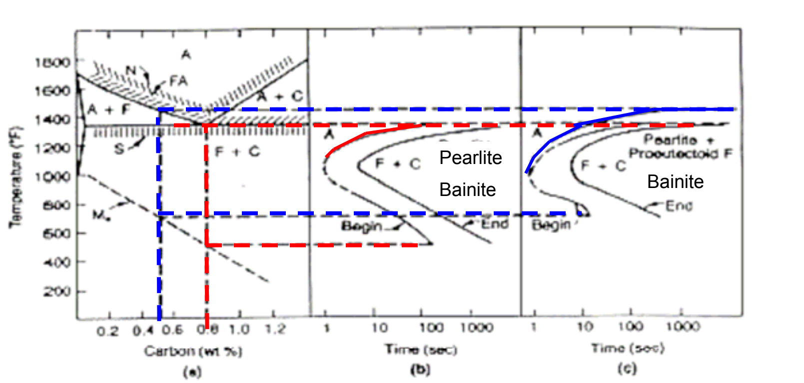
Lecture 5:
Heat Treatment of Steel

MMat 380

Lecture outline

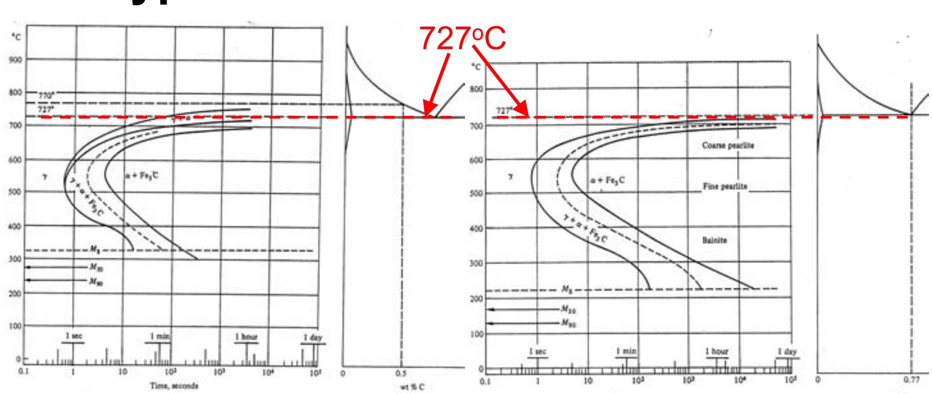
- TTT diagrams (hypo and hyper eutectoid steels)
- CCT vs TTT diagrams
- Austenizing Heat Treatments
  - For **hypo**eutectoid – mild steels
  - For **hyper**eutectoid steels
- Other Heat Treatments (no austenizing)
- Stress Relief

Hypoeutectoid steel
(non-equilibrium transformation)



Phase diagram eutectoid Hypoeutectoid

Hypoeutectoid and eutectoid steels



Hypoeutectoid Eutectoid

Hypoeutectoid steels (<0.8%C)

- As we decrease the transformation T in 0.5%C steel then:
  - Decrease amount of proeutectoid ferrite and increase amount of pearlite
  - Decrease proeutectoid ferrite grain size – increase strength (Hall-Petch equation)

$$\sigma_y = \sigma_o + kd^{-1/2}$$

  - Decrease spacing of pearlite

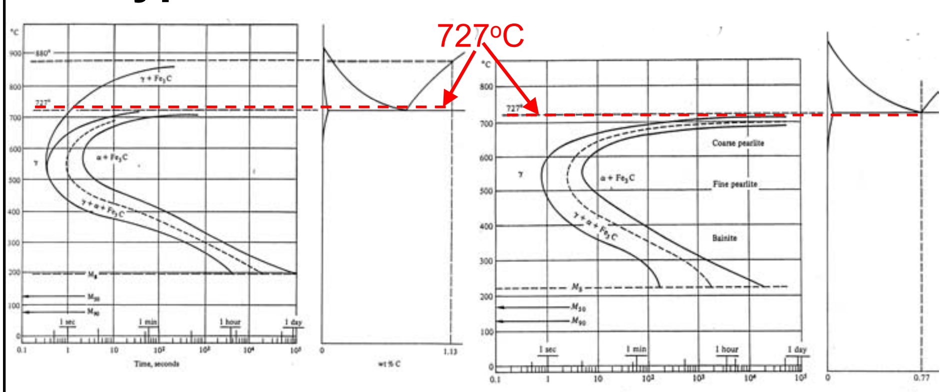
Hypoeutectoid steels

- Fe_3C nucleates P transformation
- Shift in eutectoid composition with lower transformation temp
  – Can get 100% pearlite in 0.4%C steel

Hypoeutectoid steels

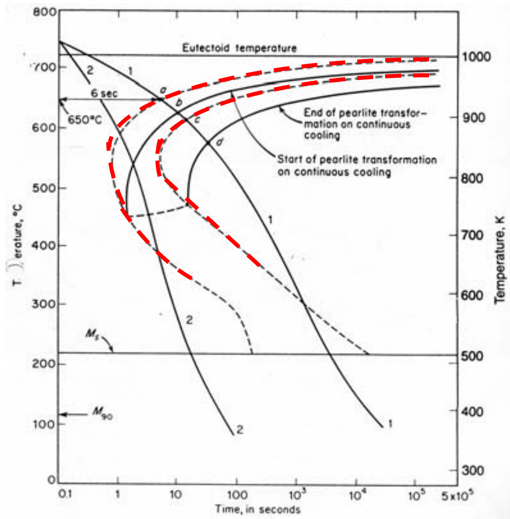
- As transformation T decreases
  - increase pearlite and decrease proeutectoid ferrite (ratio of α/Fe_3C in pearlite increases)
  - Finer pearlite
  - Finer grain size for proeutectoid ferrite
  - Change in eutectoid composition
  - Change in A_3 and A_1

Hypereutectoid and eutectoid steels



Hypereutectoid   Eutectoid

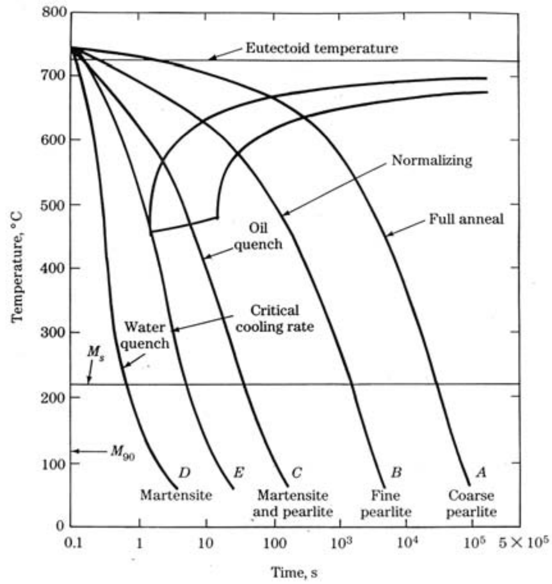
TTT to CCT curve



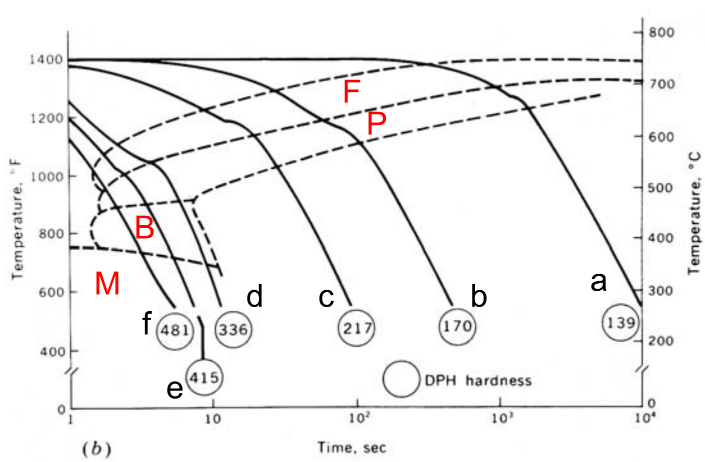
CCT vs TTT diagram

- Transformation curve pushed **down** and to the **right**
  - (i.e. lower temperature and increased time)
- Pre-transformation thermal force required is constant
  - i.e. isothermal @ 650°C – 6 seconds
    = 723-625°C – continuous in 8 seconds

CCT diagram (eutectoid steel)

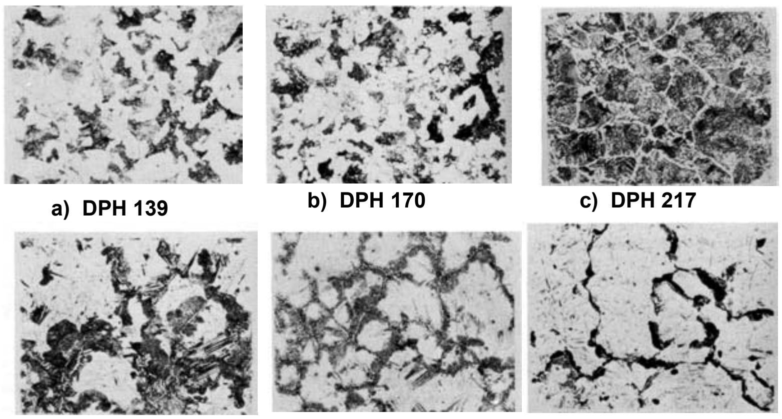


CCT diagram (1030 steel)



Microstructure (1030 steel)

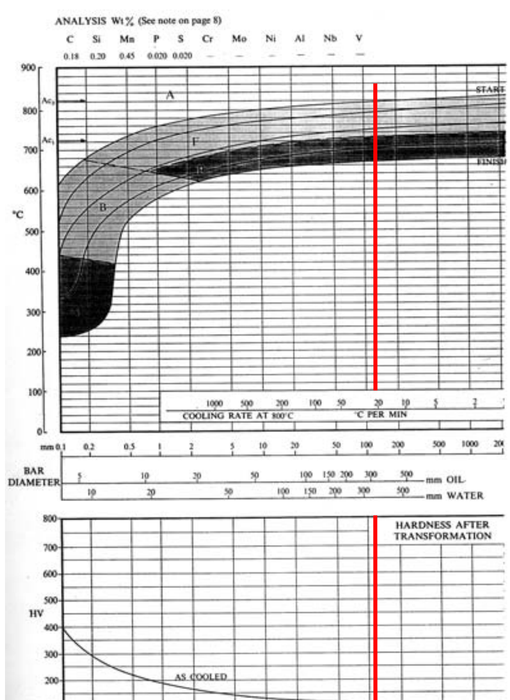
F+P F+P F+P



a) **DPH 139** b) **DPH 170** c) **DPH 217**

d) **DPH 336** e) **DPH 415** f) **DPH 481**

F+P+B+M F+P+B+M P+B+M



CCT diagram

Heat treatment of steel

- Heat to γ and **austenitize –** control cool

Hardening quench to martensite and temper

Martempering quench to above Ms and equilibriate
cool to martensite and temper

Austempering quench to above Ms and hold to bainite

Normalize air cool (@ ~5-10°C/min) - α & pearlite

Full anneal furnace cool (@~1°C/min) - α & pearlite

Heat treatment of steel

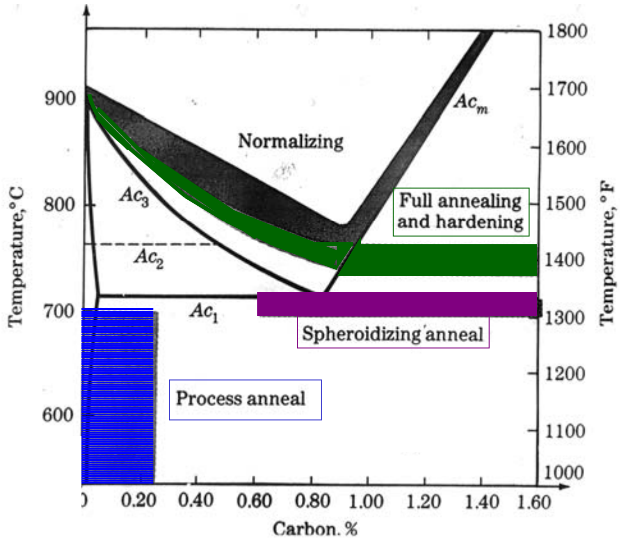
2. Heat to temperatures < 723°C

Spherodize softening (Fe_3C spherodizes
- free machining steels)

Process Anneal recrystallize ferrite (low %C steel)

Stress relief usually low %C structurals

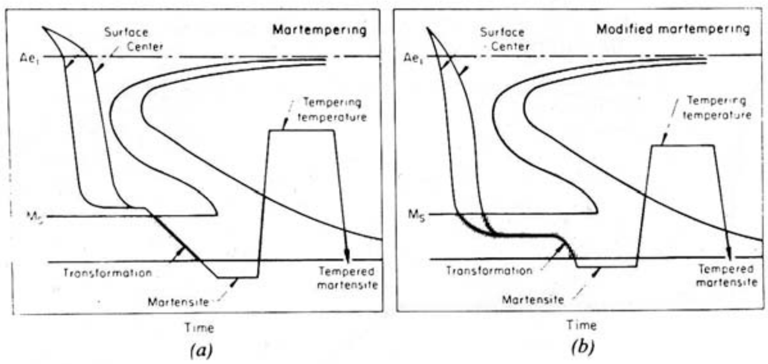
Heat Treatments



Martempering

- Modified quenching procedure used to minimize distortion/residual stresses of heat treated material and decrease cracking
  - Austenitize the steel
  - Quench it in hot oil/molten salt to a T slightly above/below M_s
  - Hold it in the quench medium until T uniform throughout the steel
  - Cool at a moderate rate to prevent drastic T differences between the surface and centre of the steel

Martempering



Martempering effects

Heat treatment	R_c	Impact (ft-lb)
Water quench and temper	53.0	12
Martemper and temper	53.0	28

Austempering

- Produces: **bainitic structure in plain-carbon steel**
  - Austenitize the steel
  - Quench into a hot salt bath @ a temp slightly above M_s held isothermally
  - Cooled to room temperature **in air**

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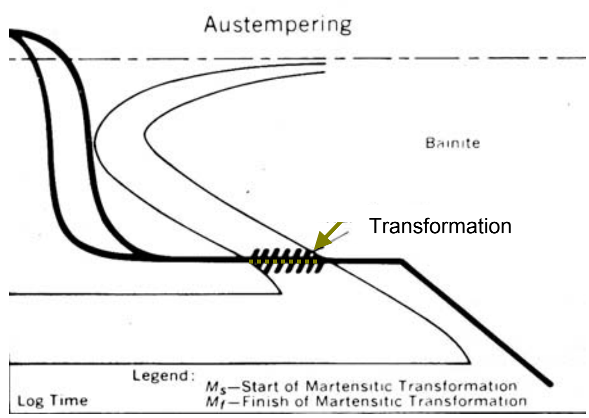
Austempering



Austempering

- **Advantages over conventional Q+T**
  - Improved ductility and impact strength for a given hardness
  - Decrease cracking and distortion quenching
- **Limitations for plain carbon steels**
  - Relatively thin sections (i.e. 3/8" max) – lawn mower blades; good shovels

Normalizing/Annealing

- Normalizing - ~5-10°C/min
- Annealing - ~1°C/min

- Reasons for normalizing (castings/plate etc.)

1. Refine grain size
   – increase strength
   – increase toughness
   – decrease d-b transition temperature

- eg: pressure vessels, ship plate, pipelines, digesters etc.

Normalizing/Annealing

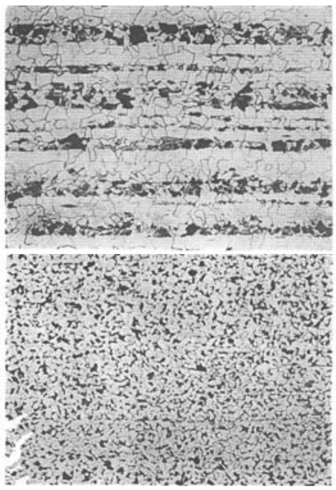
2. Redistribute solute in castings etc.

 - high temperature diffusion

Reasons for annealing:

- Fully soften material
- Put it in its most ductile state

Microstructure



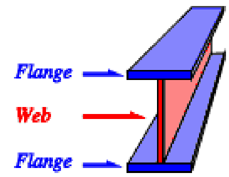
- Annealed (1°C/min)
  - Yield pt: 250 MPa
  - % elongation/2 in: 37
- Normalized (10°C/min)
  - Yield pt: 310 MPa
  - % elongation/2 in: 35

Mechanical properties

Normalized structures are stronger because:

- Finer pearlite
- More pearlite
- Finer α grain size

Example: I-beam



- low %C structural (0.2%C)
- Cooling rate to α & pearlite important for strength
  - Web - **thin** cools **first** from rolling temp.
  - Flange - **thick** cools **slowly** from rolling temp.

Therefore

- Flange has lower σ_y than web
- Code requires specification from web (strongest)
  - (i.e. 370 MPa Y.S)
- Flange is higher stressed but **may** have lower strength

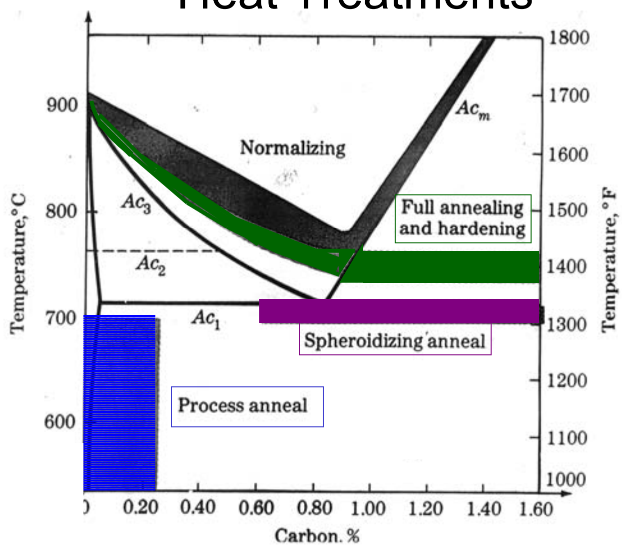
Normalizing/Annealing of hypereutectoid steel

- **Normalizing**
  - ~5-10°C/min
  - extensive grain boundary network of proeutectoid Fe_3C
- **Annealing**
  - ~1°C/min
  - **no** extensive grain boundary network of proeutectoid Fe_3C

for C contents >0.8%:

- % elongation values of normalized structure << annealed

Heat Treatments



Heat treatments of steel

- Heat to temp < 723°C (no austenizing)
  - Spherodize (Fe_3C spherodizes – free machining steels)
    - softening
  - Process anneal
    - Recrystallize ferrite (low %C steel)
  - Stress relief
    - Usually low %C structurals

Spherodizing

- 24 hrs @ temp just under A_1
  - carbides will spherodize if held for long time < 723°C
  - softens and puts steel in free machining condition
- sometimes buy steel in spherodized condition for good dimensioning on machining and then heat treat later

Process anneal

- 1 hr @ 600-650°C (no austenizing)
- Recrystallizes cold worked ferrite
- Y.S and UTS drastically reduced
- Sometimes used to selectively treat localized cold worked areas
- used in production of steel wire, nails etc.

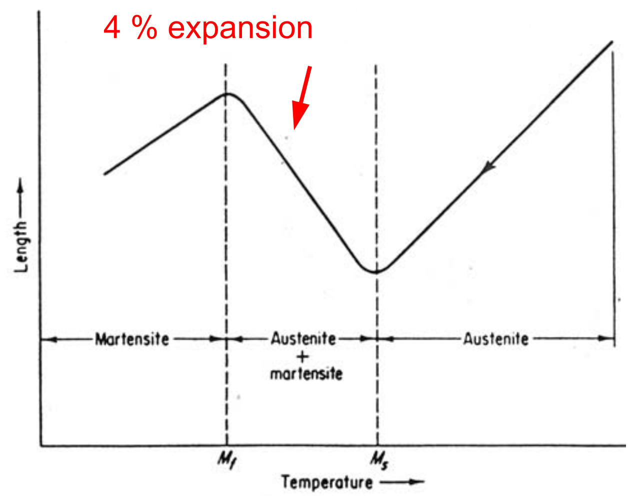
Stress relief

- Up to 678°C (times up to 24 hrs; thermal blankets)
- Done to relieve residual stresses
  - @ hi temp dislocations rearrange to relieve stresses (easier mobility @ high T – lower YS)
  - After cooling residual stress is reduced
- Less chance of fatigue, stress corrosion etc.
- Digestors and other pressure vessels have to be stress relieved to remove residual stresses associated with welds

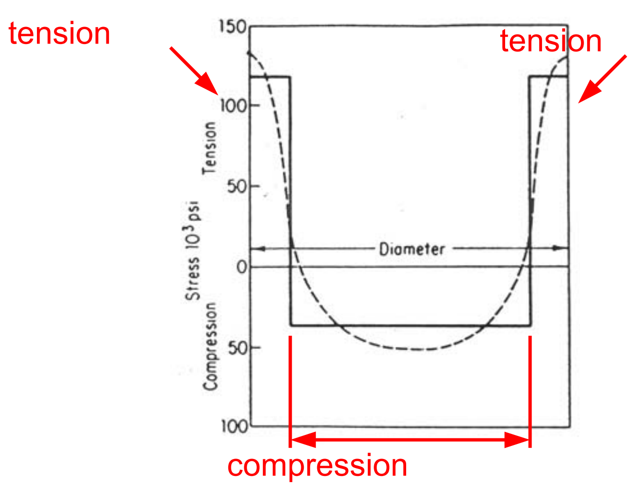
Internal residual stresses

- May develop because of:
  - **Plastic deformation** processes such as machining or grinding
  - **Non-uniform cooling** of a piece that was produced or fabricated at an elevated temperature
  - **Phase transformation** induced upon cooling; parent and product phases have different densities

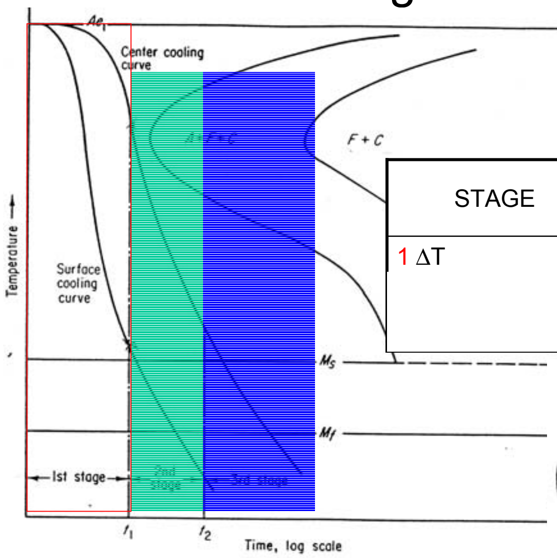
Dilation curve for martensite formation



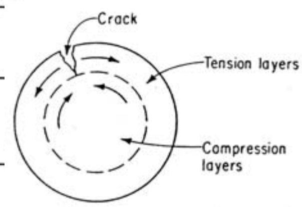
Typical residual stresses



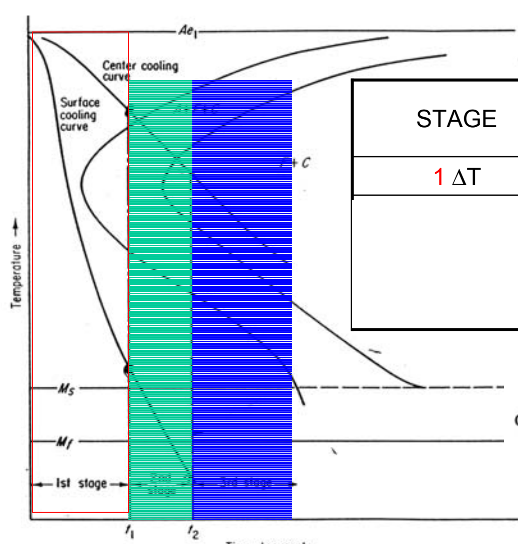
Through hardening



STAGE	STRESS CONDITION	
	SURFACE	CENTRE
1 ΔT	Tension	Compression



Shallow hardening



STAGE	STRESS CONDITION	
	SURFACE	CENTRE
1 ΔT	Tension	Compression