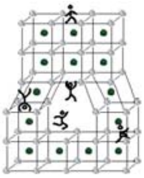
Metals

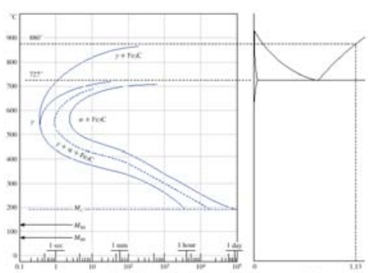


Wednesday, Oct. 15, 2003

MATS275: INTRODUCTION TO MATERIALS SCIENCE

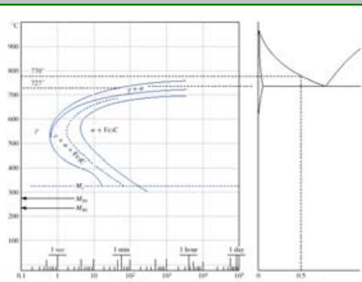
- Annealing Steels
- How Steel is Made
- Alloy Steels
- Stainless Steel
- Non-Ferrous Metals
  - Aluminum
  - Magnesium
  - Titanium
  - Copper
  - Nickel
  - Others

Hypereutectoid Steel



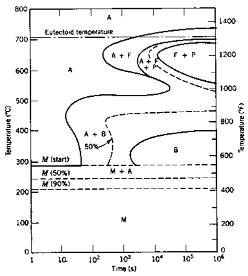
1.13 % C

Hypoeutectoid Steel



0.5 % C

4340 Alloy Steel



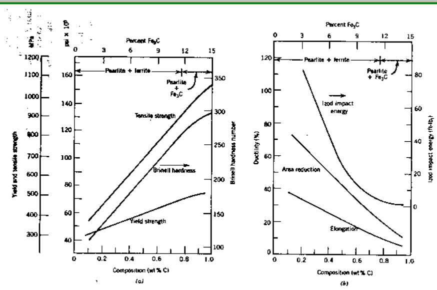
Rules of Thumb

- Cementite
- Martensite
  - hard but brittle
- Ferrite
  - ductile and soft - machinable

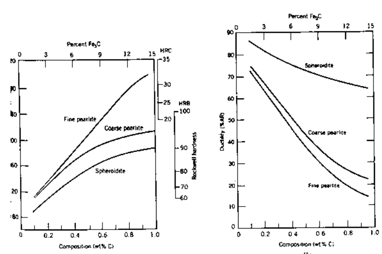
Characteristics of Phases

- Pearlite
  - ferrite mixed with cementite - makes it hard
- Fine Pearlite
  - even harder and stronger
    - grain boundary adhesion
    - grain size strengthening
- Spheroidite
  - hard & strong because of small grains, but also ductile

Pearlite
Effect of Carbon Content



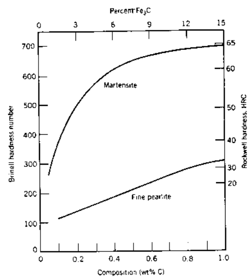
Pearlite & Spheroidite



Characteristics of Phases

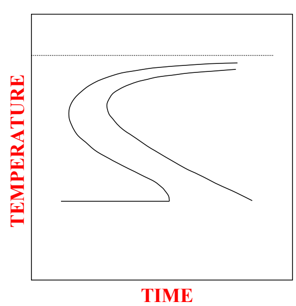
- Martensite
  - hardest and strongest
    - alloy effects (rather than grain size)
    - few slip directions in BCT
  - most brittle - almost unusable
    - quenching can lead to cracking
    - swelling due to BCT

Martensite



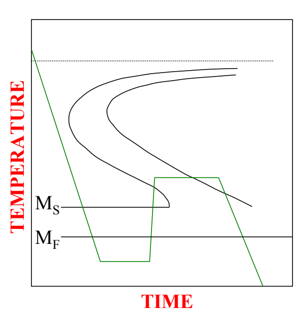
TEMPERING

- Martensite converts to small grains of cementite in ferrite - help to reinforce it.



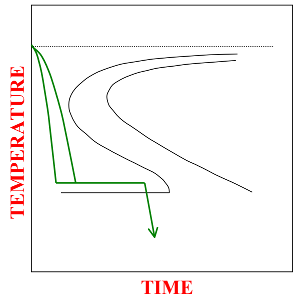
TEMPERING

- **Martensite converts to small grains of cementite in ferrite - help to reinforce it.**
- ***Spheroidite***
- **Thermal stresses on quench can cause cracking.**



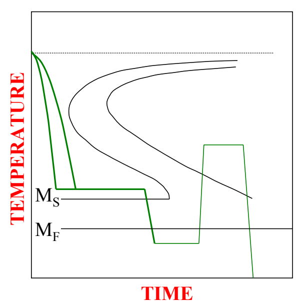
MARTEMPERING

- Hold just above Martensite temperature to equilibrate



MARTEMPERING

- **Hold just above Martensite temperature to equilibrate**



Annealing

- Process Anneal
  removes effects of work-hardening, restores ductility
  - Stress Relief
  - Normalizing
- Full Anneal

Iron & Steel

- 2.0 - 4.5 wt % C = Cast Irons
- 0.05 - 2.0 wt % C = Steel
  - >5 wt % other elements = high-alloy steel
  - <5 wt % other elements = low-alloy steels
- *>90 wt % of the metallic materials used by humans are ferrous alloys*

ρ = 7.87 g/cc, BCC, T_m = 1538°C

How To Get Steel

- Coke + iron ore into blast furnace.
  - Reduction Rxn $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$
- Pig iron transferred to oxygen furnace.

$$FeO + C \rightarrow Fe + CO$$

  - Before reaction starts, lime is added as a flux
  - Alloying elements added

Why Alloys?

- **Plain carbon steels cannot be strengthened past 100,000 psi without a substantial loss in ductility and impact resistance.**
- **Large area pieces of plain carbon steel are subject to temperature gradients - non-uniform martensite formation.**
- **Plain carbon steels are more easily oxidized and corroded.**
- **Plain carbon steels are less impact resistant at low temperatures.**
- **Some plain carbon steels must be quenched so rapidly that warping and/or cracking become a problem.**

What Alloys?

AISI#	Elements	AISI#	Elements
13xx	Mn	5xxx	Cr
40xx	Mo or Mo & S	61xx	Cr, V
41xx	Cr, Mo	86xx	Ni, Cr, Mo
43xx	Ni, Cr, Mo	87xx	Ni, Cr, Mo
44xx	Mo	88xx	Ni, Cr, Mo
46xx	Ni, Mo	92xx	Si or Si & Cr
47xx	Ni, Cr, Mo		
48xx	Ni, Mo		

AISI = American Iron and Steel Institute
SAE = Society of Automotive Engineers

What Alloys Do

	Dissolve in Ferrite	Dissolve inCarbide	Form Carbide	Form Compound
Ni	○			
Si	○			$SiO_2 \cdot M_xO_y$
Mn	○	○	$(Fe,Mn)_3C$	$MnS, MnO \cdot SiO_2$
Cr	○	○	$(Fe,Cr)_3C$	
Mo	○	○	Mo_2C	
W	○	○	W_2C	
V	○	○	V_4C_3	
Ti	○	○	TiC	

Other Treatments of Steels

- Carburizing and Nitriding
  - anneal in CH_4, CO, or CO_2
  - anneal in NH_3
- Case Hardening
  - flame heat outside to form Martensite

form areas that are susceptible to fatigue and wear but not necessarily shock

Stainless Steels

- ALL have at least 12% Cr
- Ferritic - up to 30% Cr, <0.12% C
  - low cost, good strength …structural uses
- Martensitic - 12-17% Cr, 0.15-1.0 % C
  - hard, resists corrosion … knives, bearings, etc.
- Austenitic - <0.03% C, 7 - 20% Ni
  - resists corrosion, non-magnetic, expensive

Aluminum Alloys

- Formed by Hall-Herault process
  - electrolytic reduction of Al_2O_3
- Abundant and inexpensive
- Light Weight
- Corrosion Resistant
- Non-Toxic

ρ=2.71 g/cc, FCC, T_m=660.4°C

Magnesium Alloys

- Extracted from Chlorides in Sea Water
- Very Reactive With Air
- More Expensive Than Al
- Light Weight
- hcp So Not Very Ductile

ρ = 1.74 g/cc, HCP, T_m = 649°C

Titanium Alloys

- Separated at High Temperature From Ore
- Very Expensive
- Corrosion Resistant (TiO_2)
- Light Weight
- hcp up to 882°C then bcc
- Embrittled by Light Elements at High Temp

ρ = 4.51 g/cc, HCP, T_m = 1668°C

Copper Alloys

- Separated From Ore by Melting
  - slag drained off
- Highly Conductive
- Ductile
- Alloys
  - Cu-Zn = Brass
  - Cu-Sn = Bronze
  - Cu-Be = spring copper

ρ = 8.94 g/cc, FCC, T_m = 1084°C

Nickel Alloys

- Derived from ore
- Used in High T Alloys
  - Monel = Ni/Cu
  - Inconel = Ni/Cr/Fe
  - Hastelloy = Ni/Mo/Fe/Cr
  - Superalloy = Ni/Al
- Corrosion Resistant

ρ = 8.90 g/cc, FCC, T_m = 1453°C

Zinc, Lead, and Others

- Zinc
  - Galvanization
- Lead
- Refractory Metals
  - Mo, Rh, Ta, W
- Precious Metals
  - Au, Ag, Pd, Pt