J. Jeswiet lectures, 2005 edition.

The fine print

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Lecture 21

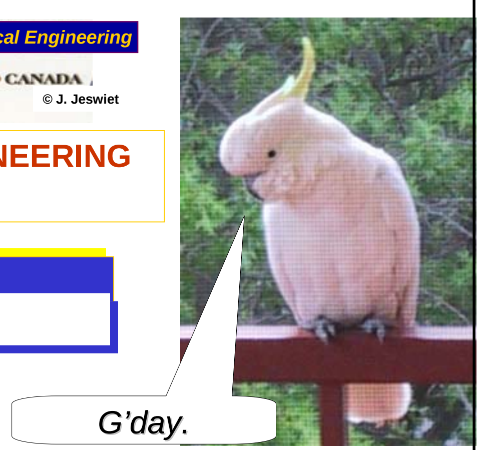
Queen's University, Mechanical Engineering

KINGSTON • ONTARIO • CANADA

MANUFACTURING ENGINEERING
MECH 213

Topic:

STEEL II



The last day we ended with definitions of the different carbon ranges for steels

Low carbon steel:	0.10 – 0.30 %C
Medium carbon steel:	0.30 – 0.85 %C
High carbon steel:	0.85 – 1.3 %C

Classification of Steels

- Various countries adopt their own standards for classifying steels
- In North America the four digit system of the AISI and SAE is used

- In the SAE and AISI methods of numbering

  the first two numbers indicate the level of alloying

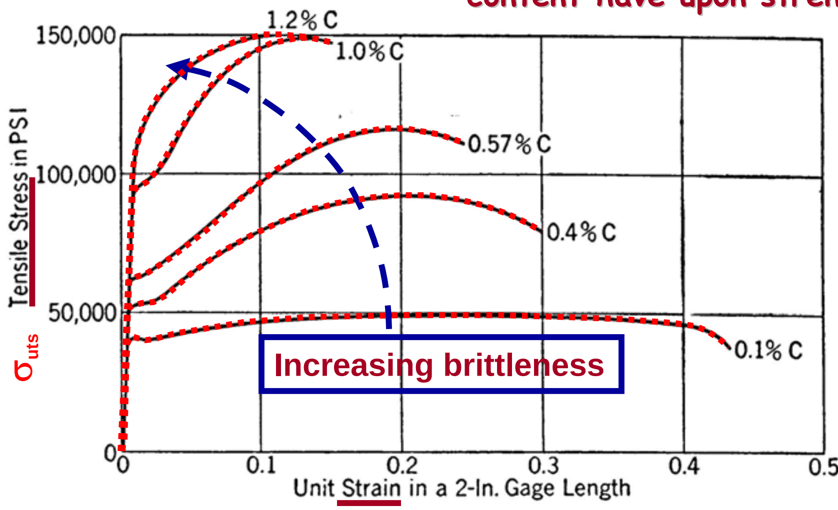
  the last two digits indicate carbon content in hundredths of a percent by weight

1020

low alloying 0.20 wt% C

Question:

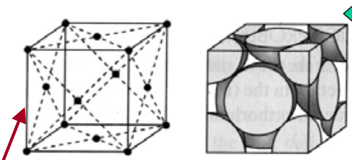
What effect does increasing carbon content have upon strength?



Stress-strain diagrams for typical hot-worked iron-carbon alloys.

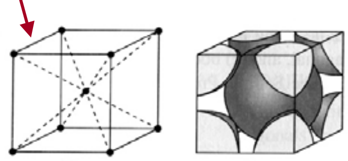
Now consider the Iron – Carbon Phase Diagram

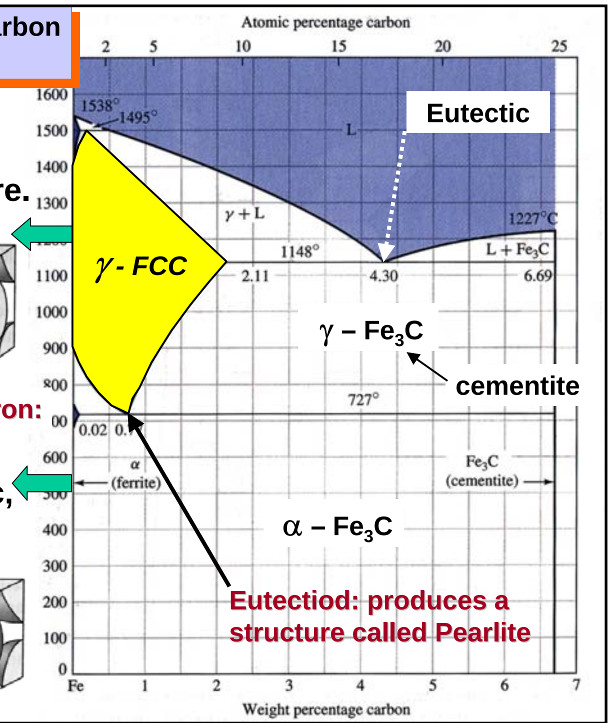
- **Austenite, γ, has a face-centred cubic , FCC, crystal structure.**



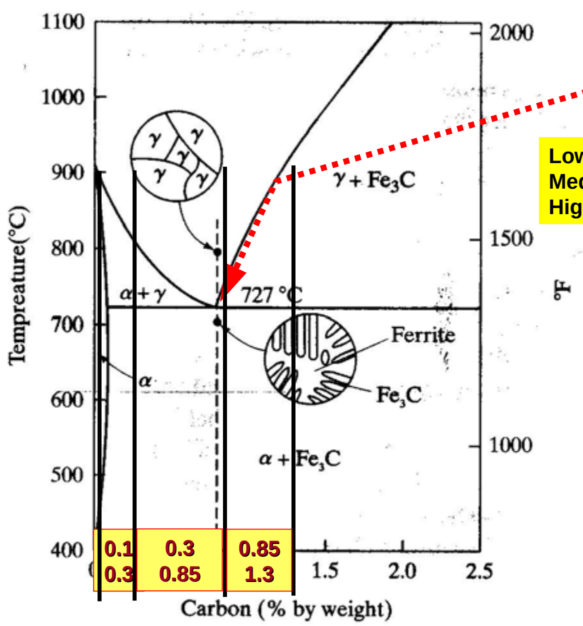
useful allotropic forms of iron:

- **Ferrite, α, has a body-centred cubic, BCC, structure.**





The Eutectoid is very important in steel making



Eutectoid, Pearlite,

$\alpha - Fe_3C$

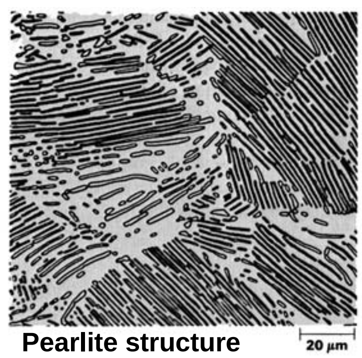
Low carbon steel:	0.10 – 0.30 %C
Medium carbon steel:	0.30 – 0.85 %C
High carbon steel:	0.85 – 1.3 %C

Schematic illustration of the microstructures for an iron–carbon alloy of eutectoid composition (0.77% carbon), above and below the eutectoid temperature of 727 °C (1341 °F).

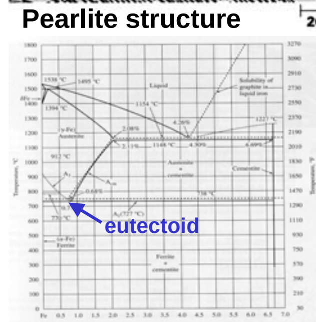
Steel Crystal Structures

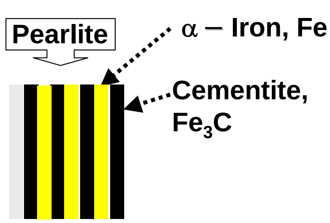
Pearlite

- **Pearlite is made up of cementite (Fe_3C) lamellae, and ferrite (Fe).**
- **cementite is black and ferrite is white in this figure.**
- **100% Pearlite occurs at the eutectiod. To the left of the eutectiod, ferrite increases and pearlite decreases**
- **To the right of the eutectiod, the amount of cementite increases**



Pearlite structure



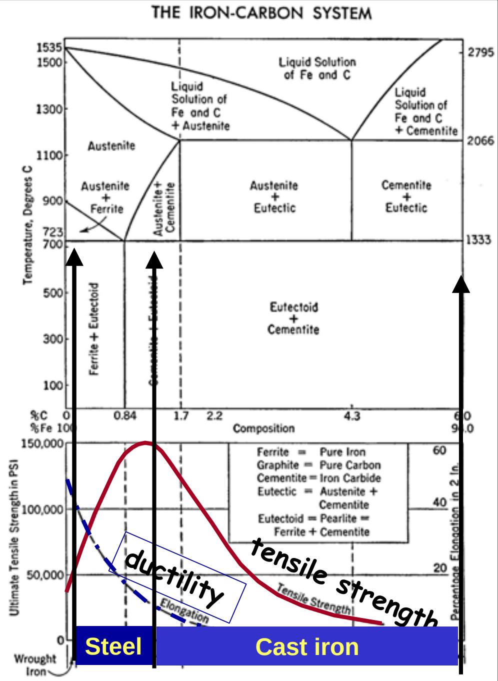


Low carbon steel; 0.10 – 0.30 %C

Medium carbon steel: 0.30 – 0.85 %C

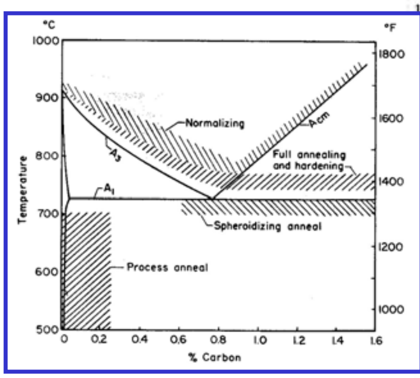
High carbon steel: 0.85 – 1.3 %C

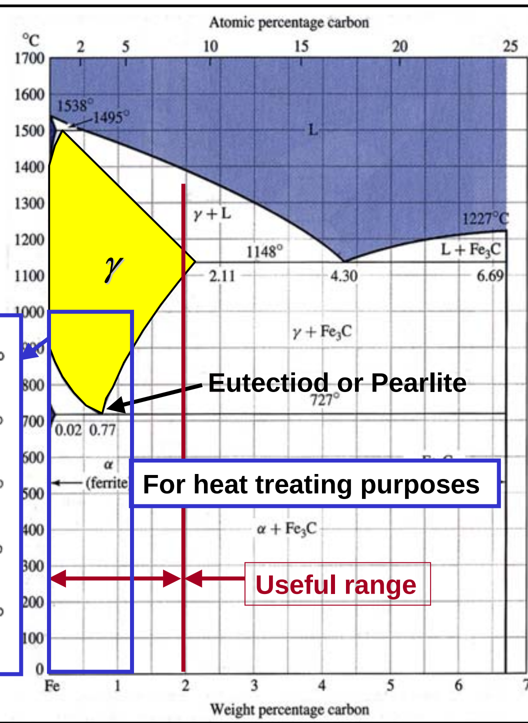
Observe what happens as carbon content increases:



Equilibrium diagram and properties of the iron-carbon syste

Iron Carbon Diagram



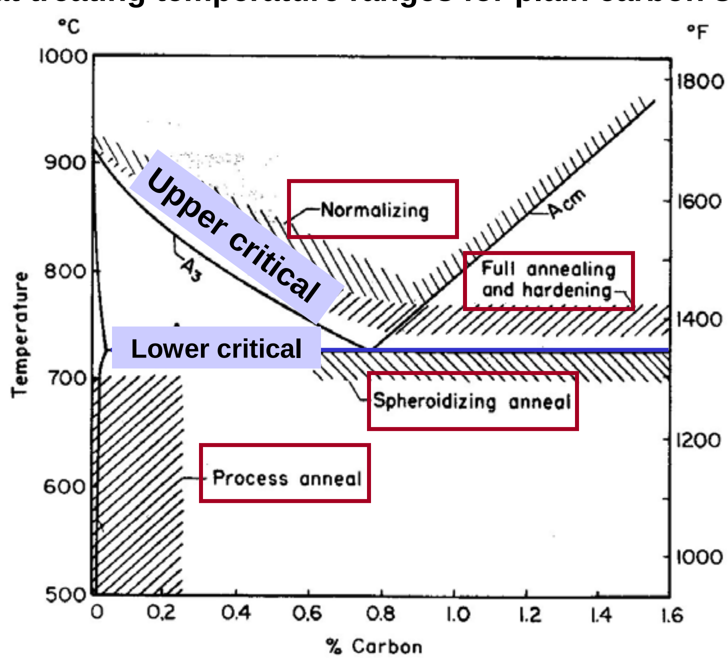


Important types of Heat Treatment in Steel are:

- **Normalizing**
- **Annealing**
- **Full Anneal**
- **Process Anneal**
- **Spheroidizing Anneal**

See the appendix for today's lectures to see definitions.

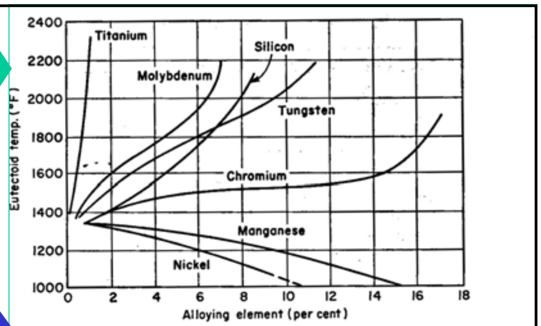
Heat treating temperature ranges for plain carbon steels



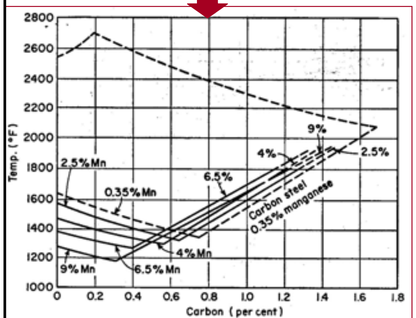
Alloying has an effect upon the Eutectoid Temperature

and upon the carbon content

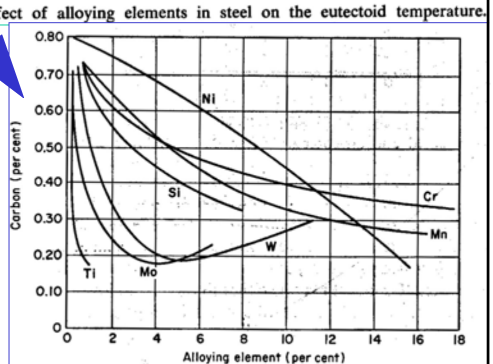
and upon the size of the austentitic zone



Effect of alloying elements in steel on the eutectoid temperature.



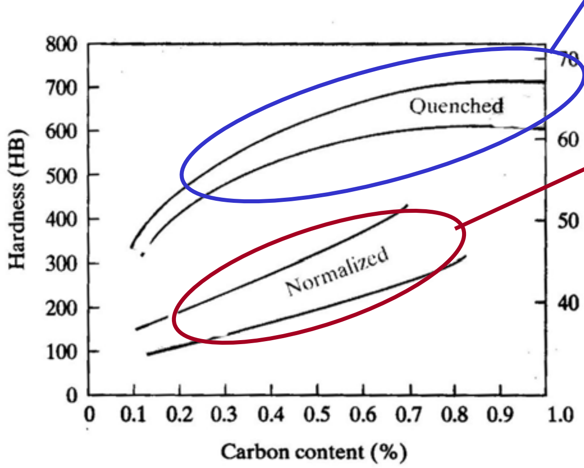
Effect of manganese on the austenite phase region.

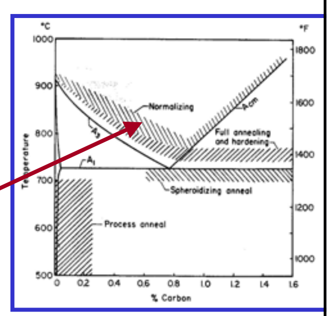


Effect of elements on the carbon content of the eutectoid.

The rate of cooling can also have a large effect upon the microscopic structure of the steel

martensitic structure



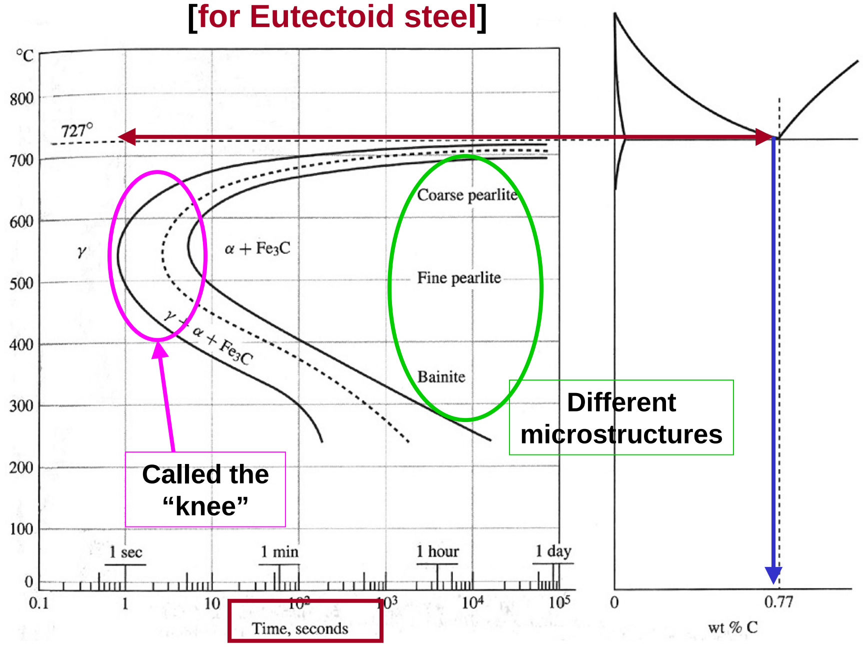


Hardness of steels in the quenched and normalized conditions, as a function of carbon content.

Phase diagrams are equilibrium diagrams & are derived by cooling slowly

- However, if the alloy is cooled at faster rates, different micro-structures and properties can be achieved
- Time, the rate at which cooling occurs, temperature of the solution and transformation are all inter-related
- This give us another diagram called the TTT diagram

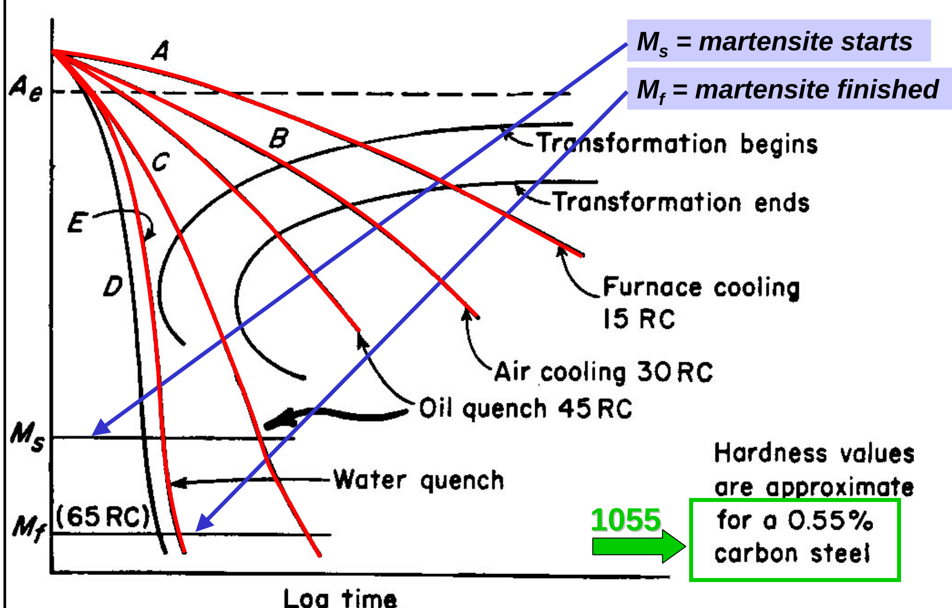
Time Temperature Transformation – TTT [for Eutectoid steel]



Time Temperature Transformation

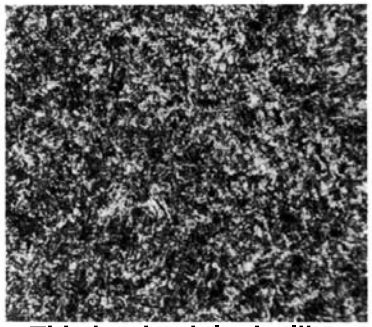
- The knee of the TTT diagram indicates where changes in microstructure begin to occur.
- If the temperature of the steel can be lowered quickly enough a change in microstructure can be avoided until it is desired; changes can be "frozen" for a while
- In general the faster the steel is quenched the harder it will become
- Because rapid cooling can cause thermal stresses (and cracking) a balance must be achieved between rapid cooling and stress relief

Some examples of cooling curves



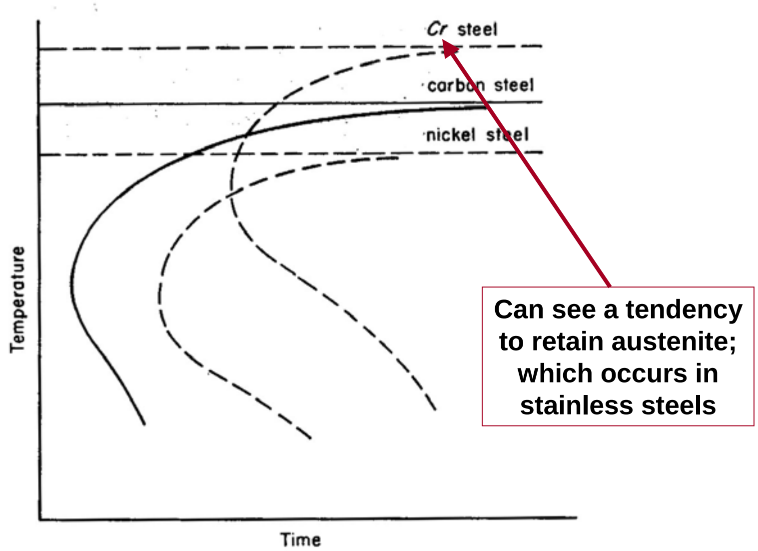
Steel Crystal Structures

- Martensite forms only when steel is quenched quickly enough to reach 225°C, without forming pearlite or bainite first.
- It is the hardest of all steel crystal structures.
- As-quenched it has very high strength, but has very low fracture resistance, or toughness.



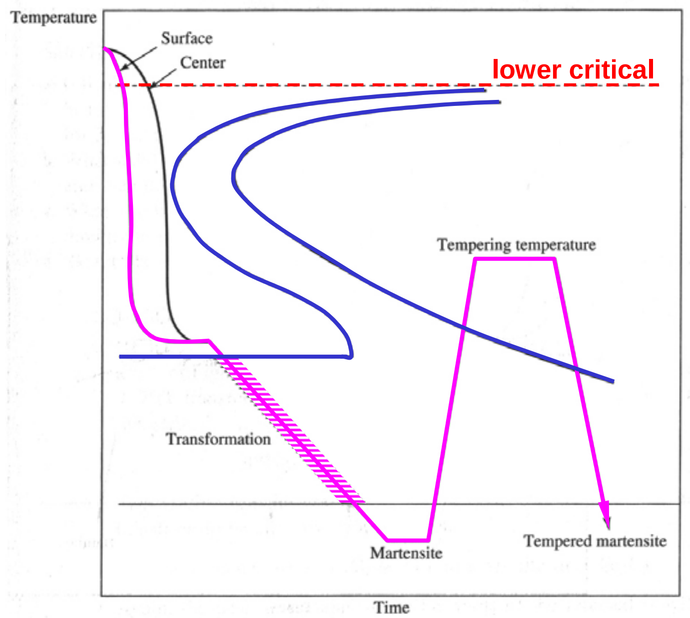
This is what it looks like under 500X magnification

The TTT curves are also affected by the alloy content



Schematic effect of nickel and chromium on the isothermal transformation diagram.

Quenching & Tempering; some strategies



Tempering

- This consists of reheating the steel to a given temperature to allow formation of one or a combination of the following:

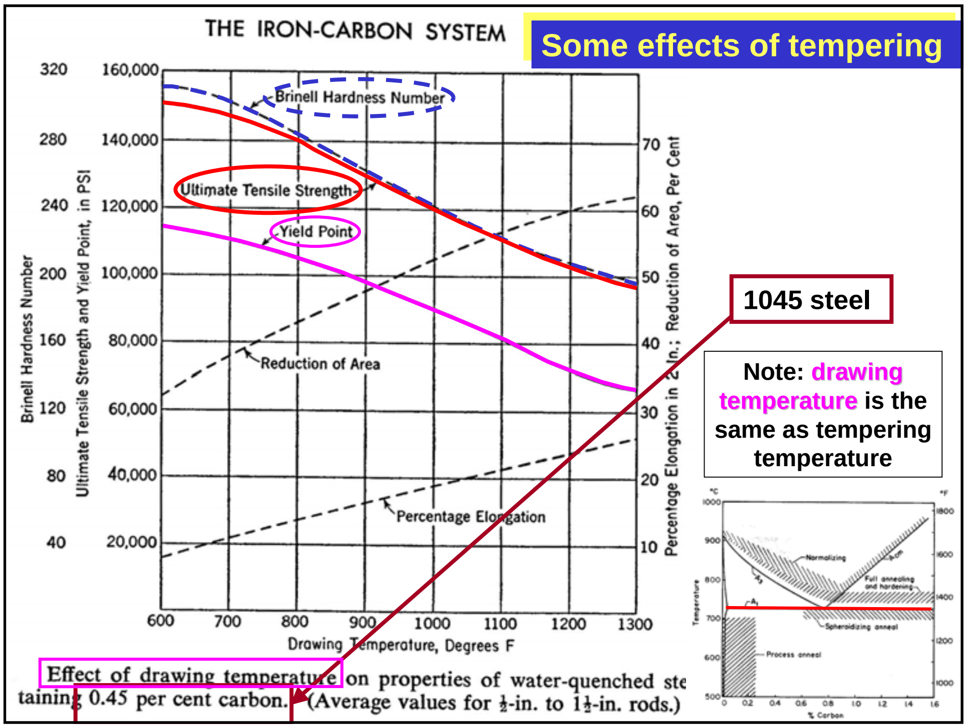
  cementite,

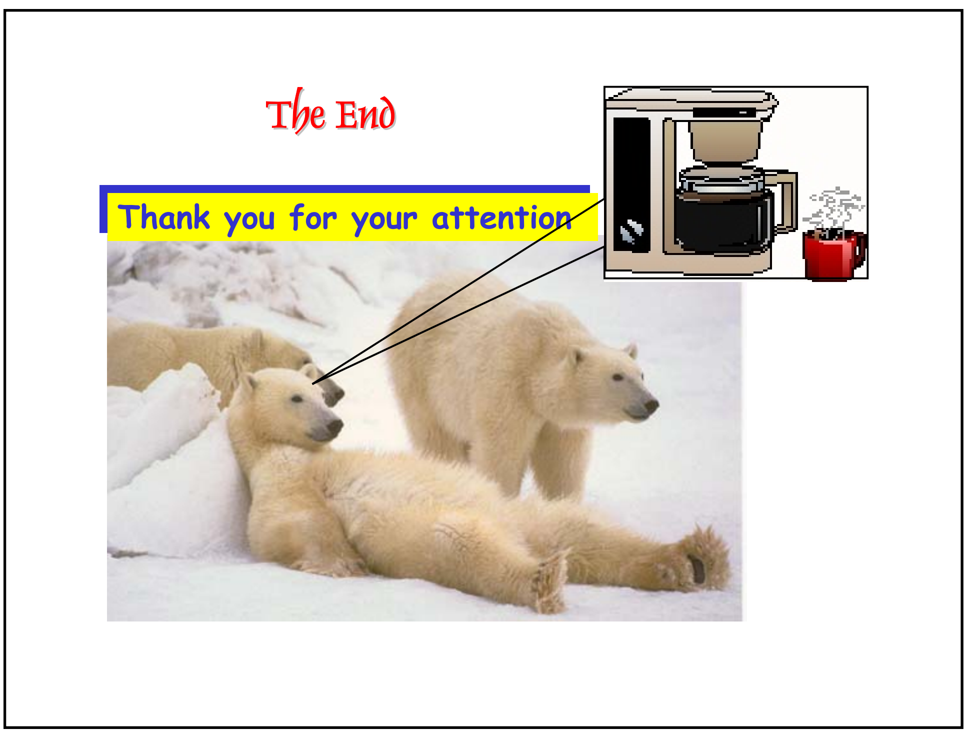
  ferrite,

  spheroidization [clustering of carbon atoms],

  carbides in the case of alloying elements,

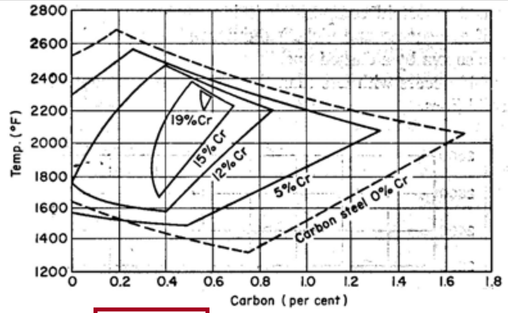
  new microstructures (such as bainite or pearlite)
- The chief goal of tempering is to toughen the steel and decrease its brittleness
- a tempering stage is often applied in the case of martensitic steels


THE IRON-CARBON SYSTEM
Some effects of tempering
Brinell Hardness Number
Ultimate Tensile Strength and Yield Point, in PSI
Percentage Elongation in 2 in.; Reduction of Area, Per Cent
Brinell Hardness Number
Ultimate Tensile Strength
Yield Point
Reduction of Area
Percentage Elongation
Drawing Temperature, Degrees F
1045 steel
Note: drawing temperature is the same as tempering temperature
Effect of drawing temperature on properties of water-quenched ste
taining 0.45 per cent carbon. (Average values for ½-in. to 1½-in. rods.)

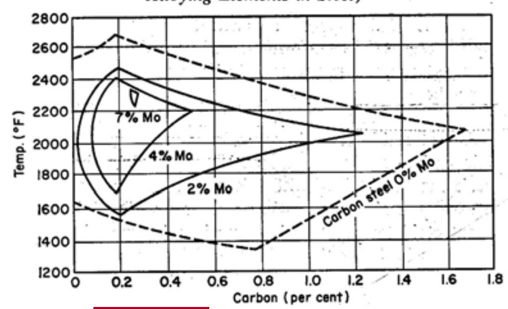

The End
Thank you for your attention

Two Alloys which are used for either increasing Hardenability or corrosion resistance or both,

affect the austenitic zone as shown



Effect of chromium on the austenite phase region. (After Bain, *Alloying Elements in Steel*)



Effect of molybdenum on the austenite phase region. (After Bain, *Alloying Elements in Steel*)

Normalizing: Heating a steel part of heavy section to a temperature 100° C above the upper critical range and then cooled in still air

Normalizing plays an important role in grain size.

1st the grain size is controlled by the size of the Austenite grains, from which they form on cooling;

2nd when steel is heated to just above the upper critical the grain growth is primarily a function of temperature and time

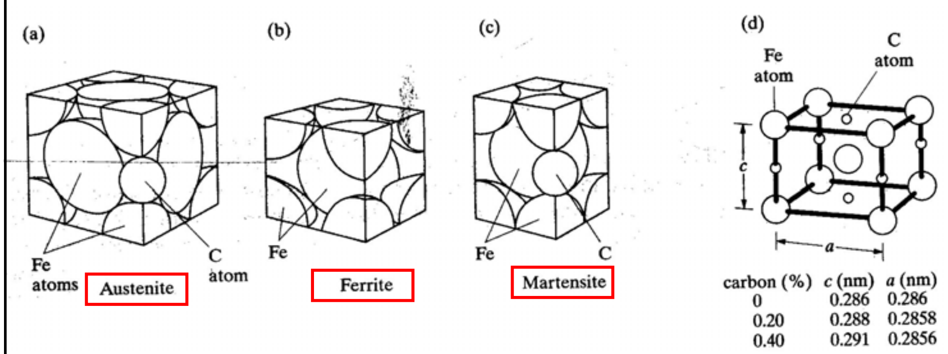
Annealing: any any heating and cooling operation that is applied to induce softening

Full Anneal: steel is heated to 100°C above the upper critical

Process Anneal: steel is heated to a temperature just below the lower critical

Spheroidizing Anneal: Any process of heating and cooling that produces a round or globular form of carbide in steels

Atomic models of three steel structures



Examples of steels:

xx **indicates** the carbon content

10xx Plain carbon
11xx Free-cutting carbon
13xx Manganese (1.75%)
2xxx Nickel (3.50 or 5.00%)
31xx Nickel (1.25%), chromium (0.65 or 0.80%)
33xx Nickel (3.50%), chromium (1.55%)
40xx Molybdenum (0.25%)
41xx Molybdenum (0.20%), chromium (0.95%)
43xx Molybdenum (0.25%), chromium (0.50 or 0.80%), nickel (1.80%)
46xx Molybdenum (0.25%), nickel (1.80%)
48xx Molybdenum (0.25%), nickel (3.50%)
5xxx Chromium
5xxxx Chromium
61xx Chromium (0.80 or 0.95%), vanadium (0.10 or 0.15%)
86xx Nickel (0.55%), chromium (0.50%), molybdenum (0.20%)
87xx Nickel (0.55%), chromium (0.50%), molybdenum (0.25%)
92xx Silicon (2.00%), manganese (0.85%)
93xx Nickel (3.25%), chromium (1.20%), molybdenum (0.12%)
94xx Nickel (0.45%), chromium (0.40%), molybdenum (0.12%)
97xx Nickel (0.55%), chromium (0.17%), molybdenum (0.20%)
98xx Nickel (1.00%), chromium (0.80%), molybdenum (0.25%)

COMBINING TENDENCIES OF ELEMENTS IN ANNEALED STEEL.

Element	Dissolve in Ferrite	Dissolve in Austenite	Form Carbide	In Nonmetallic Inclusions	Form Special Intermetallic Compounds	In Elemental State
Nickel	Ni	Ni			NiSi (?)	
Silicon	Si	Si		$SiO_2 \cdot M_xO_y$		
Aluminum	Al with	Al		Al_2O_3 etc.	Al_xN_y	
Zirconium	Zr →	Zr		ZrO	Zr_xN_y	
Phosphorus	P ease	P				
Sulfur	S	S		{MnFeS, ZrS}		
Copper	Cu	Cu				Cu when $> \pm 0.8\%$
Manganese	Mn	Mn ↔	Mn	{MnS, MnFeO, $MnO \cdot SiO_2$}		
Chromium	Cr time	Cr ↔	Cr	Cr_xO_y		
Tungsten	W →	W ↔	W			
Molybdenum	Mo and	Mo ↔	Mo			
Vanadium	V temp.	V ↔	V	V_xO_y	V_xN_y	
Titanium	Ti	Ti ↔	Ti	Ti_xO_y	{$Ti_xN_yC_z$, Ti_xN_y}	
Lead						Pb (?)
Principal effect:	Strengthen	Increase hardenability	Reduce hardenability Fine-grain Toughness	Deoxidizers and grain-growth control	Increase hardness	Increase machinability