Quiz 4 – Quench and Temper of Steel,Age Hardening

You Should Be Able to:

- For **Iron-Carbon** alloys:
  - state the composition, structure, and relative properties of austenite, ferrite, cementite, pearlite, bainite, and martensite; know how each is formed, where the carbon is, and in what form the carbon is.
  - explain the effect of cooling rate on equilibrium structures and the effect on properties (e.g. ferrite grain size, lamellar spacing of pearlite).
  - name the processing steps required to produce a quenched and tempered steel, the microstructures present at each step, and the relative mechanical properties resulting from those microstructures.
  - use a TTT diagram to predict microstructure for nonequilibrium conditions.
  - state what hardenability is, how hardenability can be increased, and how it can be measured.
  - state what is measured in the Jominy test and explain how results are used.
  - be able to use Jominy results and cooling rate as a function of diameter graphs to predict properties throughout a quenched cylinder.
- Within the context of phase formation and change, you should know the importance of diffusion and what factors affect the diffusion of atoms in a solid. As an example, what is the role of carbon diffusion in the formation of martensite?

- In the area of **age hardening** (precipitation hardening) :
  - State the factors necessary for age hardening to be possible.
  - *Name the three steps in the age hardening process, the microstructural changes associated with each step, and the relative mechanical properties which result from those microstructures.*

- compare and contrast age hardening and quench and tempering in terms of procedure, microstructure and properties.

Vocabulary

Chap 10	*Chap 11*
Athermal transformation	Annealing
Bainite	Artificial Aging
Coarse pearlite	Full annealing
Fine Pearlite	Hardenability
Martensite	Jominy end-quench test
Phase transformation	Natural aging
Spheroidite	Overaging
Tempered martensite	Precipitation Hardening
Thermally activated transformation	Solution heat treatment
	Spheroidizing

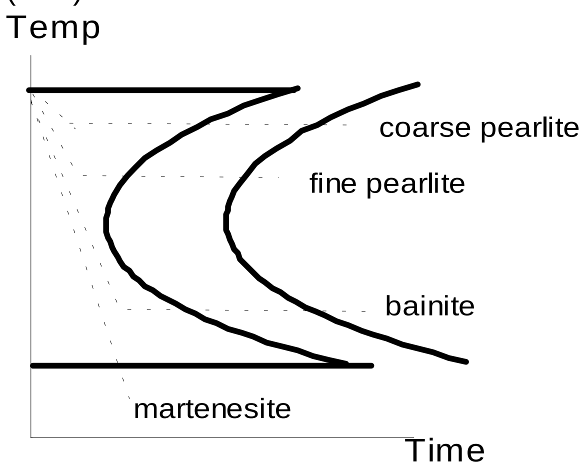
Heat Treated Steel and Aluminum - If we purchase a higher performance steel (e.g. a good hand tool or high performance (chrome-moly) bicycle) it may be called "Tempered" steel. The term "aircraft aluminum" may be used for the high end aluminum bicycles (6061 or 7075). In both cases the metals have been heat treated and have microstructures that are not predicted by the equilibrium phase diagram. Therefore, we use other diagrams to determine microstructure and properties.

Steel: Quench and Temper

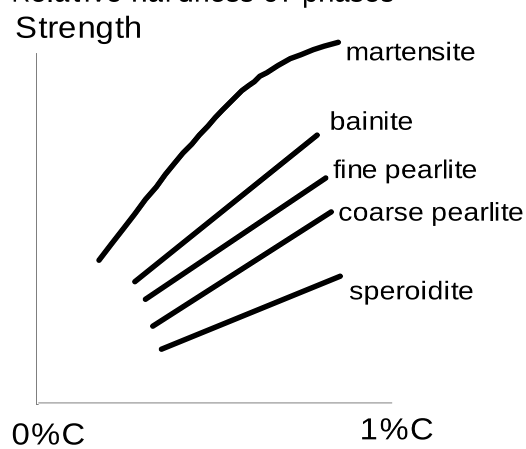
Step 1 -	Heat to form Austenite	**Austenitize**
Step 2 -	Cool rapidly to form Martensite	**Quench**
Step 3 -	Heat to soften and regain ductility	**Temper**

Quench

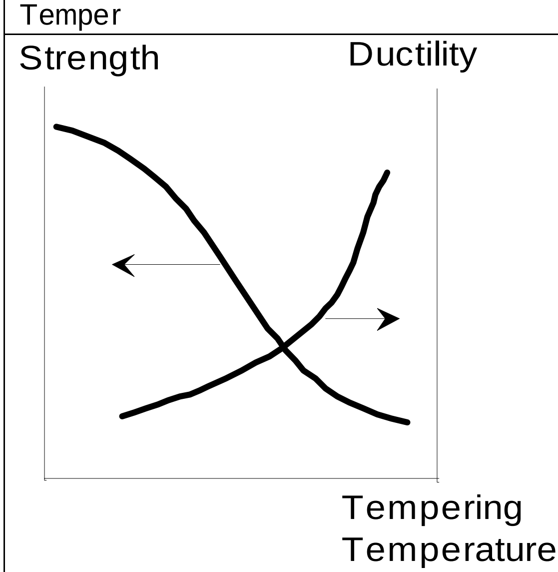
Isothermal transformation diagram (ITT)



Relative hardness of phases

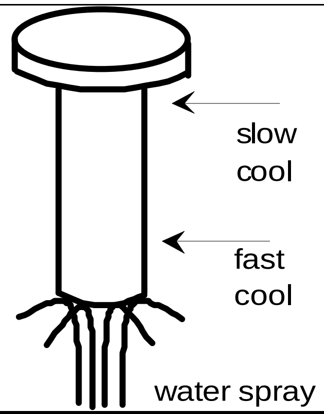
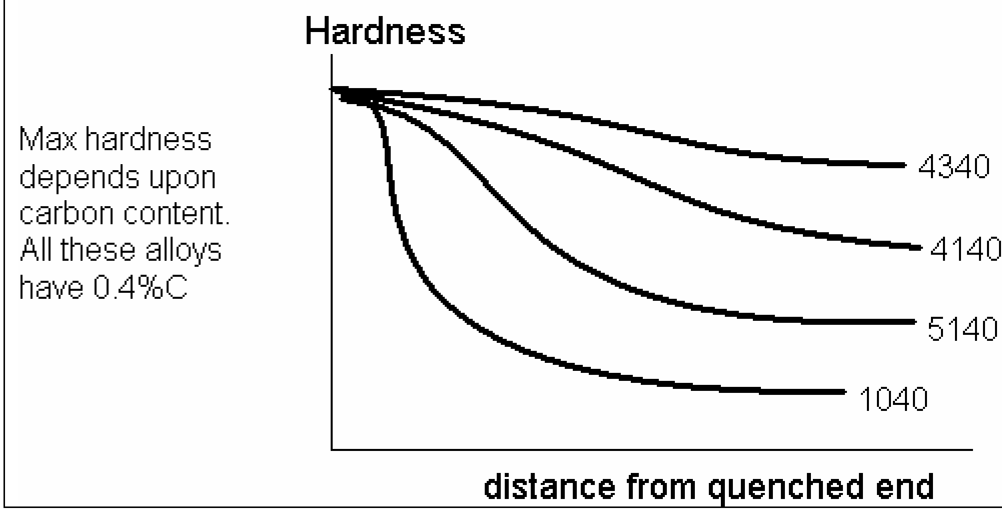


Temper



Quenching produces a very hard but also very brittle martensite (BCT, body centered tetragonal with carbon causing distortion of the BCC) structure that is not generally usable.

Tempering lowers strength and increases ductility the levels preferred by the designer (carbon diffuses out of BCT and structure goes back toward BCC)

Hardenability - Jominy End Quench Test	
	Austenitize the bar then quench one end with a water spray. After bar is cool, measure hardness at intervals along the length of the bar. This measures hardness as a function of cooling rate. Hardenability is the ability to form martensite at slower cooling rates.
	

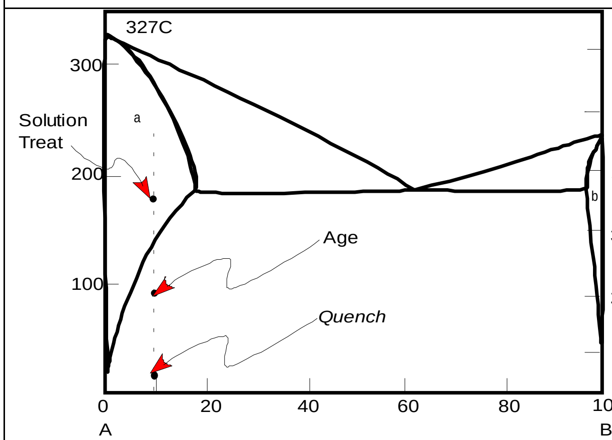
Structure-Properties-Processing: Strength in heat-treated steel comes from the significant lattice distortion caused by the formation of the distorted BCT microstructure. Since the distortion results from trapped interstitial carbon, increasing carbon content increases strength. Tempering lowers the strength. This method is attractive because of the very high strength levels, good ductility, and the engineer's degree of control over the process.

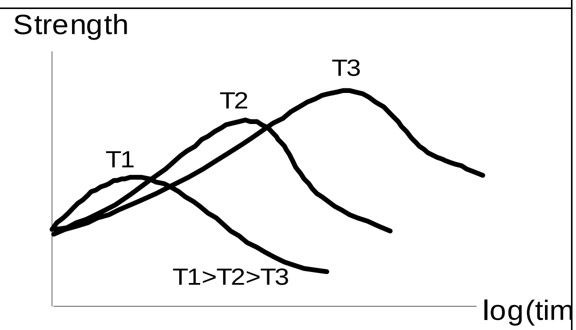
Precipitation Hardening
(Age Hardening)

Step 1 -	Heat to form single phase region	**Solution Treat**
Step 2 -	Cool rapidly to prevent diffusion	**Quench**
Step 3 -	Heat to control diffusion of 2nd phase	**Age**

Steps are shown on phase diagram, but diagram does not predict microstructure of steps 2 and 3.

Aging - Note that the as-quench strength is low and strength increases with time. High temps mean faster diffusion.





Comparison of Q&T and Age Hardening

	Q&T			AGING		
Step	**Name**	**Micro**	**Prop**	**Name**	**Micro**	**Prop**
Heat						
Cool						
Reheat						

Links:

A really nice unit on **precipitation hardening** from our British cousins
http://aluminium.matter.org.uk/content/html/eng/default.asp?CATID=61&PAGEID=989848382

This is a good one for ITT diagrams and microstructure
http://www.matter.org.uk/steelmatter/metallurgy/7_1_2.html

Here you can move your cursor on an Iron carbon phase diagram and see what phases are present
http://www.matter.org.uk/steelmatter/metallurgy/6_1_3_1.html