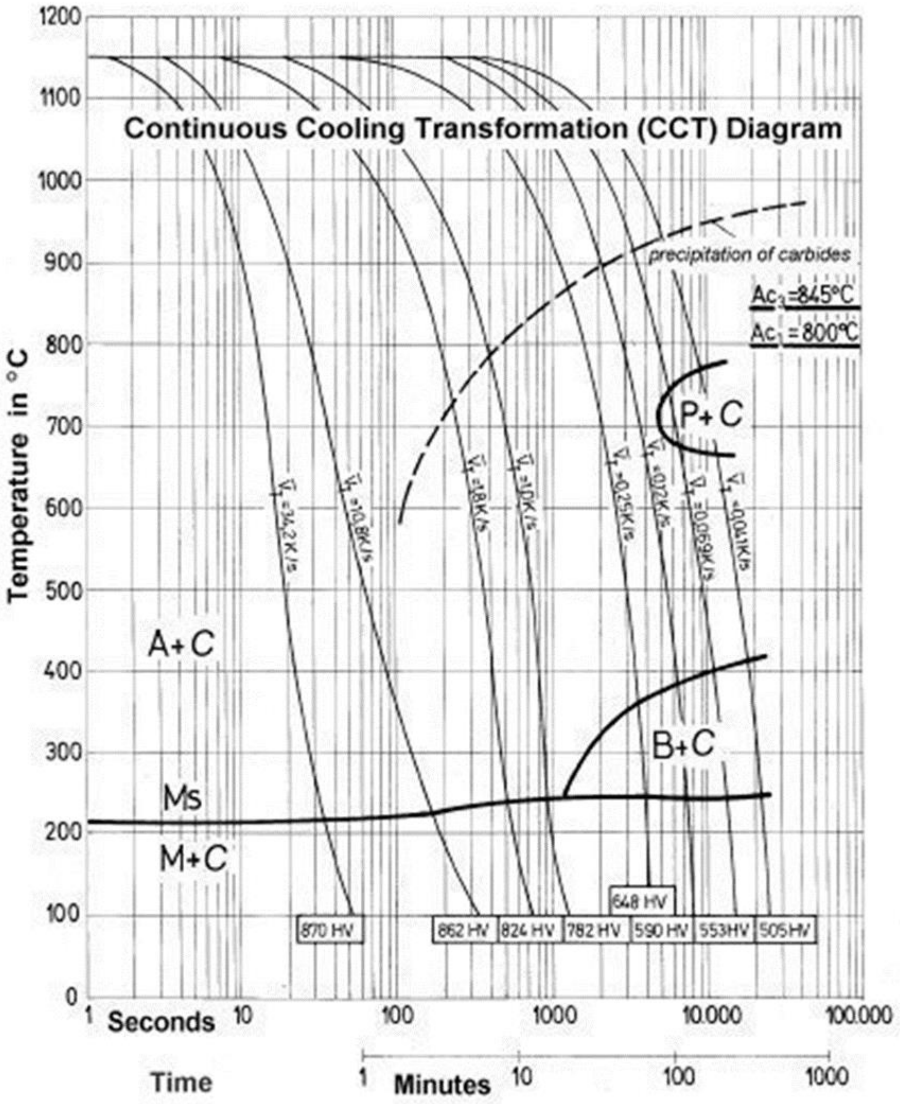


Figure 4.16 Various types of TTT diagrams for alloy steels.



Time-temperature isothermal transformation (TTT) diagram for AISI type 6150 carbon steel, austenitized at 850°C.



Continuous cooling transformation (CCT) diagram for AISI type M3/2 steel.

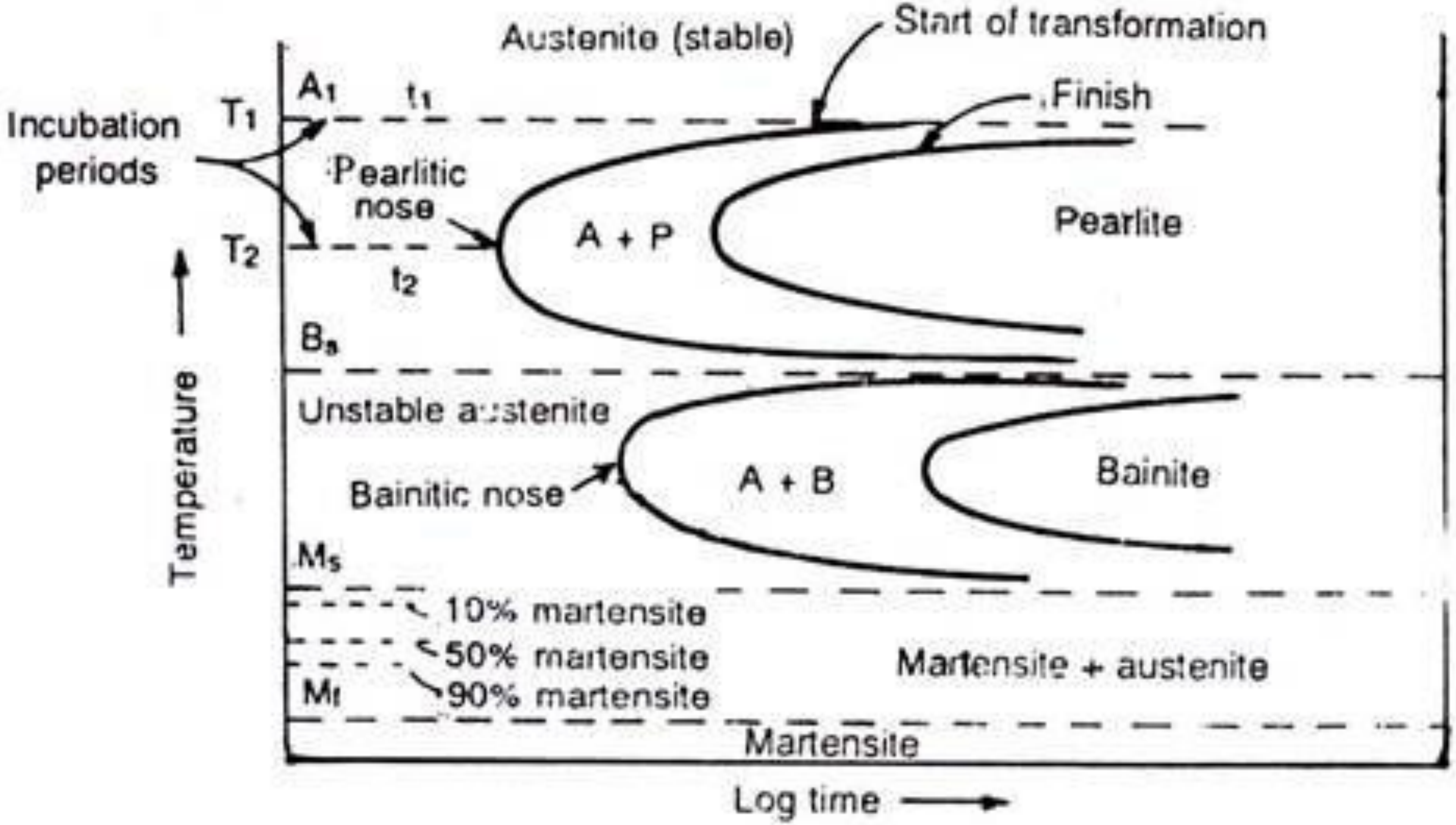


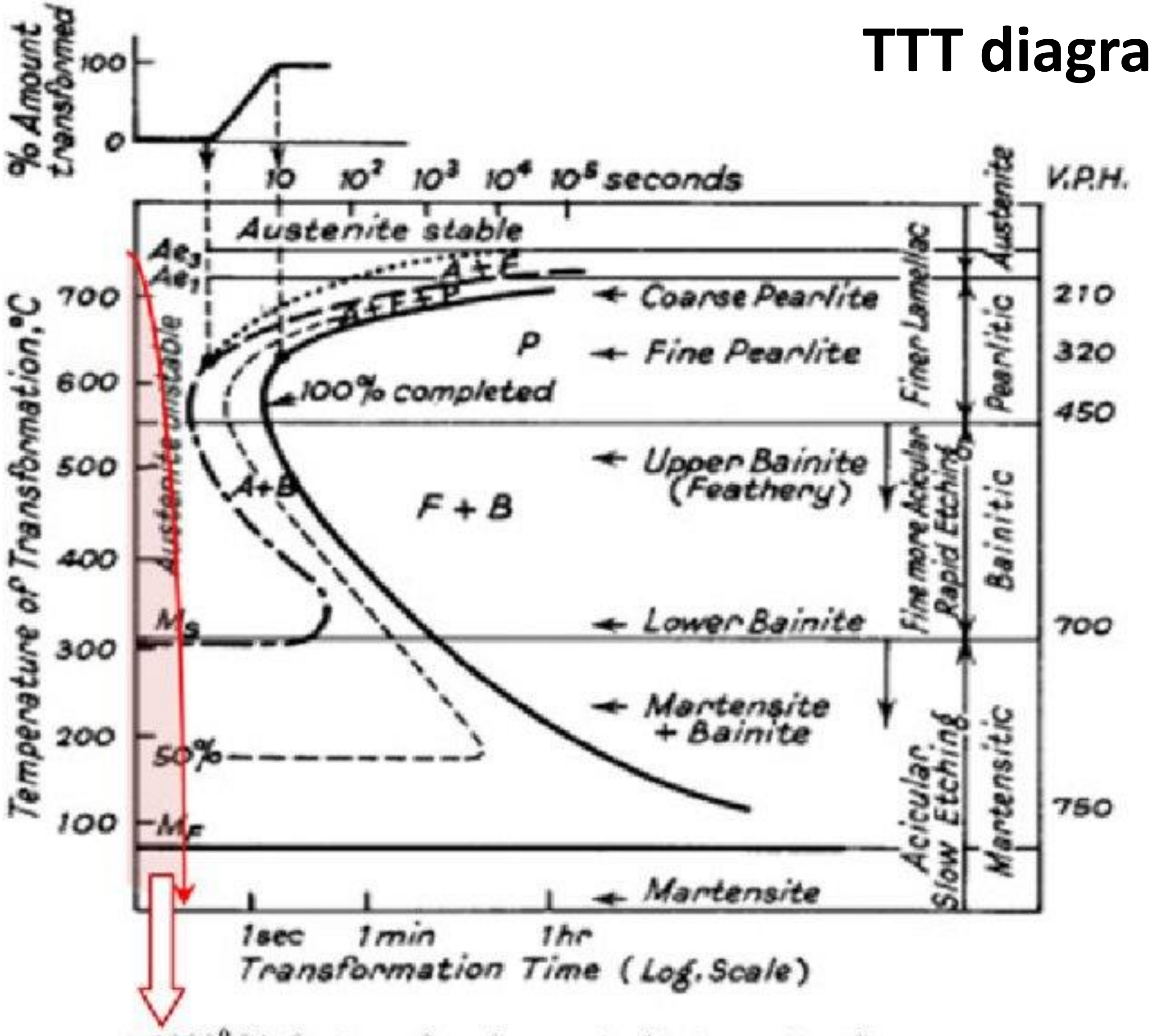
Fig. 3.1. Idealised TTT diagram. As under-cooling increases, incubation period decreases, (at T_1 is t_1 and at T_2 is t to become minimum and then it increases again.

Factors affecting TTT diagram

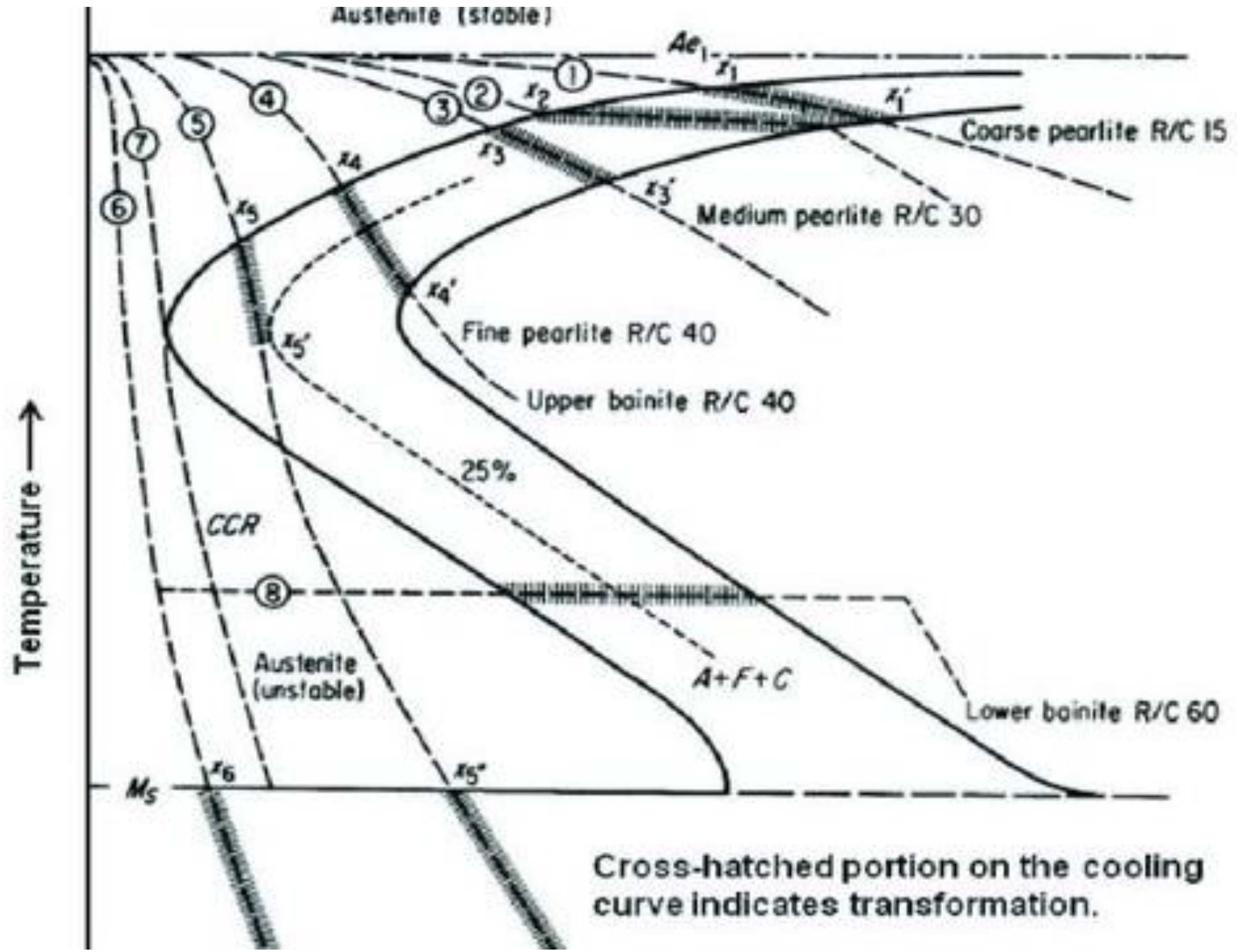
1. Composition of steel-
   (a) carbon wt%,
   (b) alloying element wt%
2. Grain size of austenite
3. Heterogeneity of austenite

- Carbon wt%-As the carbon percentage increases A3 decreases, similar is the case for Ar3 , i.e. austenite stabilizes. So, the incubation period for the austenite to pearlite increases i.e. the C curve moves to right.
- However after 0.77 wt%C any increase in C, Acm line goes up, i.e. austenite become less stable with respect to cementite precipitation. So transformation to pearlite becomes faster. Therefore C curve moves towards left after 0.77%C.
- The critical cooling rate required to prevent diffusional transformation increases with increasing or decreasing carbon percentage from 0.77%C and e for eutectoid steel is minimum. Similar is the behavior for transformation finish time.
- Pearlite formation is preceeded by ferrite in case of hypoeutectoid steel and by cementite in hypereutectoid steel. Schematic TTT diagrams for eutectoid, hypoeutectoid and hyper eutectoid steel are shown **Figs. 5(a)-(b)** and all of them together along with schematic Fe-Fe3C metastable equilibrium are shown in **Fig. 6**. γ=austenite CP=coarse pearlite P=pearlite FP=fine pearlite UB=upper Bainite LB=lower Bainite M=martensite MS=Martensite start temperature M50=temperature for 50% martensite formation

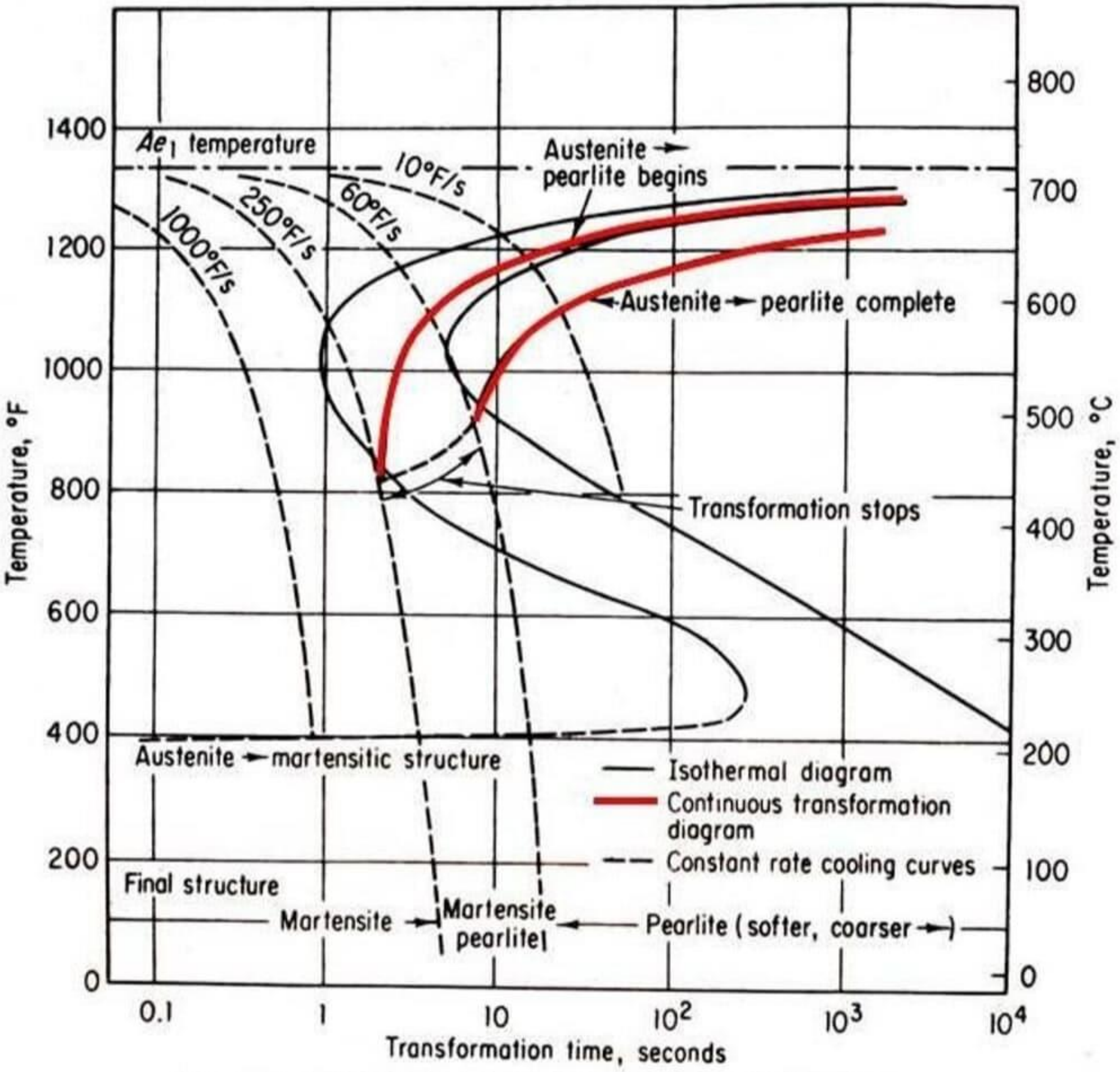
TTT diagram for 0.65 % carbon steel



$v > 1000^0C/s$ for transforming austenite-to-martensite

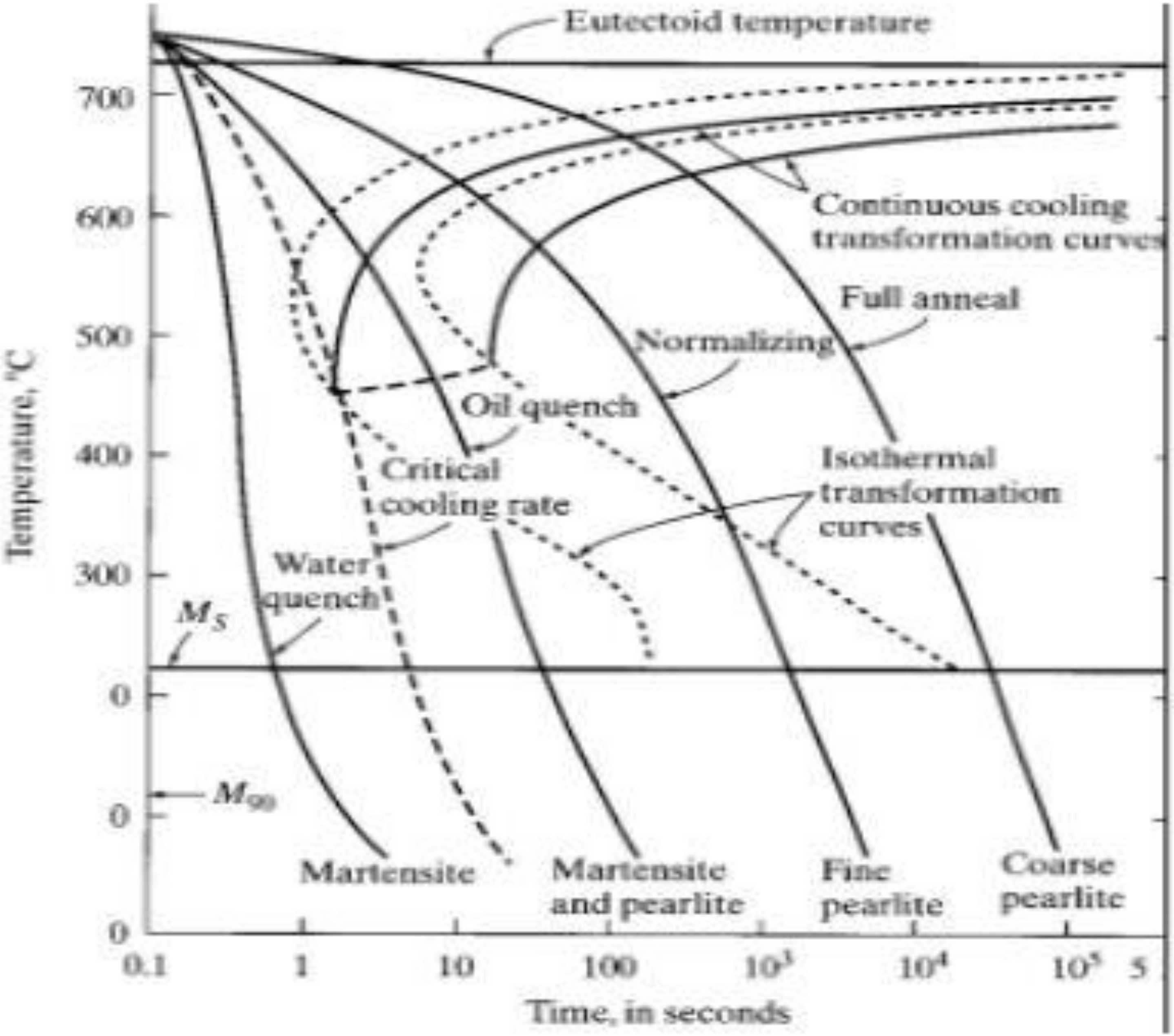


Cooling curves superimposed on the hypothetical I-T diagram.



Continuous Cooling-Transformation (C-T) Diagram

(Derived from the isothermal transformation diagram for a plain-carbon eutectoid steel)


Eutectoid temperature
700
600
500
400
300
0
0
0
Temperature, °C
Continuous cooling transformation curves
Full anneal
Normalizing
Oil quench
Critical cooling rate
Isothermal transformation curves
Water quench
M_S
M_{90}
Martensite
Martensite and pearlite
Fine pearlite
Coarse pearlite
0.1
1
10
100
10^3
10^4
10^5
5
Time, in seconds

End