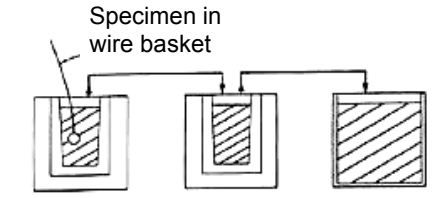
Lecture 3:
Phase Transformations in Steel
(IT Diagrams)

MMat 380

The question:

What happens when steel is quickly cooled below equilibrium temperatures?

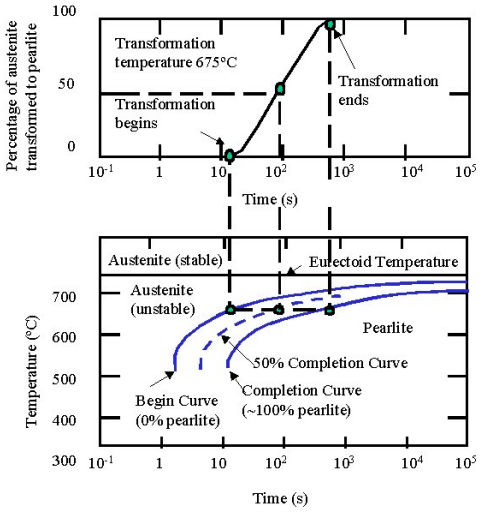
Experimental set-up:



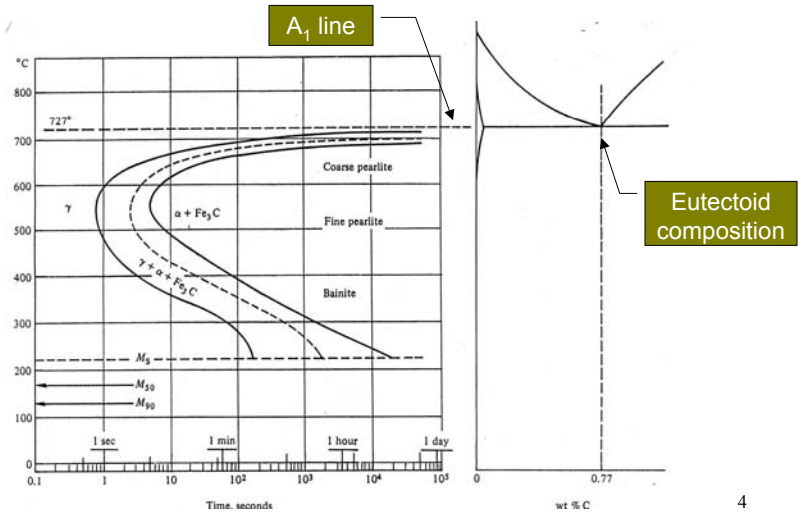
Temperature Time Transformation (**TTT**) diagram or Isothermal Transformation (**IT**) diagram illustrates what happens

Deriving IT diagram

- Results of many experiments consolidated as shown



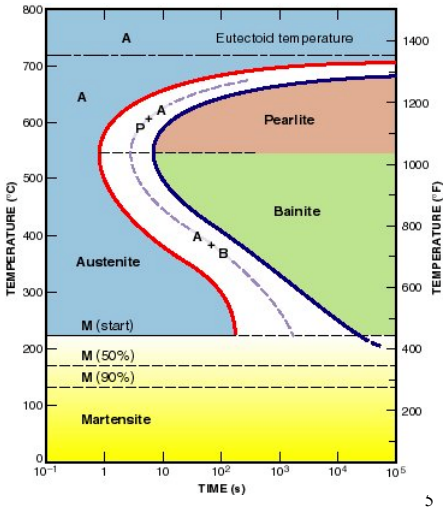
IT Diagram for an Fe-0.77%C alloy



Information from an IT diagram

Transformation temperature dictates the final microstructure

Note: Nucleation occurs first at the austenite grain boundaries (faster diffusion path than within the grain)



Rates of nucleation and growth of pearlite

- Increasing supercooling ΔT below T_{eq} decreases pearlite spacing (because of increased **N/G**)

Transformation Temp (°C)	Rate of nucleation (**N**) (nuclei/mm^3/s)	Rate of growth (**G**) (mm/s)	**N/G**
700	3×10^{-4}	1.6×10^{-5}	18.75
650	10	1.6×10^{-3}	6250
600	100	1.6×10^{-2}	6250

Eutectoid plain carbon steel

- 550-723°C austenite transforms to pearlite
  - Nucleation and growth of pearlite (P)
  - Co-operative growth of the ferrite and Fe_3C
  - Pearlite nodules grow from nuclei along prior austenite grain boundaries until impingement occurs

Effect of transformation temperature

γ (austenite) ⇒ pearlite **nucleation** (**N**) and **growth** (**G**) process

As temperature of transformation lowered:

Nucleation rate **increases**

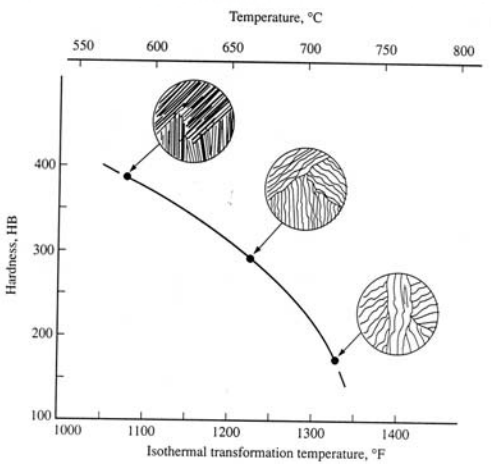
Growth rate **decreases** (diffusion dependent)

Transf. Temp.	N	G	N/G	Pearlite spacing
Low ~550°C	high	low	high	small
High ~720°C	low	high	low	large

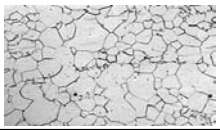
Effect of transformation T on pearlite

As T_{transf} increases:

- Spacing increases
- Strength and hardness decrease



Effect of austenite grain size

Austenite grain size **fine** 	N **high** Pearlite spacing **small**
Austenite grain size **coarse** 	N **low** Pearlite spacing **large**

Strength of pearlite

- Strength of pearlite **increases** as pearlite **spacing decreases**

$$\sigma_y(\text{MPa}) = 139 + 46.4S^{-1}$$

S = interlamellar spacing

Strength of pearlite

Hardening in pearlite is like dispersion hardening:

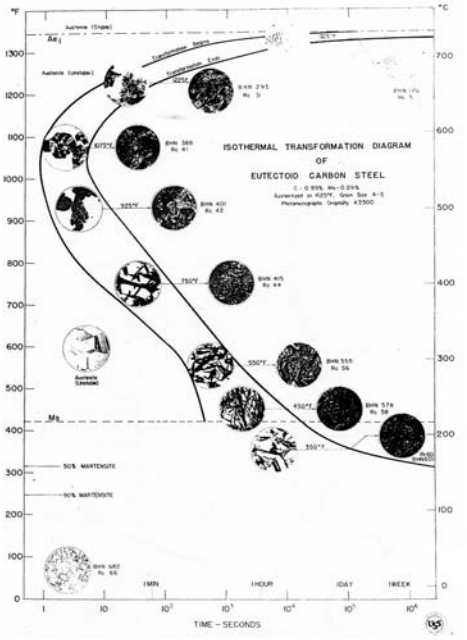
Strength α 1/interlamellae spacing

- α - ferrite (equilibrium cooling) 200 Mpa
- Pearlite (equilibrium cooling) 600 Mpa
- Pearlite (fast cooling) 2000 MPa

The "C" Shape of the IT Curve

time to start of transformation

microstructure



Bainite transformation

Below pearlite nose – transformation changes

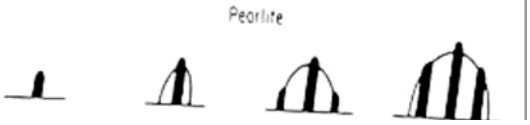
- γ - Bainite (α + Fe_3C) according to equilibrium diagram
- **Nature** of α - Fe_3C mixture changes (no longer have platelets of Fe_3C)

–Upper Bainite is feathery

–Lower Bainite is acicular

Bainite transformation

Pearlite – Co-operative growth

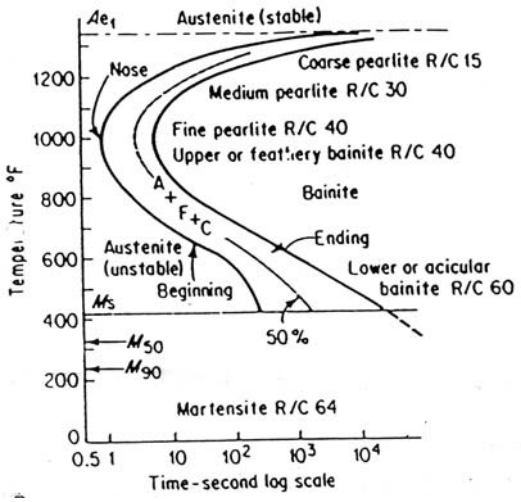


Bainite – ferrite formation followed by Fe_3C ppt.

Bainite transformation

- For slow cooling: (isothermal case)
  - With ↓ transformation temperatures, energy available to initiate transformation is less so ↑ transformation start time
- Result of "C" transformation curve – less thermal energy

Bainite and IT diagram



IT diagrams

Examples: