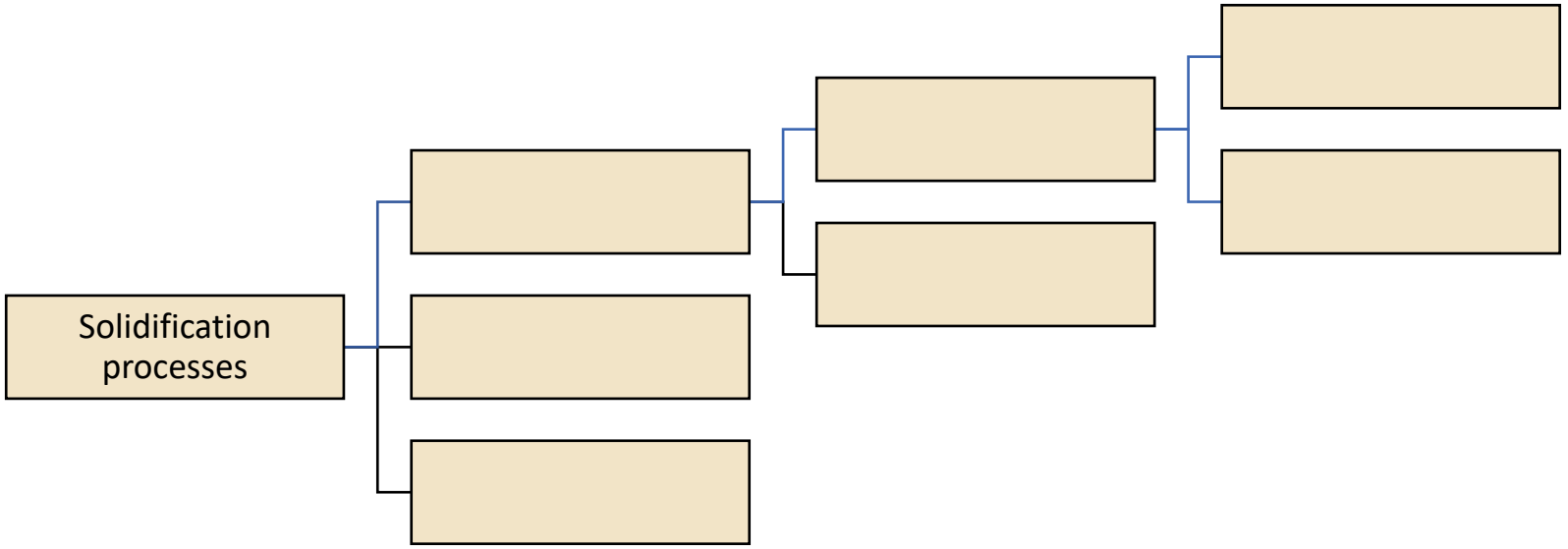
Mechanics In Design and Manufacturing

+ Casting and Heat Treatment

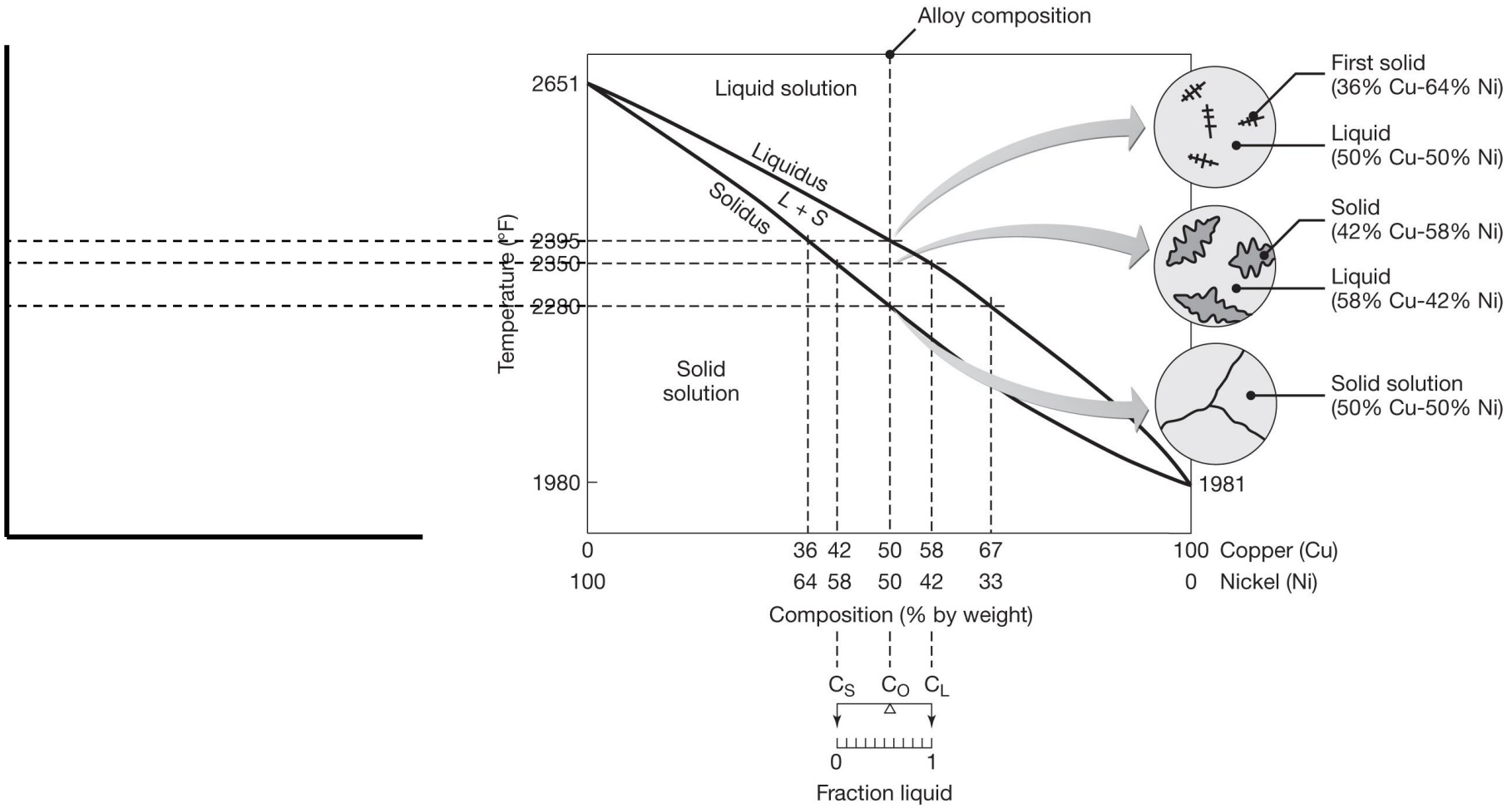
Solidification Process Categories



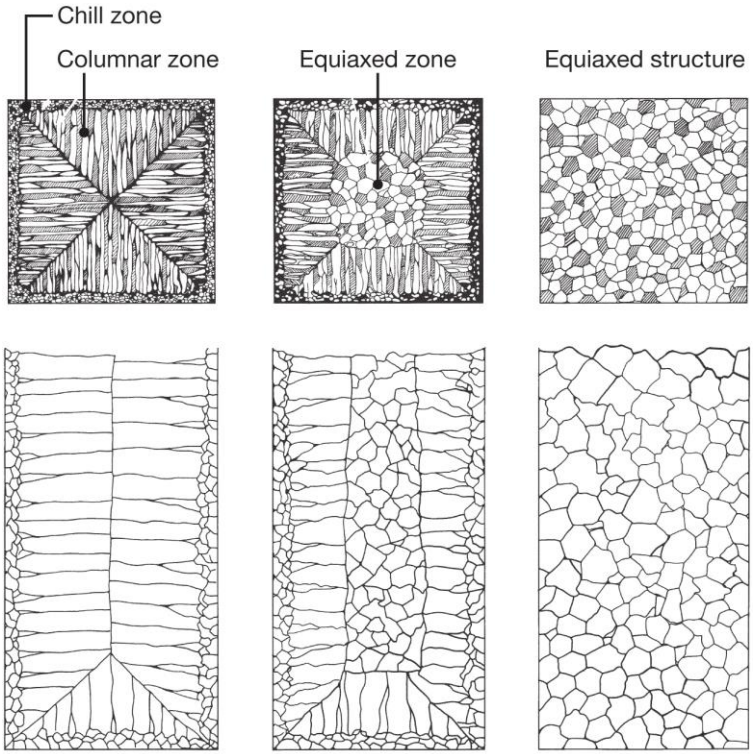
Solidification

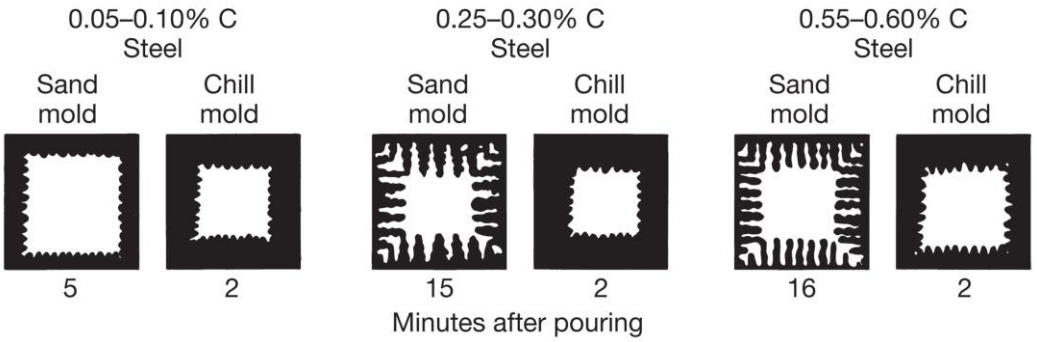
- Pure metals

Phase diagram (binary alloy)

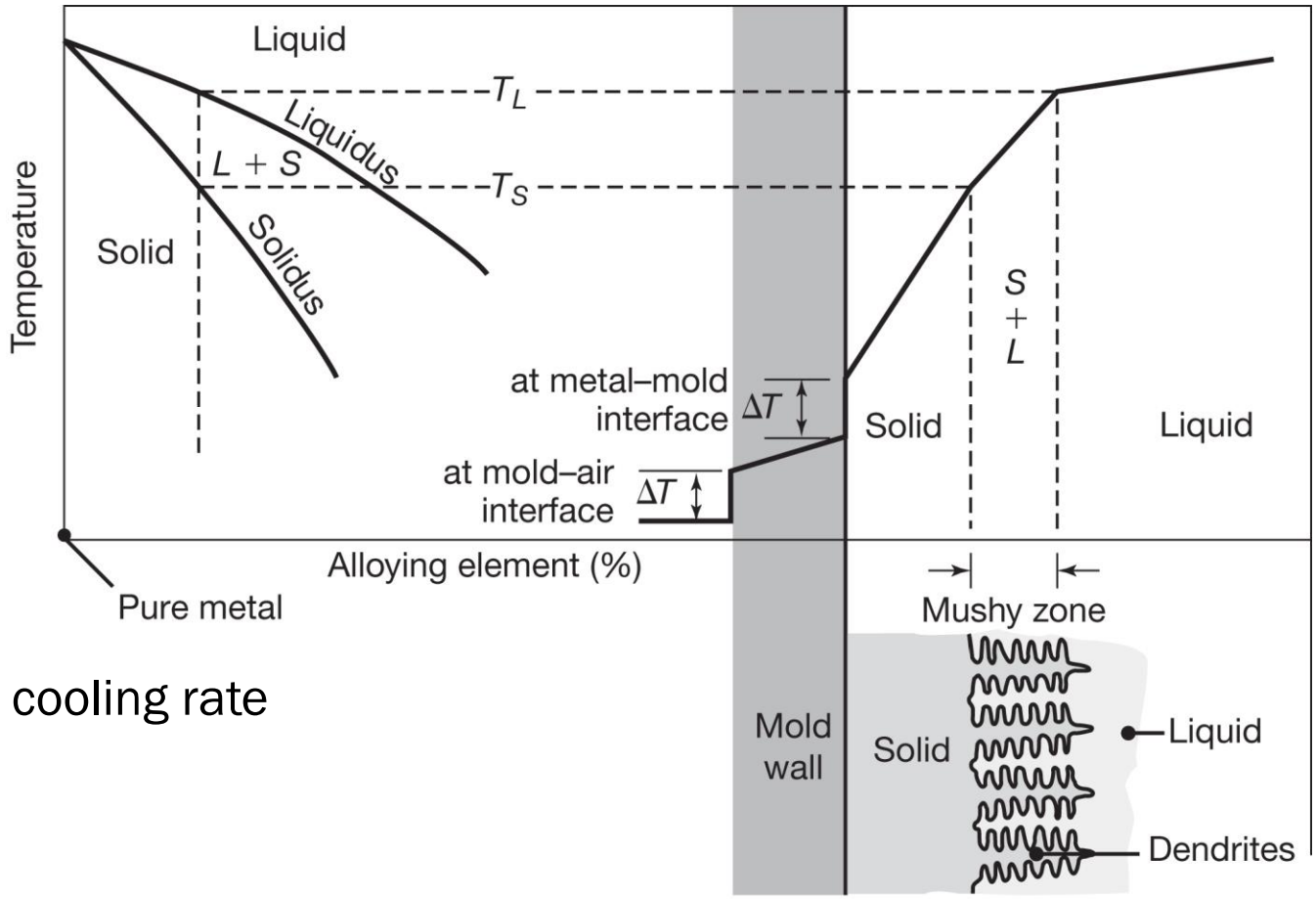


Casting and microstructure



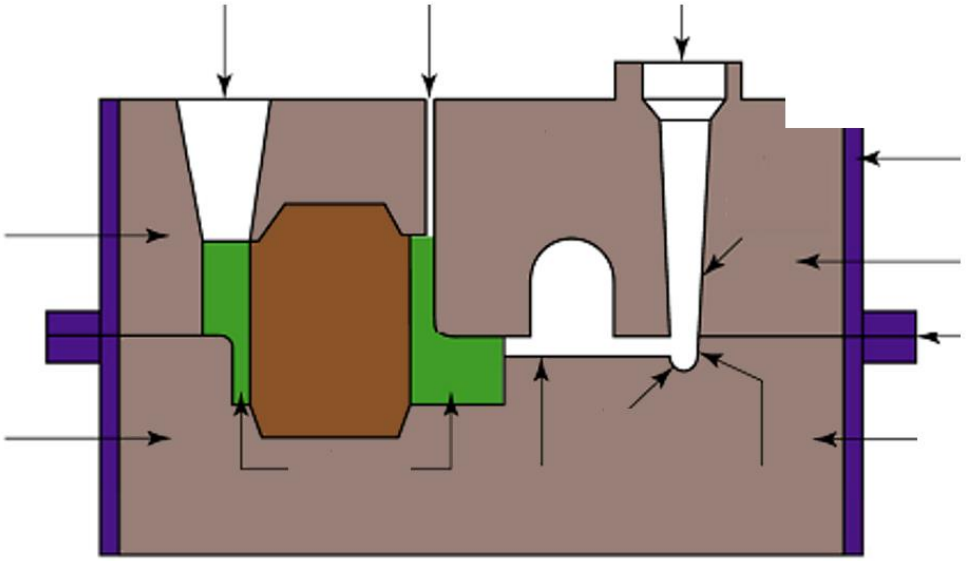


Dendrite formation



- Effects of cooling rate

Sand Casting Process (expendable mold)



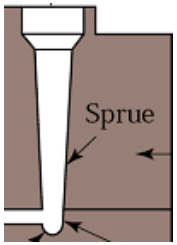
https://www.youtube.com/watch?v=BjQCrL8moqw

Lost-wax
titanium hammer

https://youtu.be/WXFRRg8YMT0?t=82

Mold Filling and Solidification

- Bernoulli



- Mass Continuity

- Turbulence

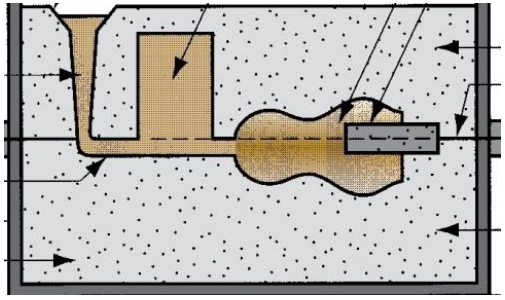
- Tapered sprue design – Find diameter at gate so no aspiration

(Given: Q=0.01 m^3/min, h=200mm, D_1=20mm, η=0.004 N-s/m^2 ρ_{al}=2700kg/m^3)

Solidification

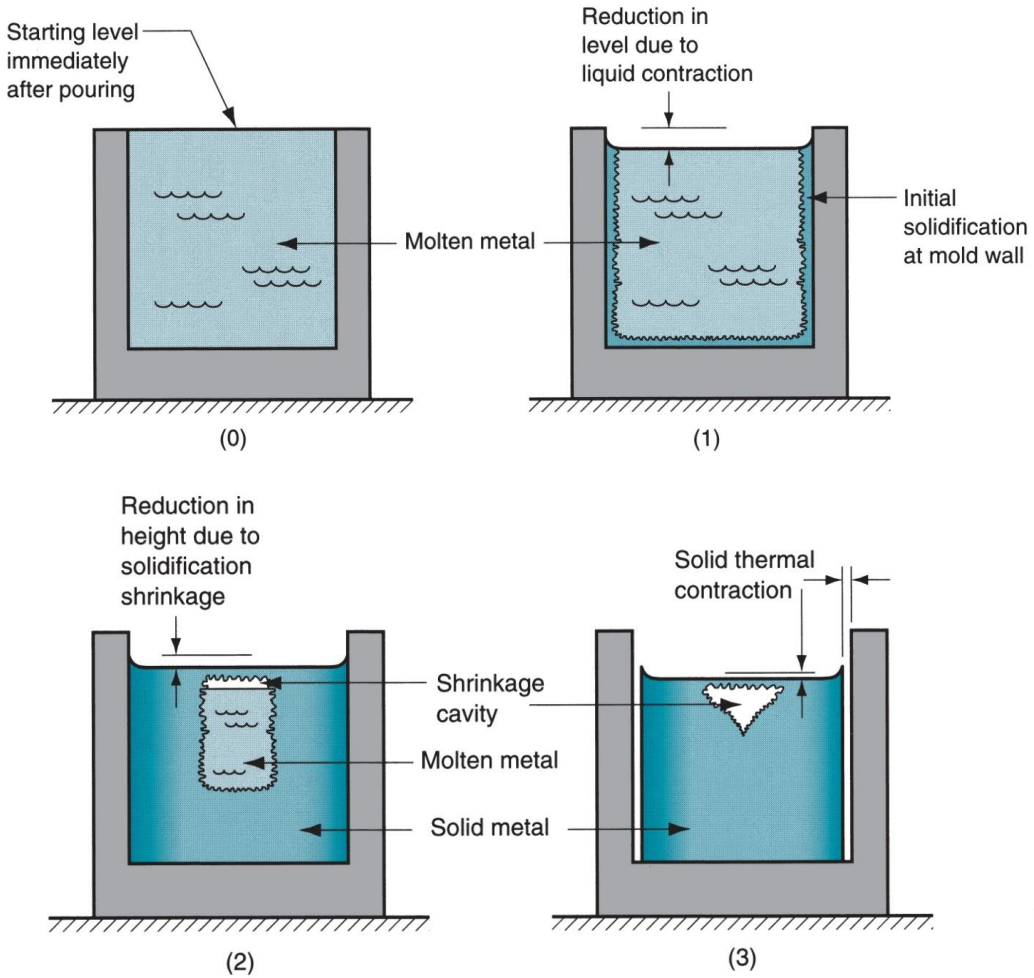
- Cooling is a function of the ratio of size and shape of the casting. (Chvorinov's rule)

- Determine if riser cools faster than the casting



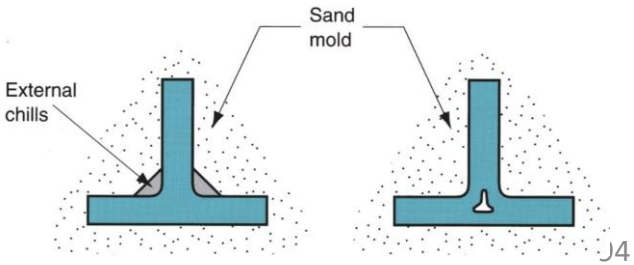
Shrinkage

Metal	Shrinkage
Aluminum alloys	1.3%
Brass, yellow	1.5%
Bronze	1.6%
Cast iron, grey	1.0%
Cast iron, white	2.1%
Magnesium alloy	1.3%
Steel, carbon	1.8%
Tin	2.0%
Zinc	1.3%



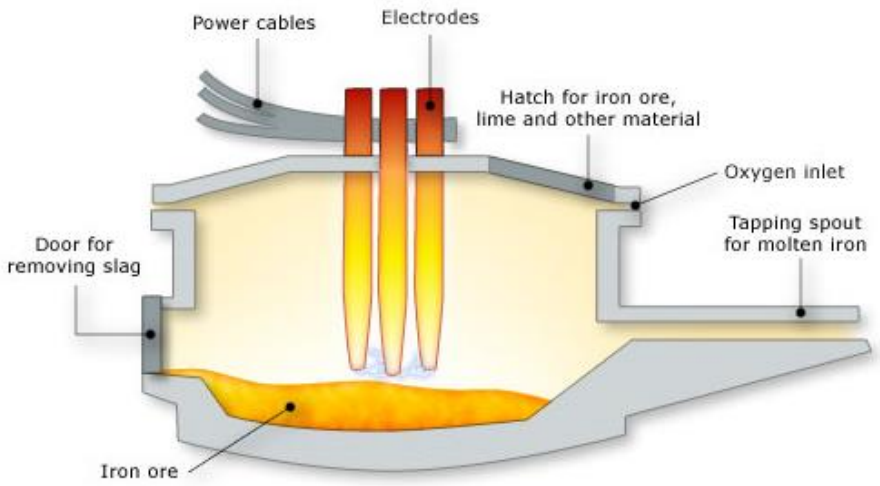
Groover 6th ed.

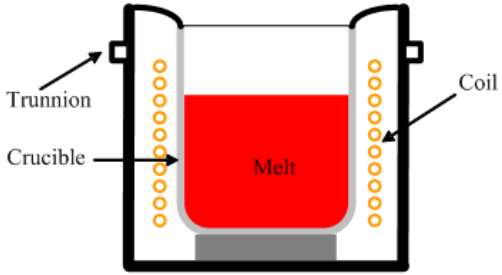
- Design/Mitigation

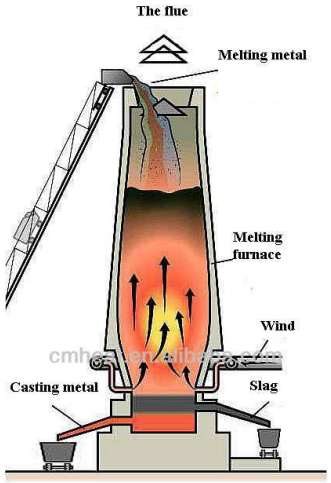


Groover 6th ed.

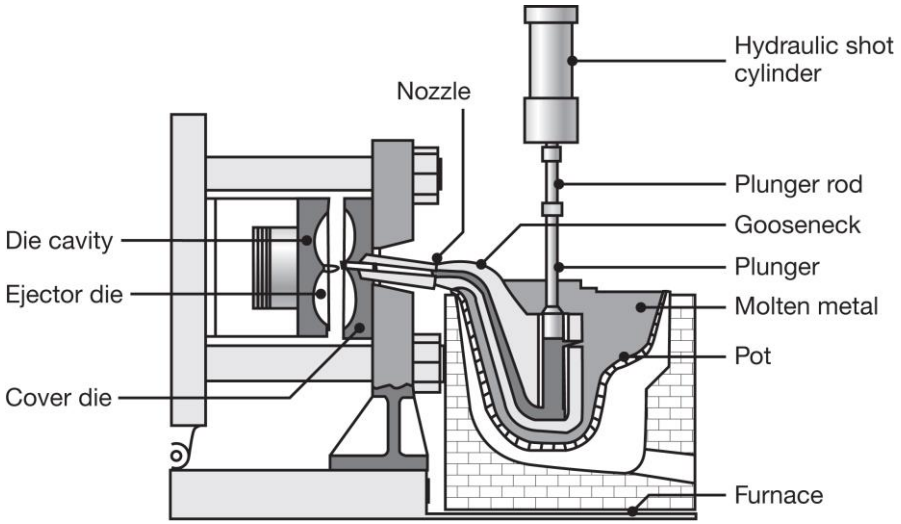
Furnaces

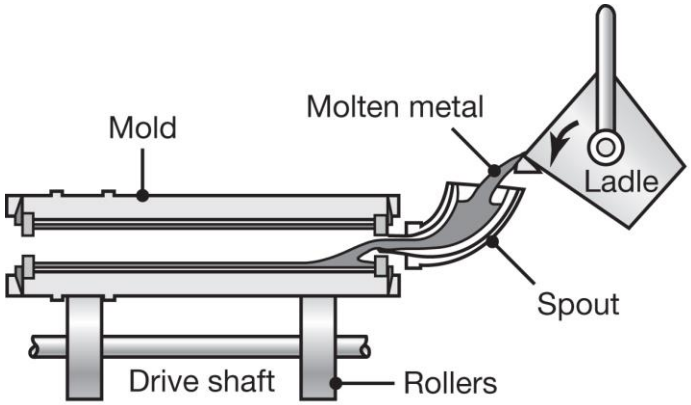

Power cables
Electrodes
Hatch for iron ore, lime and other material
Oxygen inlet
Tapping spout for molten iron
Door for removing slag
Iron ore

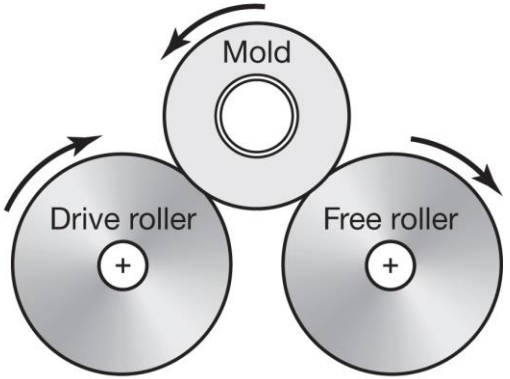

Trunnion
Crucible
Melt
Coil


The flue
Melting metal
Melting furnace
Wind
Casting metal
Slag

Permanent Mold Casting Processes

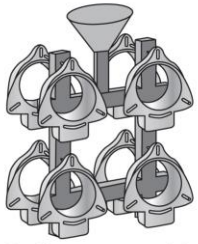


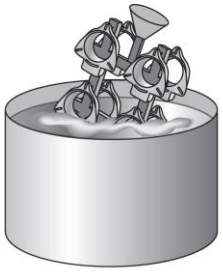


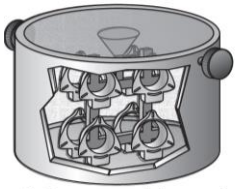


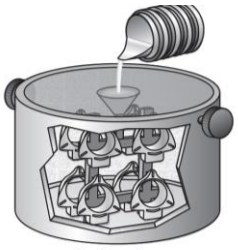
Expendable Mold Processes

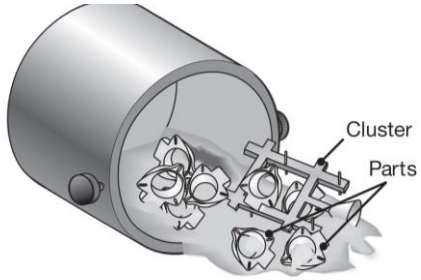

1. Pattern molding


2. Cluster assembly

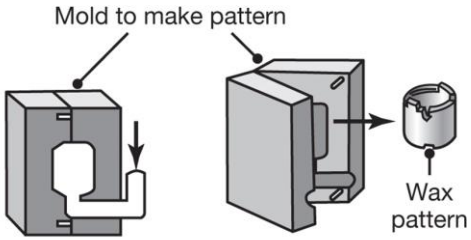

3. Coating


4. Compacted in sand


5. Casting

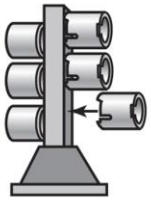


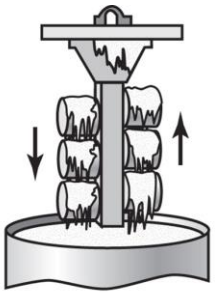
6. Shakeout

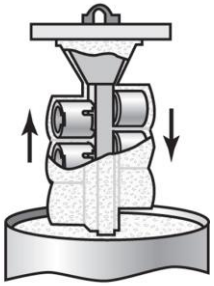


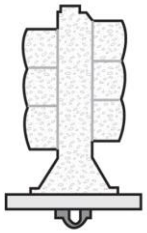
Injection wax or plastic pattern

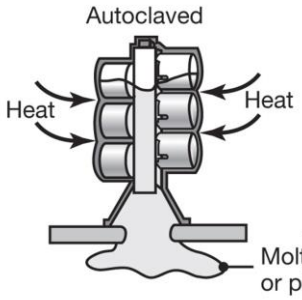
Ejecting pattern


Pattern assembly (Tree)

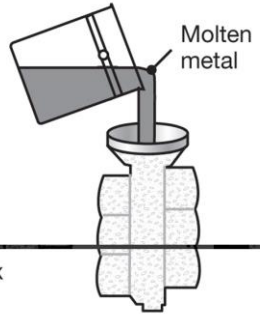

Slurry coating


Stucco coating

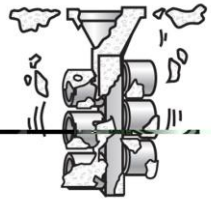

Completed mold



Pattern meltout

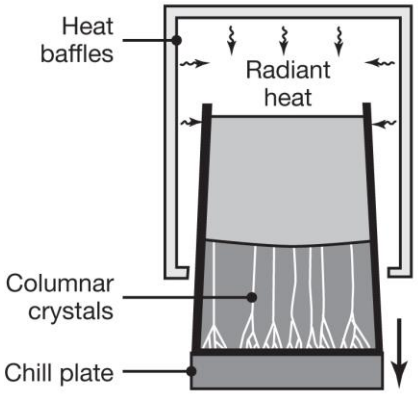


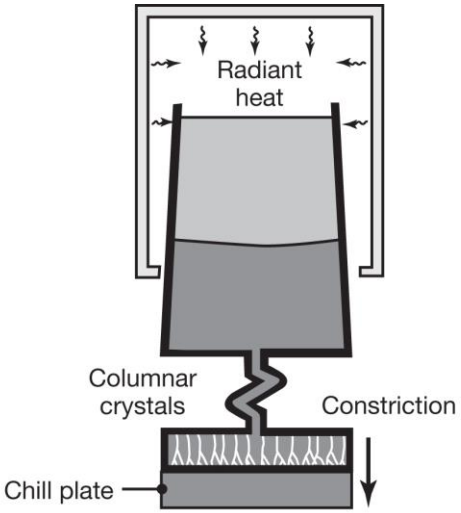
Pouring

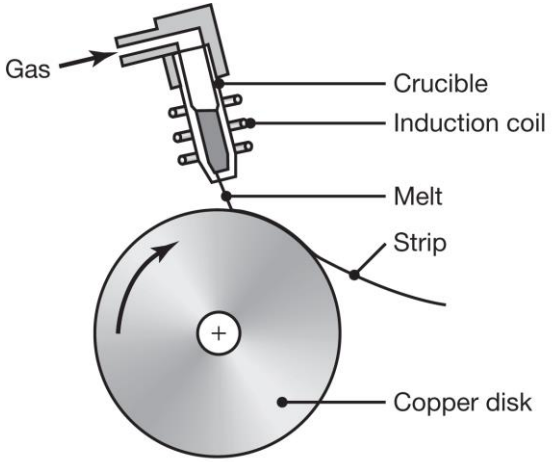

Shakeout

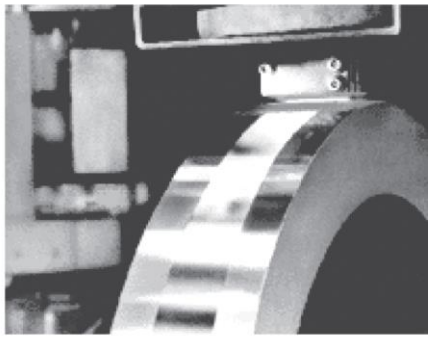
Pattern

Other Casting Process

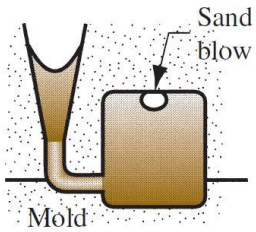


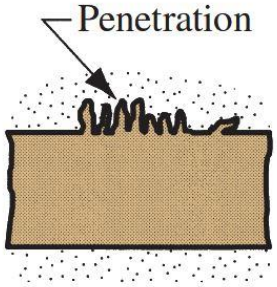


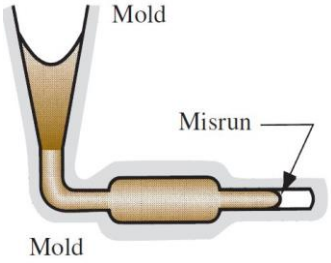


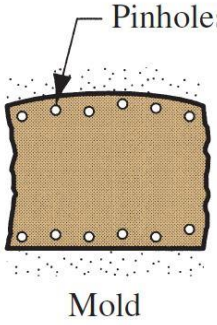


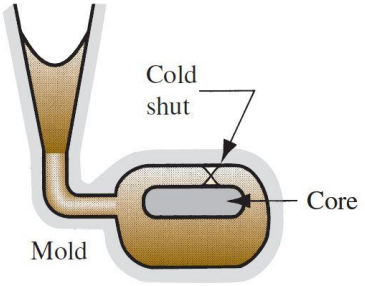
Casting Defects

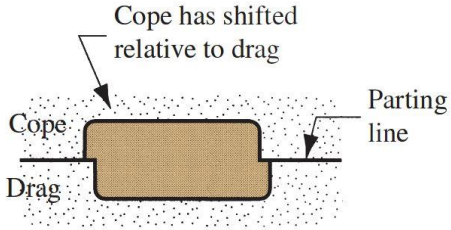


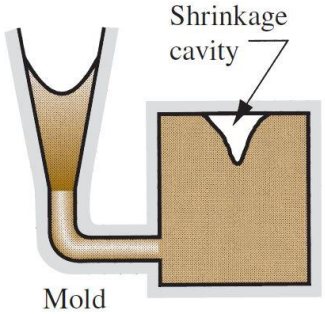






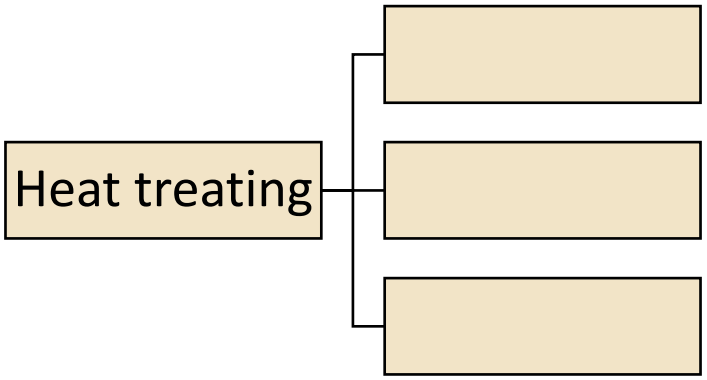




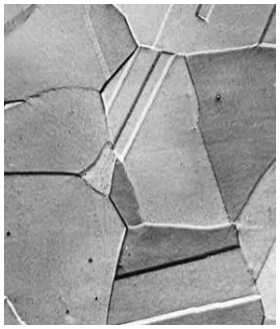


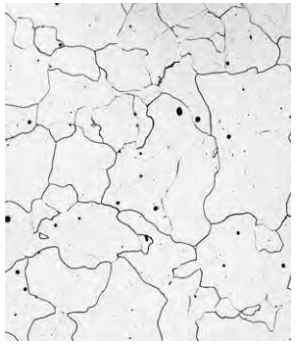
Groover 6th ed.

Heat Treating



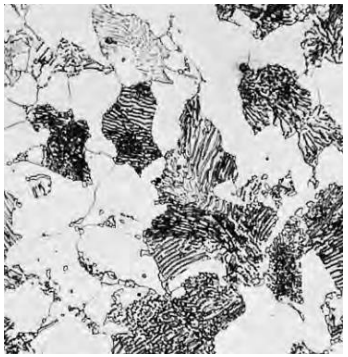
Iron-Carbon Phases/Microconstituents



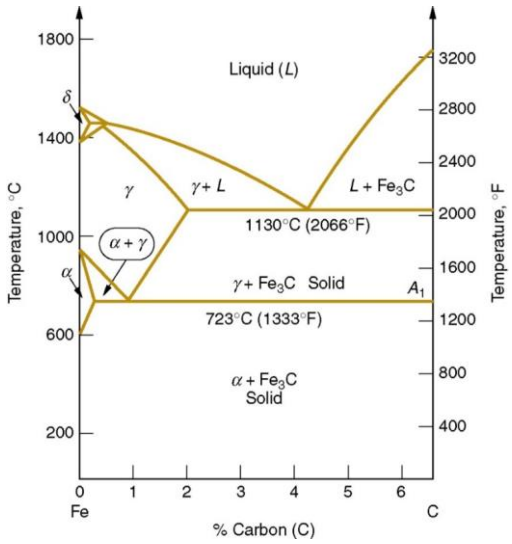


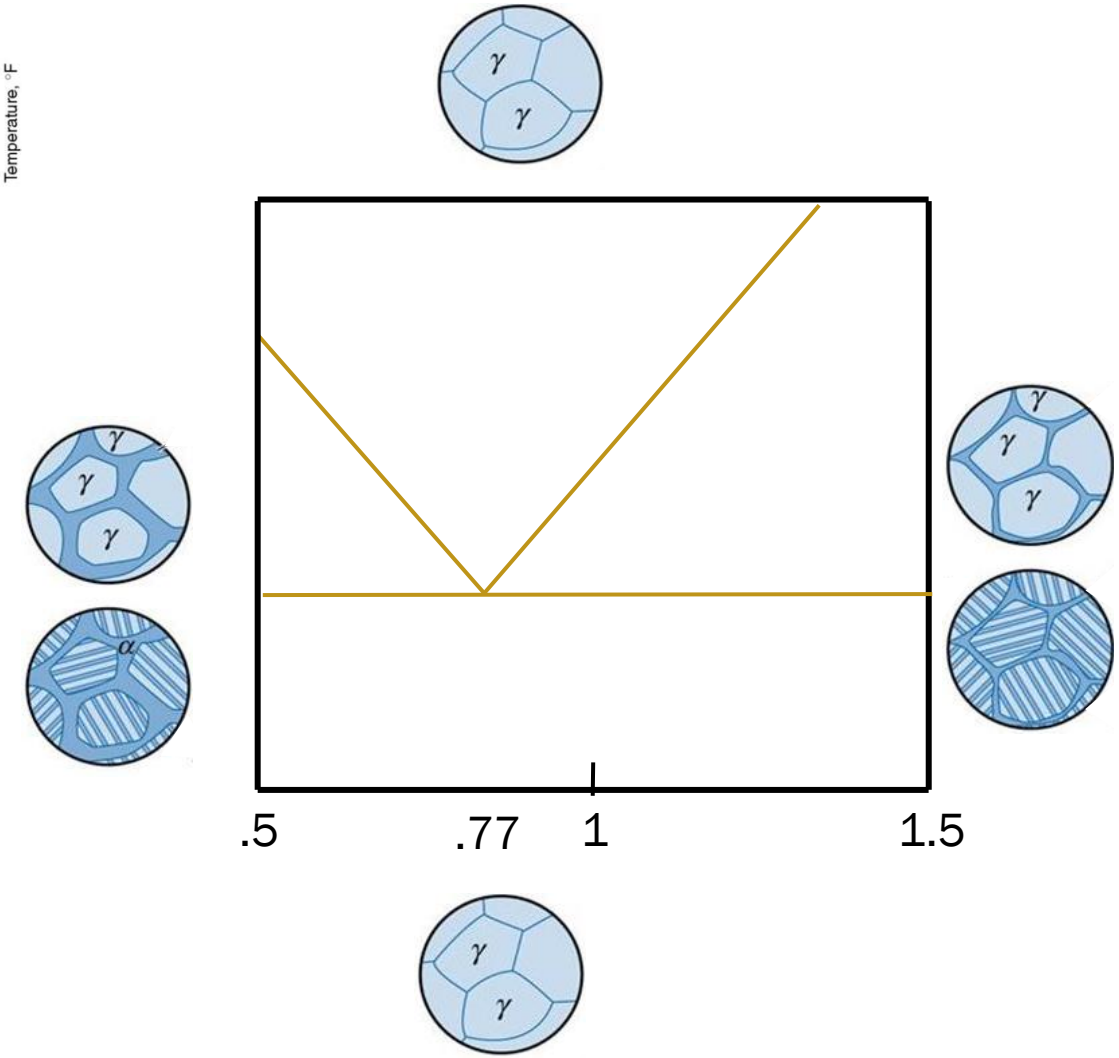
- Phases
  - Ferrite –
  - Austenite –
  - Cementite –

- Microconstituents
  - Pearlite -
  - Martensite -
  - Bainite -



Iron-Carbon Phase Diagram

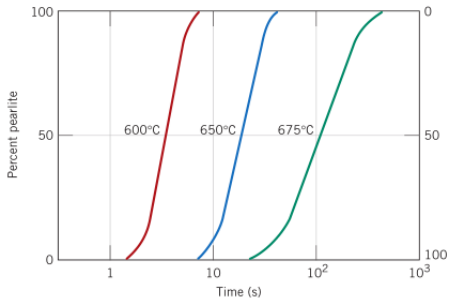


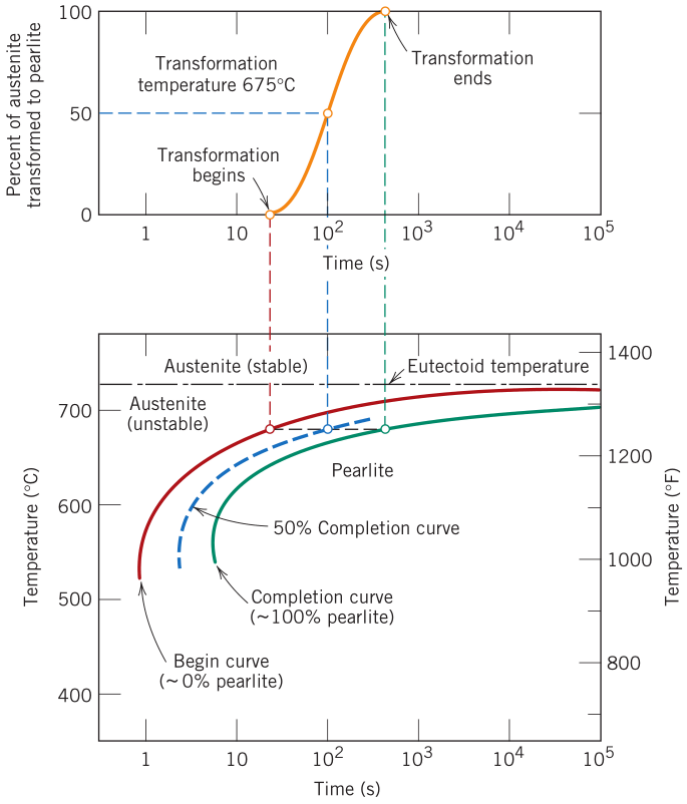


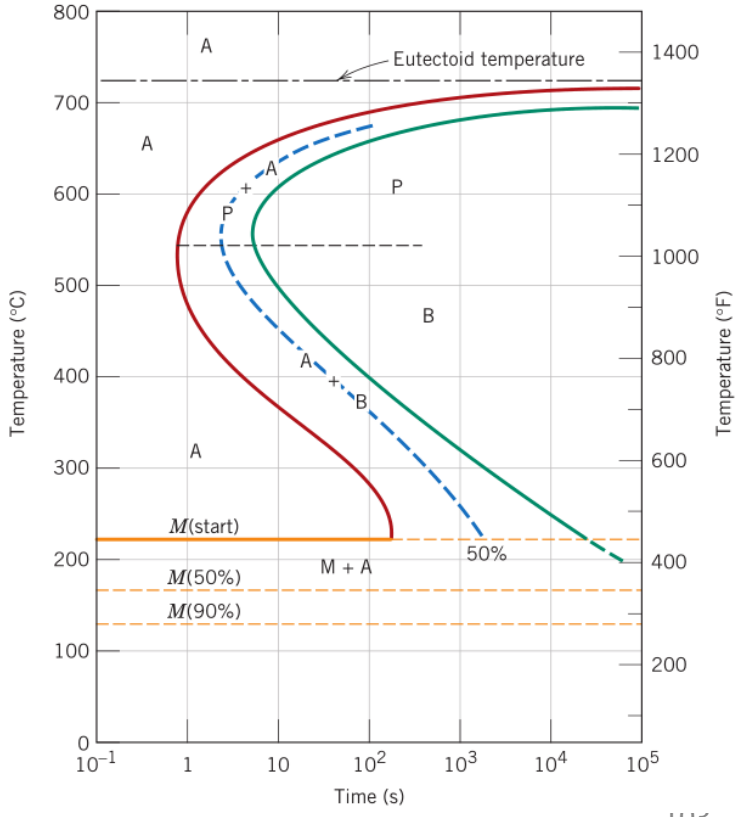
TTT Diagram

Consider microstructure resulting from

1. Rapid cool to 350°C hold for 10^4s, then quench
2. Rapid cool to 250°C, hold for 100s, then quench
3. Rapidly cool to 650°C, hold for 20s, rapidly cool to 400°C, hold for 10^3s, then quench

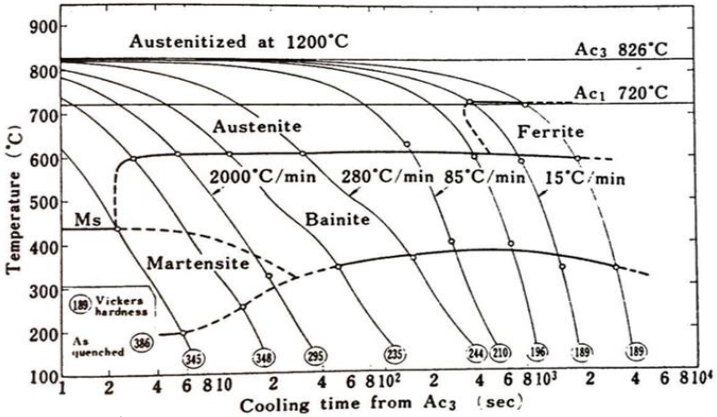




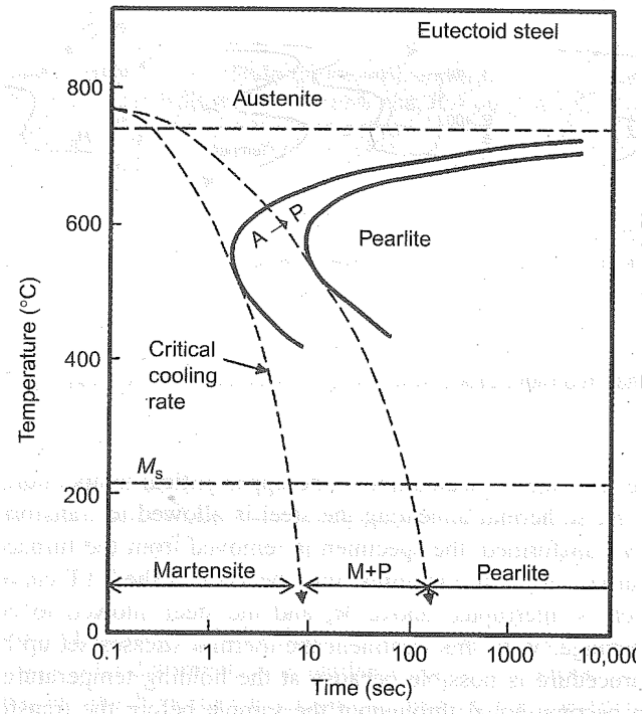


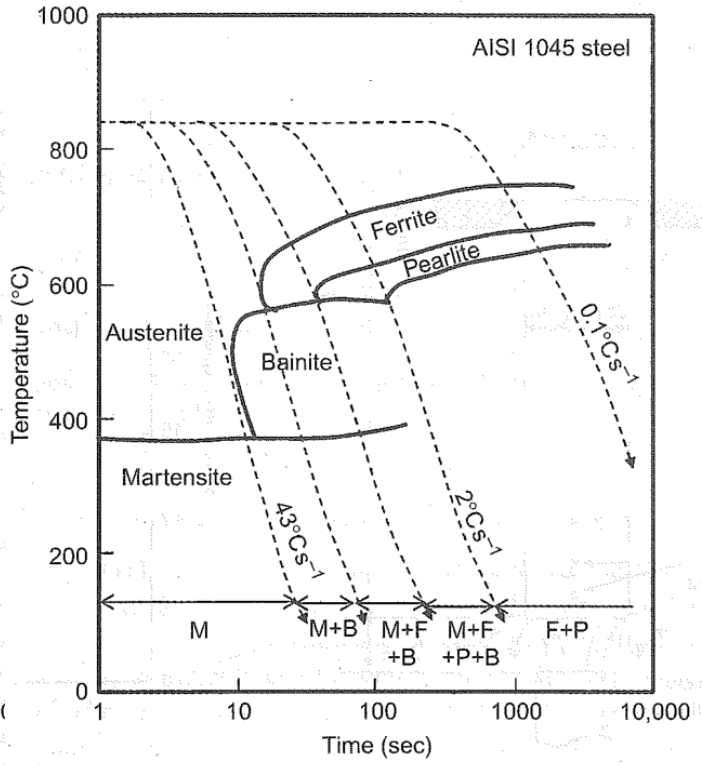
Adapted from *Callister 8e.*

CCT Diagram



Atlas of Time Temperature Diagrams for Irons and Steels, Vander Voort

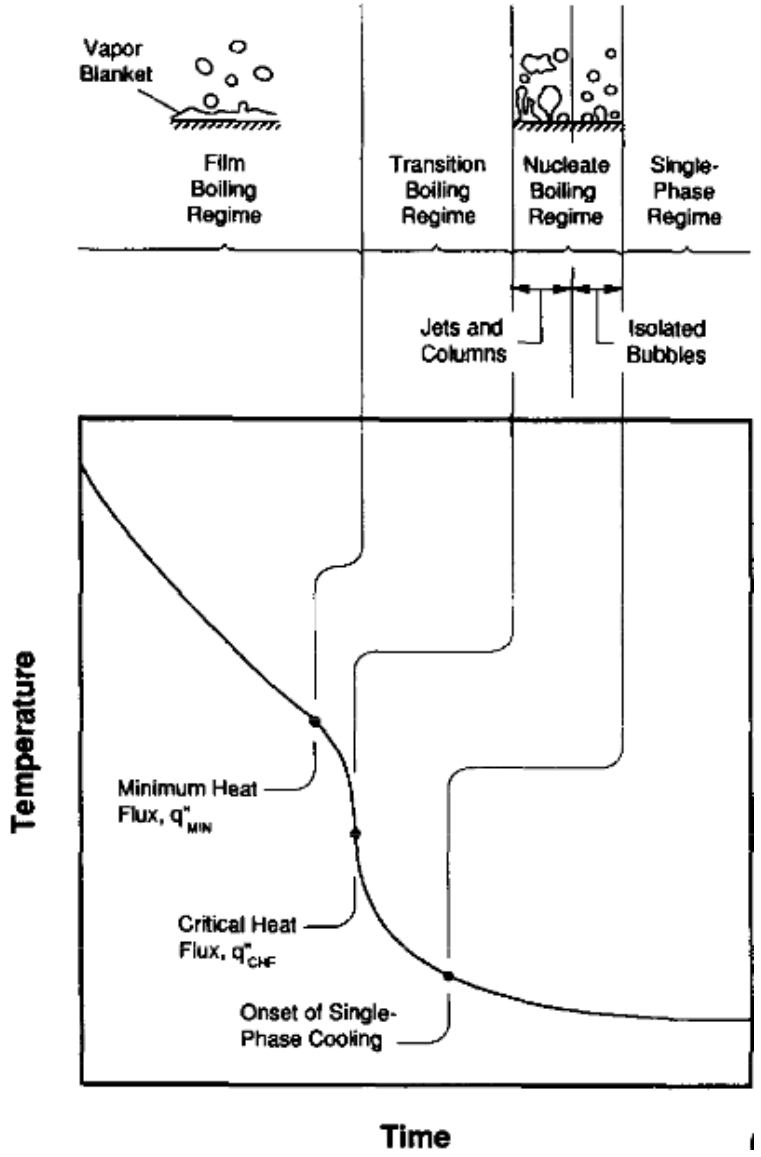




Modern Physical Metallurgy, Smallman and Ngan, 8th ed., 2014

Quenching

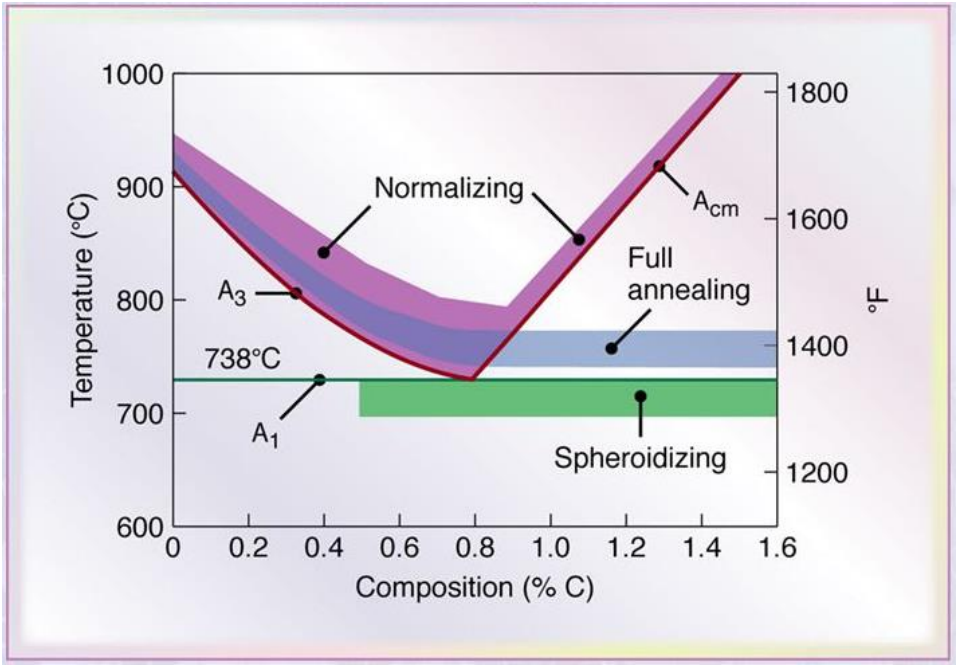
- Various quenching media are used to affect cooling rate
  -
  -
  -
  -
- Die quenching



Hall and Mudawar, Int. J. Heat Mass Transfer, 1994

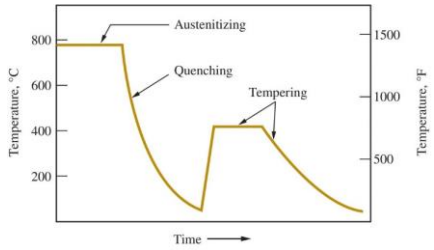
Annealing - Steels

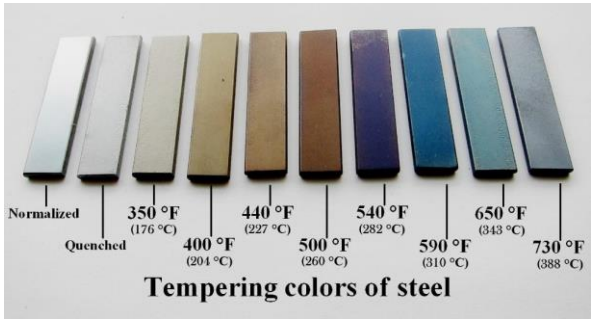
- Full Annealing
- Process Annealing
- Spheroidizing



- Normalizing

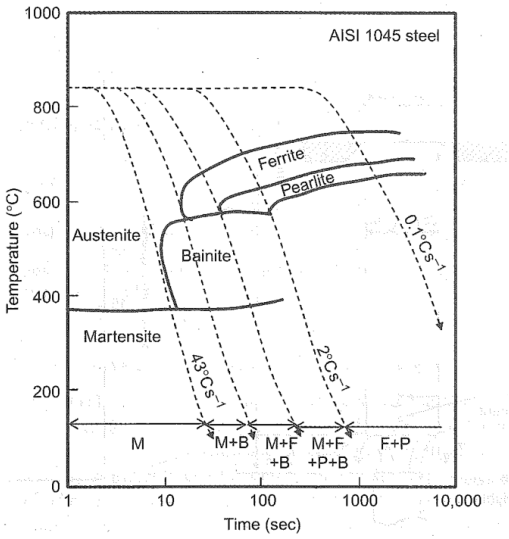
Tempering



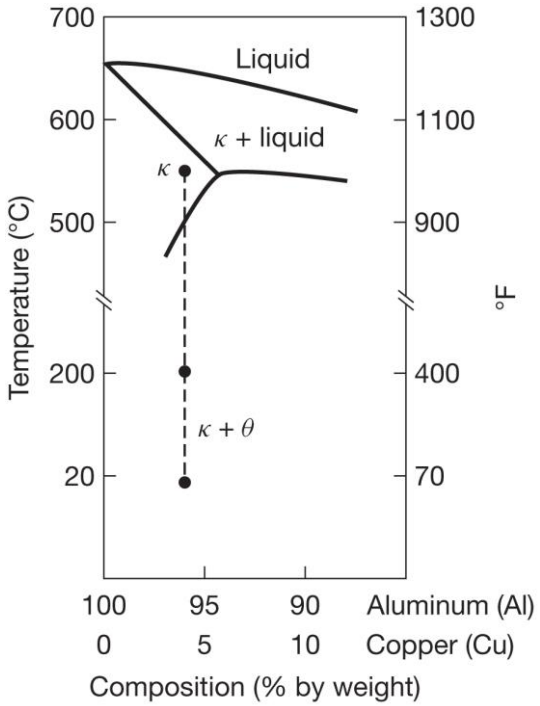


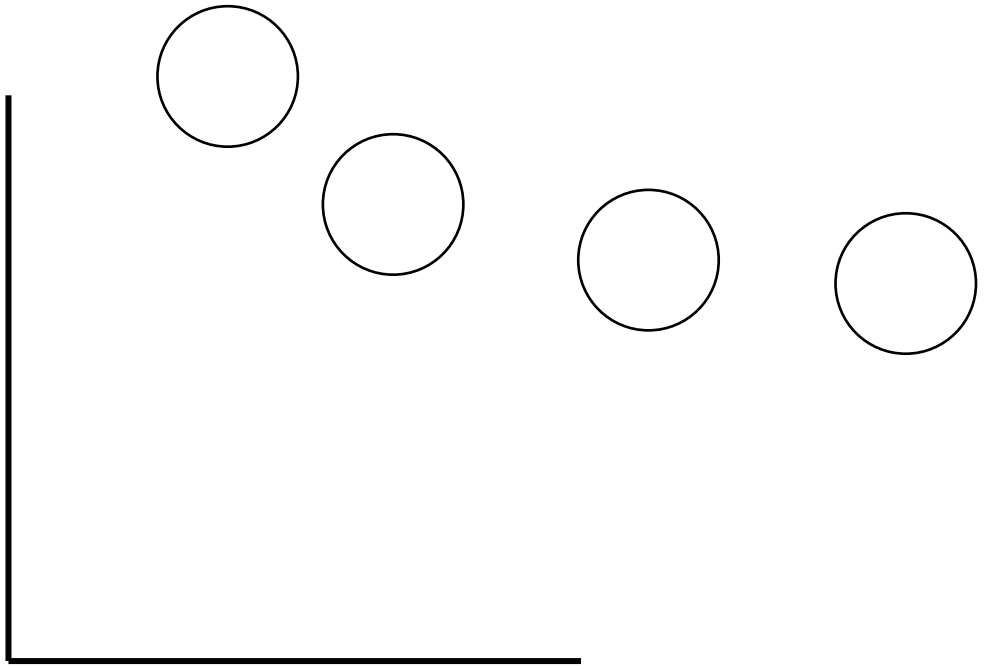
Zaereth
https://commons.wikimedia.org/w/index.php?curid=18561876

- Austempering
- Martempering
- Maraging



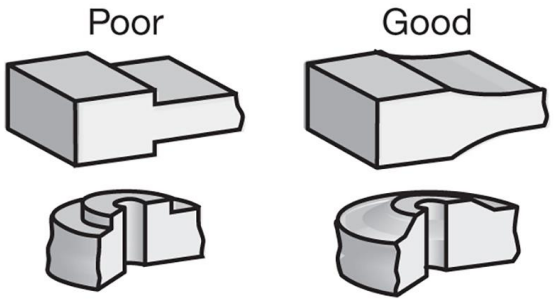
Heat Treating Non-Ferrous Materials



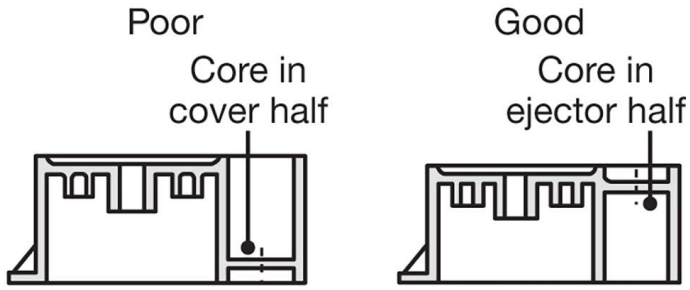


- Solution Treatment
- Precipitate/Age Hardening

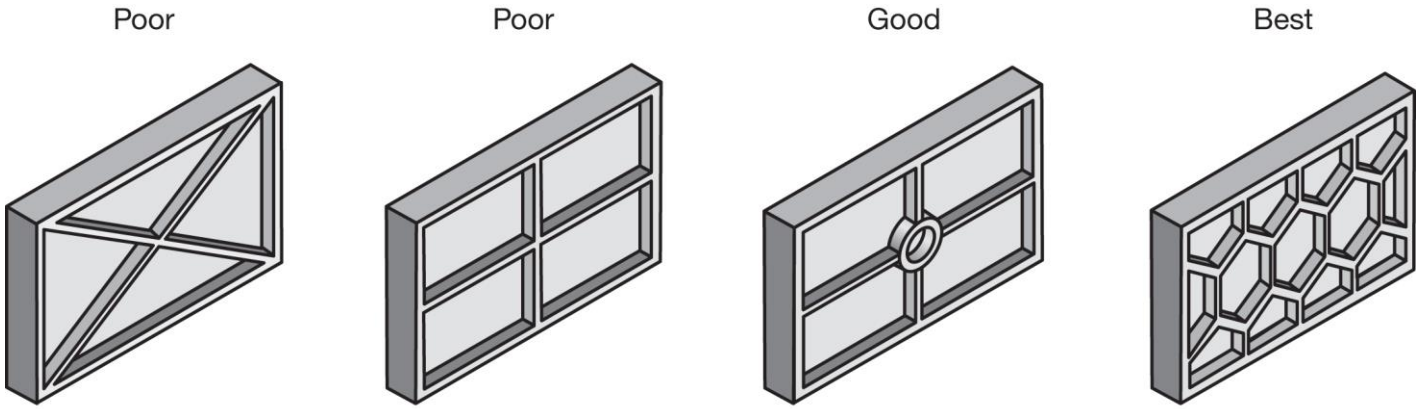
Design Considerations



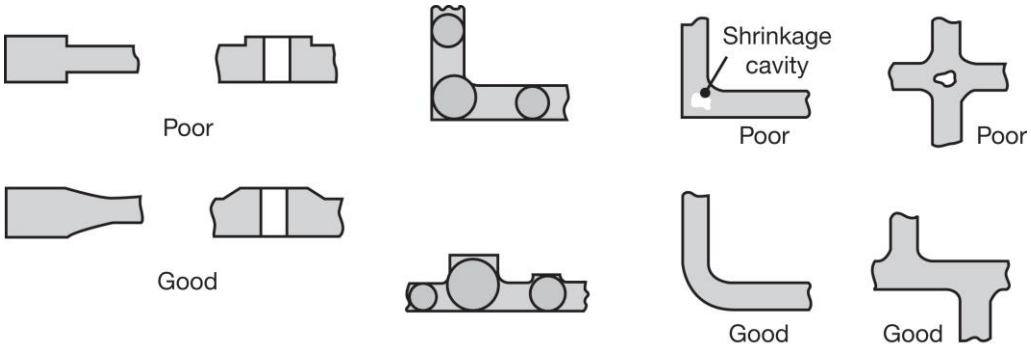
Using radii or fillets to avoid corners and provide uniform cross section.

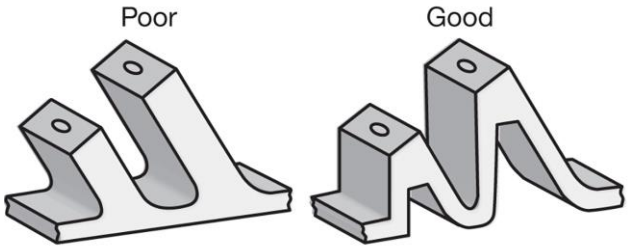


Deep cavities should be on one side of the casting where possible.

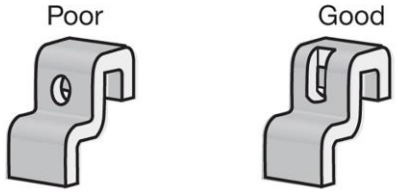


Design Considerations 2

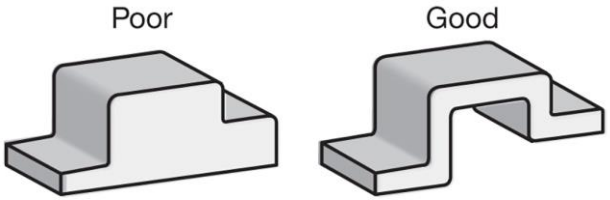




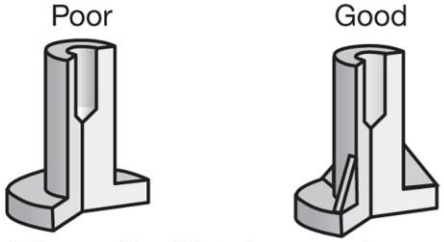
Sloping bosses can be designed for straight die parting to simplify die design.



Side cores can be eliminated with this hole design.

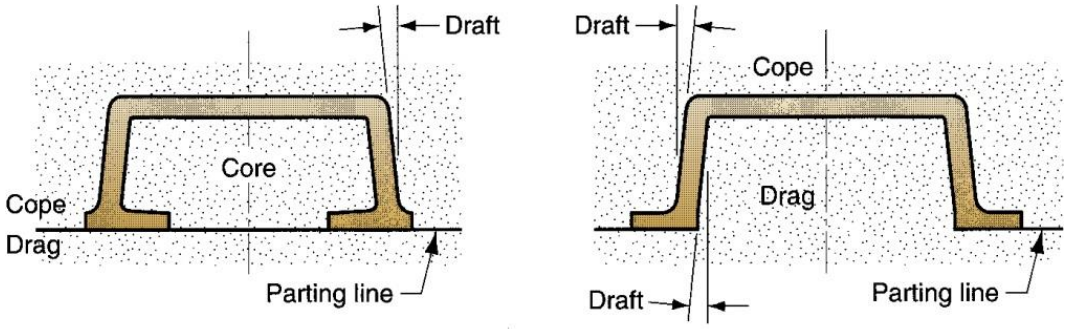


Wall sections should be uniform.



Ribs and/or fillets improve bosses.

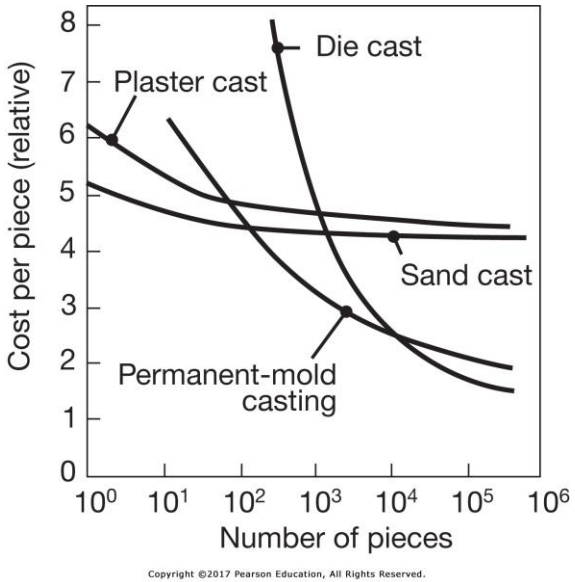
Design Considerations 3



Groover 6th ed.

- Geometry
- Allowances
- Draft
- Dimensional Tolerance

Economic Considerations



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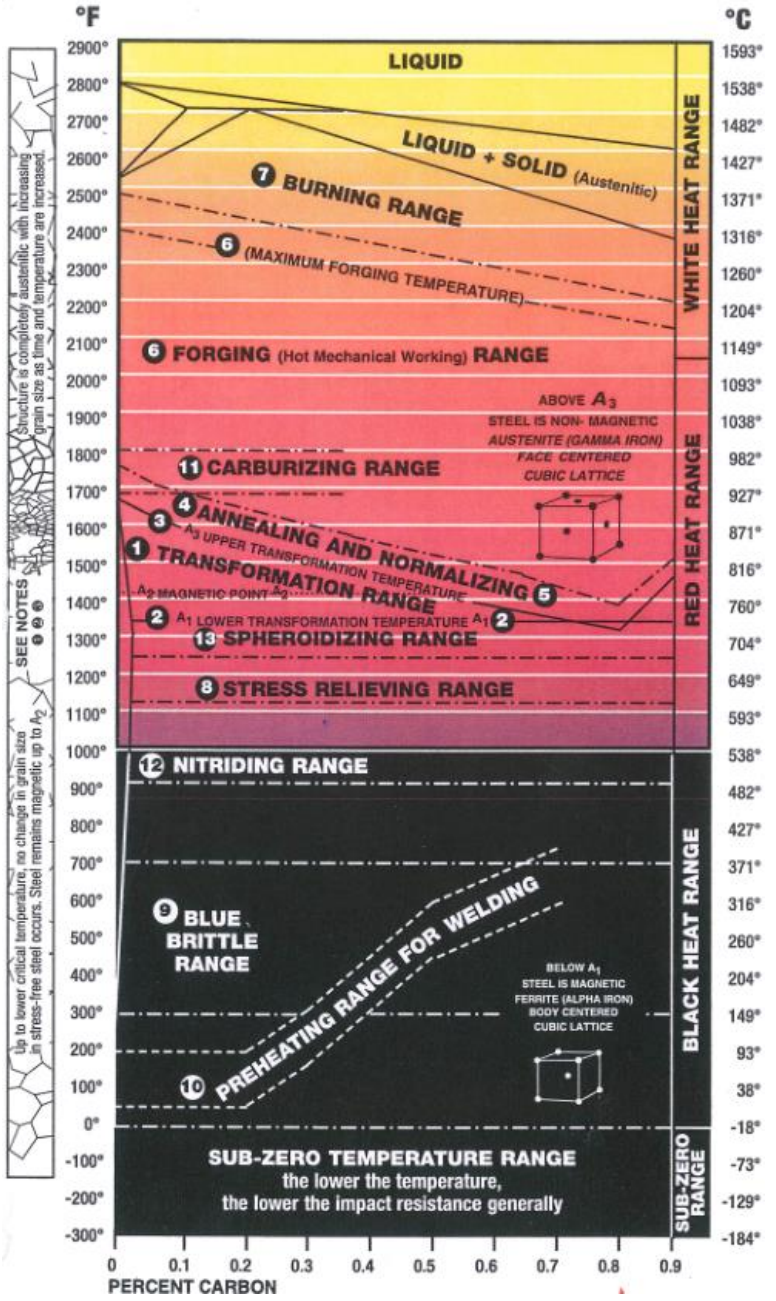
Heat Treating Equipment

Design for heat treating

- Avoid cracking warping, non-uniform properties (unless desired)
- Cooling rate must be uniform
- Guidelines, uniform thickness (or transition between sections of different thicknesses should be gradual)
- Avoid internal or external sharp corners
- Be aware that holes, grooves, keyways, splines etc. may be difficult to heat treat/crack during quenching
- Large surfaces with thin cross sections may warp

Color Chart


°F
°C
LIQUID
LIQUID + SOLID (Austenitic)
7 BURNING RANGE
6 (MAXIMUM FORGING TEMPERATURE)
6 FORGING (Hot Mechanical Working) RANGE
WHITE HEAT RANGE
ABOVE A_3
STEEL IS NON- MAGNETIC
AUSTENITE (GAMMA IRON)
FACE CENTERED
CUBIC LATTICE
11 CARBURIZING RANGE
4 ANNEALING AND NORMALIZING 5
3 A_3 UPPER TRANSFORMATION TEMPERATURE
1 TRANSFORMATION RANGE
A_2 MAGNETIC POINT A_2
2 A_1 LOWER TRANSFORMATION TEMPERATURE A_1 2
13 SPHEROIDIZING RANGE
RED HEAT RANGE
8 STRESS RELIEVING RANGE
12 NITRIDING RANGE
9 BLUE BRITTLE RANGE
PREHEATING RANGE FOR WELDING
BELOW A_1
STEEL IS MAGNETIC
FERRITE (ALPHA IRON)
BODY CENTERED
CUBIC LATTICE
10
BLACK HEAT RANGE
SUB-ZERO TEMPERATURE RANGE
the lower the temperature,
the lower the impact resistance generally
SUB-ZERO RANGE
SEE NOTES 1 2 3
Up to lower critical temperature, no change in grain size. Steel remains magnetic up to A_2
Structure is completely austenitic with increasing grain size as time and temperature are increased.
2900° 2800° 2700° 2600° 2500° 2400° 2300° 2200° 2100° 2000° 1900° 1800° 1700° 1600° 1500° 1400° 1300° 1200° 1100° 1000° 900° 800° 700° 600° 500° 400° 300° 200° 100° 0° -100° -200° -300°
1593° 1538° 1482° 1427° 1371° 1316° 1260° 1204° 1149° 1093° 1038° 982° 927° 871° 816° 760° 704° 649° 593° 538° 482° 427° 371° 316° 260° 204° 149° 93° 38° -18° -73° -129° -184°
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
PERCENT CARBON