DISPERSION STRENGTHENING

The strength and hardness in some metal alloys may be enhanced by the presence of extremely small and uniformly dispersed particles within the original phase matrix.

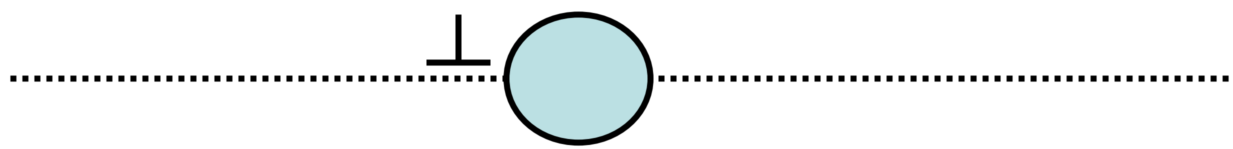
Whether introduced as insoluble particles in powder compaction (dispersion strengthening), or as precipitates in a solid state reaction (precipitation or age hardening), second phase particles are generally the most potent strengthening agent in practical high strength engineering materials. Iron-base, aluminum, nickel, titanium alloys all employ second phases to achieve high strength.

The size, shape, and amount of second phase particles controls the mechanical properties of the alloy.

Second phase particles in the form of very small uniformly distributed particles are added to the matrix. These will block dislocation motion extremely well, and strengthen the material. This is the basis for all high strength metal alloys.

- Example: Put fine particles of Al_2O_3 in aluminum:

slip plane



- Dislocations in Al cannot penetrate into alumina, they get stuck, and the strength goes up.

Precipitation Hardening

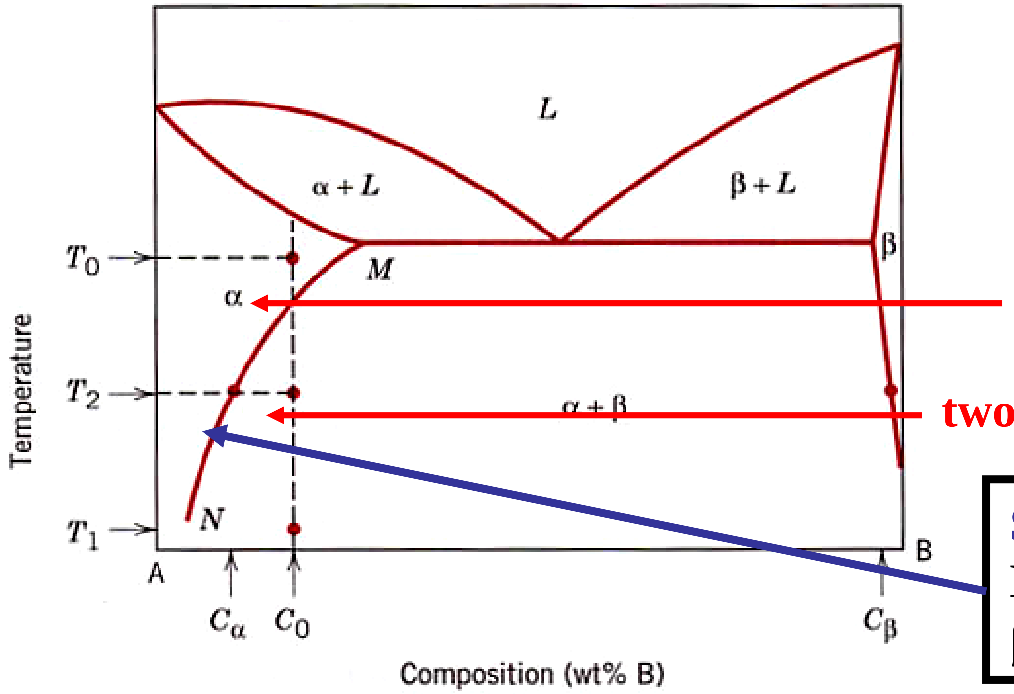
•Precipitation hardening - process in which small particles of a new phase precipitate in matrix which harden material by forming impediments to dislocation motion.

•Also known as "Age Hardening" because hardness often increases with time (even at room temperature!)

Requirements: System must have:

–an appreciable maximum solubility of one component in the other (several %)

–a solubility limit that rapidly decreases in concentration of major component with decreasing temperature



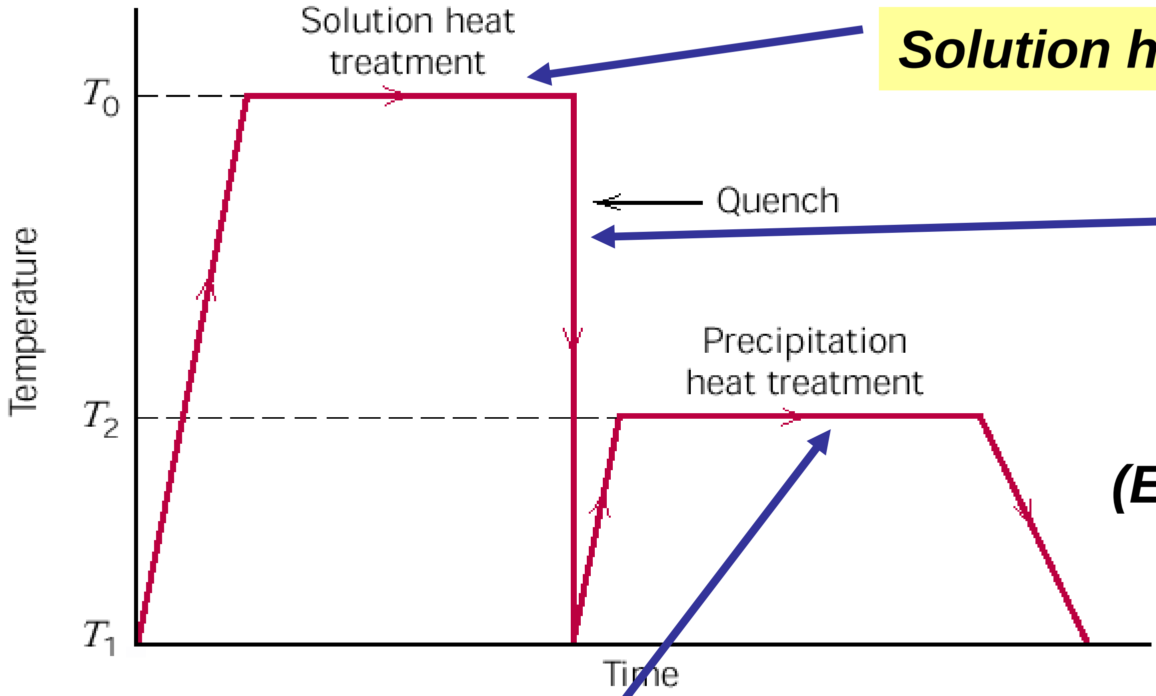
Solvus - solubility limit of B in α. Beyond this concentration second phase β will form.

- Precipitation hardening is accomplished with two separate heat treatments
- Step I :Solution heat treatment: heating composition C_o to T_o until all B atoms dissolved into α (i.e. β phase is removed) and one phase is obtained.

  Then the alloy is quenched (rapidly cooled) to T_1 so as to prevent precipitation of any β phase. A metastable situation occurs but diffusion rates are often too slow at T_1 to allow β phase precipitation for long periods of time.
- Step II : Precipitation heat treatment: Supersaturated a solid (i.e. has more B in it that it should have) heated to T_2 where kinetics allow for controlled diffusion of B to form β phase. Forms finely divided β phase. Finally, alloy is cooled to stop precipitation.

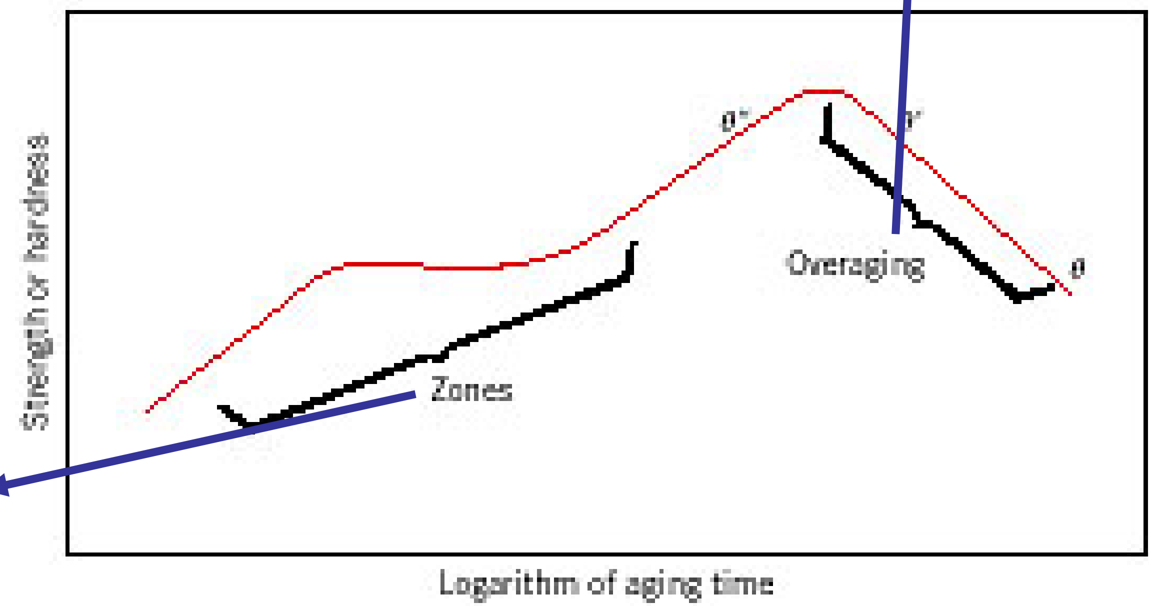
Solution heat treatment

Quench



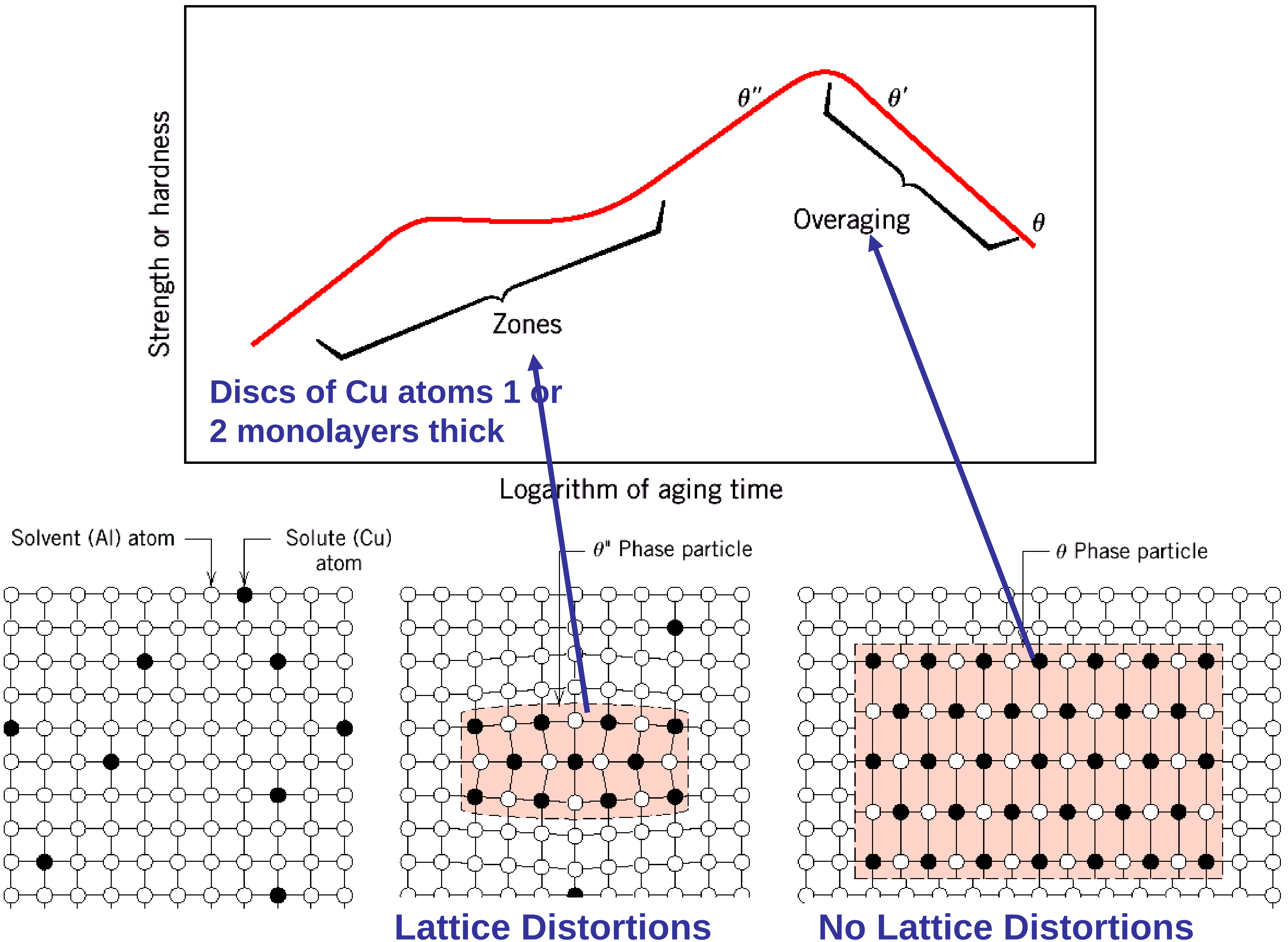
(Excessive Particle growth)

Overaging



Precipitation hardening

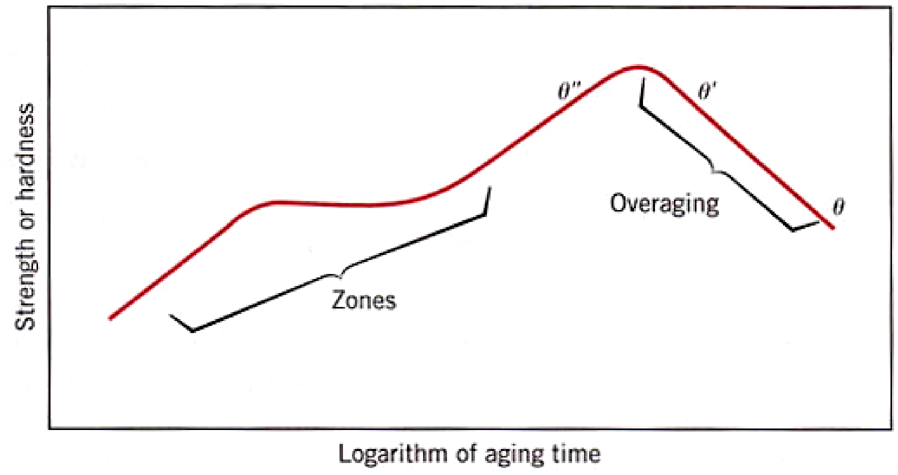
Zone forming



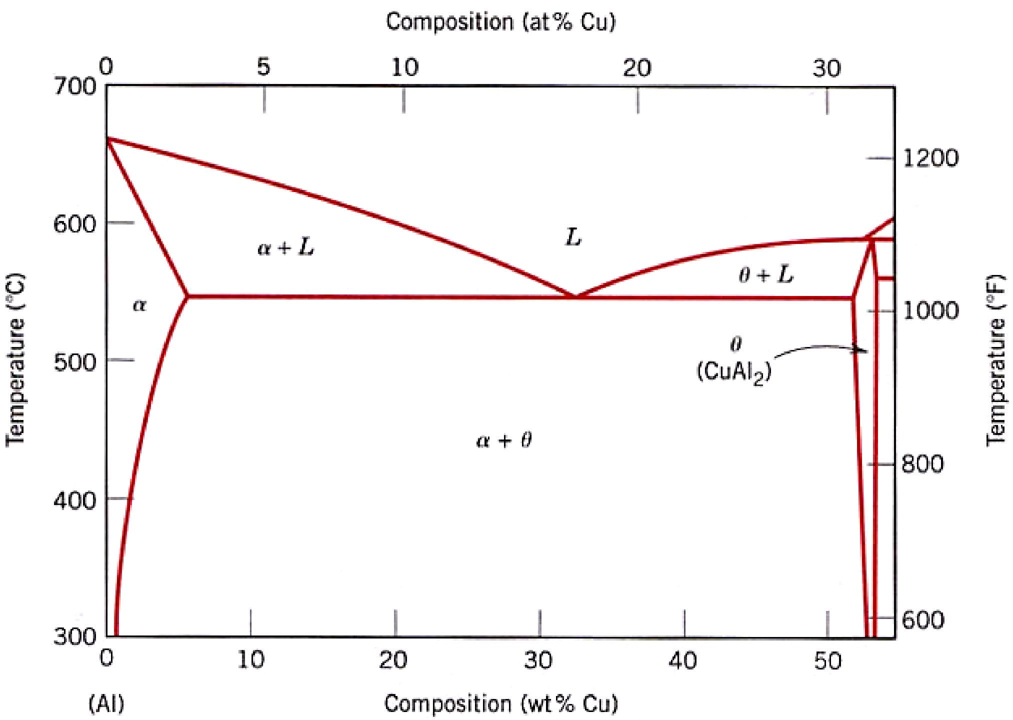
Strength or hardness
θ''
θ'
θ
Overaging
Zones
Discs of Cu atoms 1 or
2 monolayers thick
Logarithm of aging time
Solvent (Al) atom
Solute (Cu)
atom
θ" Phase particle
θ Phase particle
Lattice Distortions
No Lattice Distortions

Concerns:

- –Precipitation sometimes occurs at room temperature.
- –Overaging - if β particles are allowed to grow too large strength of alloy can diminish as particles grow. Why?



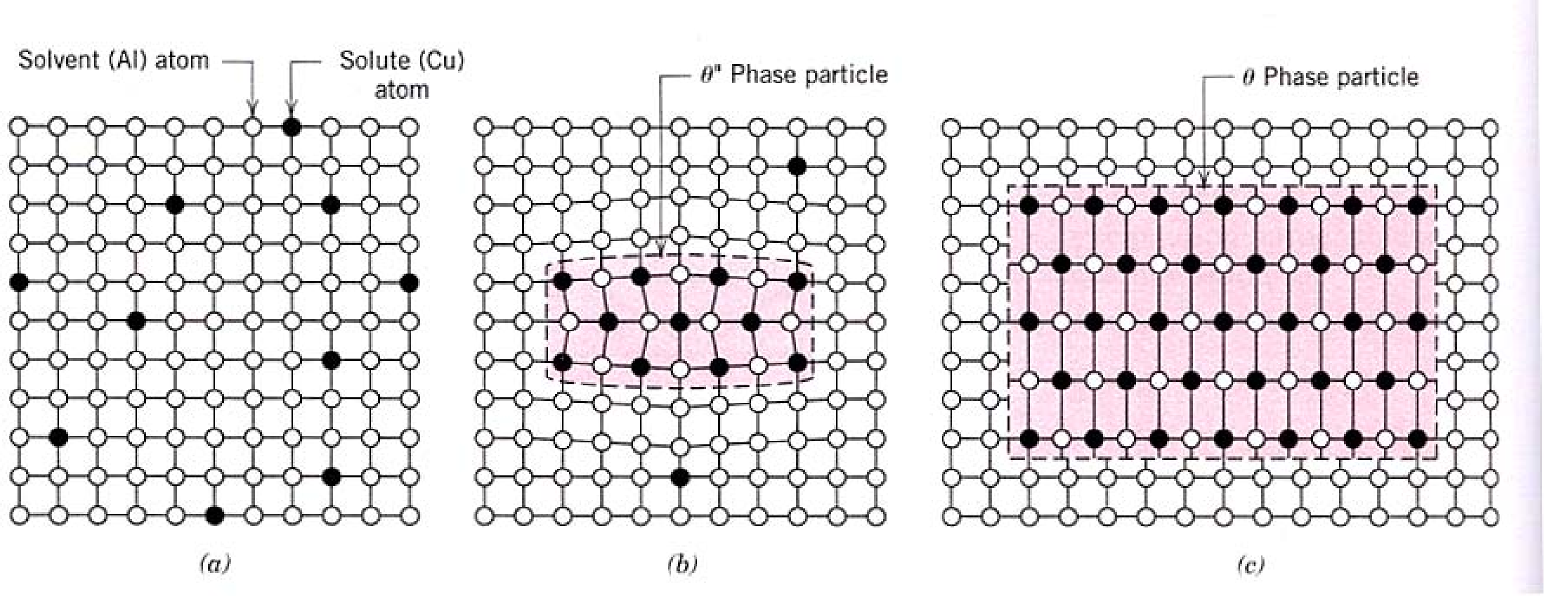
Example: Precipitation Hardening & Overaging in Al alloys



Aluminum - low density, high ductility, high reserves (8% of earth crust), easily recycled, high corrosion resistance, high luster, high conductivity, <u>but</u> low strength for a metal. Applications include automotive, aerospace, whenever low weight is desirable. Strengthened by precipitation hardening!

Example - Al(ss) (i.e. α phase) matrix with $CuAl_2$ (i.e. θ phase) precipitates

Precipitation occurs in two stages



Supersaturated a solid solution

Formation of small, coherent, particles of θ'' phase called Guinier-Preston Zones.
Stress field associated with lattice strain impedes dislocations more effectively than θ

Overaging - θ'' continue to grow and become incoherent with matrix.
Phase now becomes θ phase
Lattice strain reduced.
Dislocations motion not as restricted as in θ '' phase

The most quoted age hardening curve is that for Al-Cu alloys performed in the late 40s. Keep in mind that age hardening was known empirically (Alfred Wilm) as a technologically useful treatment from the early days of aluminum alloys.

Higher Cu contents result in higher maximum hardness because larger volume fractions of precipitate are possible.

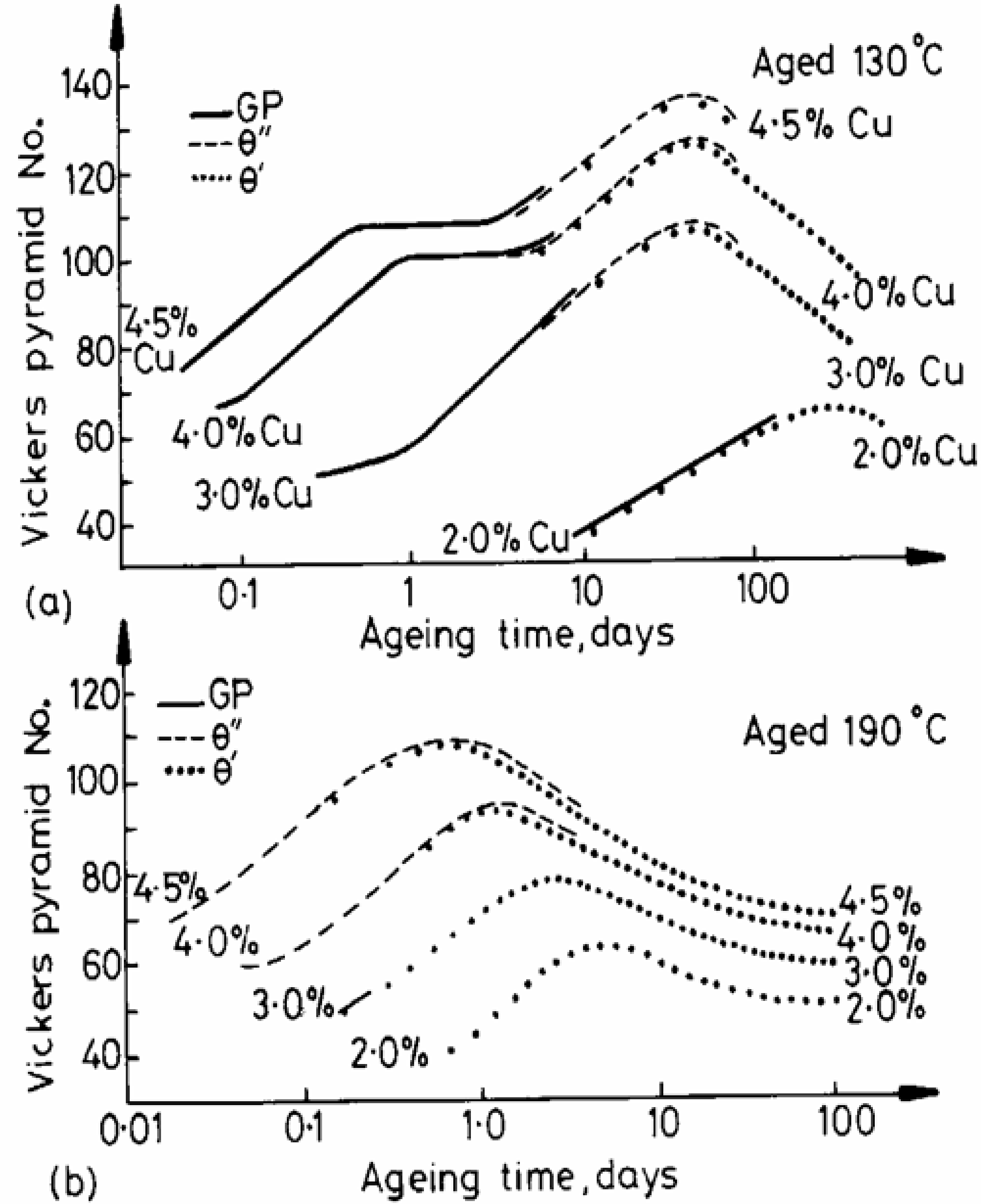
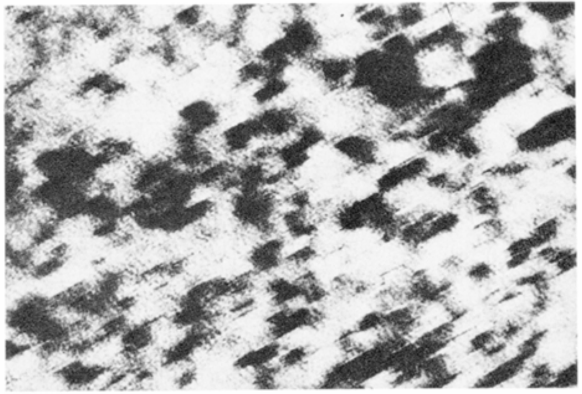
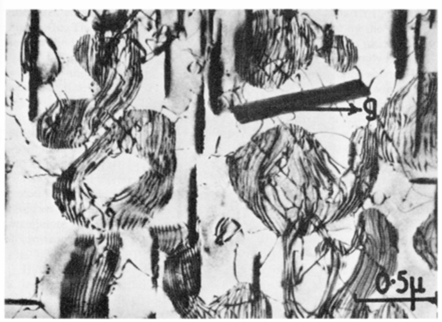


Fig. 5.37 Hardness v. time for various Al–Cu alloys at (a) 130 °C (b) 190 °C. (After J.M. Silcock, T.J. Heal and H.K. Hardy, *Journal of the Institute of Metals* **82** (1953–1954) 239.





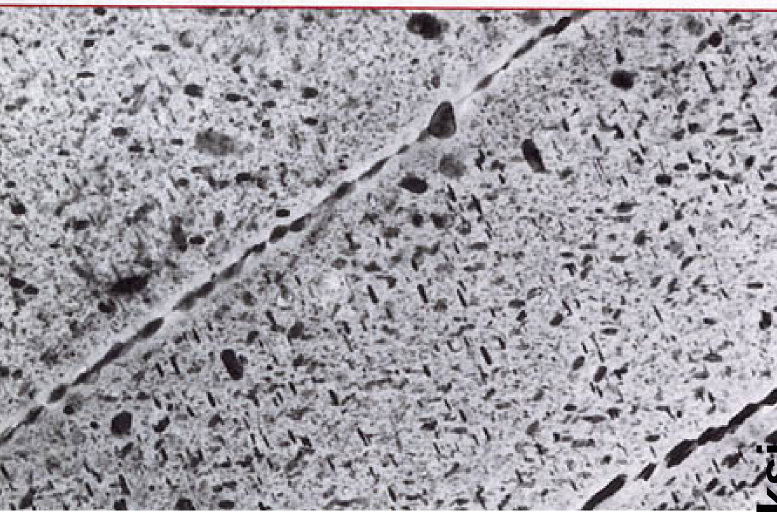
- After solution annealing, Al-Cu alloy is at its softest.
- Immediately after quenching, final shaping and machining are conducted before age hardening begins.
- Age hardening may require heating (artificial aging) although many Al-Cu alloys age harden at room temperature (natural aging).
- Some alloys experience precipitation hardening at room T. These have to be refrigerated to prevent hardening.

Example:

Al 2024 Al-Cu rivets and wing plates for aircraft construction.

solution treated, quenched and refrigerated at suppliers plant, shipped in dry ice.

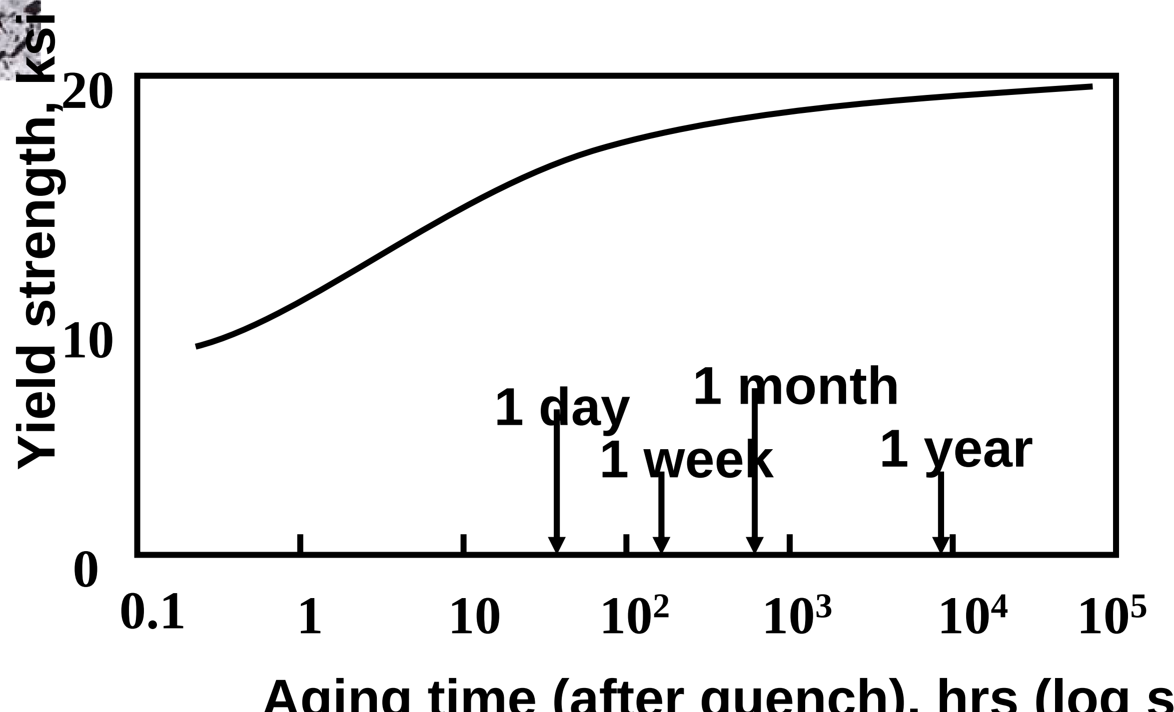
rivets are driven (deformed) in cold state. Wing sections shaped (deformed) in cold state



Application

Micrograph of precipitation hardened Al alloy aircraft wing segment.
GP zones are typically only a few atoms thick and 25 atoms across

Natural aging curve for 6061 Al alloy



•Al-Cu and Al-Cu-Mg alloys

- •Al-Cu model alloy, not used much in practice
- •Al-Cu-Mg "Duralumin" (Al-3.5Cu-0.5Mg-0.5Mn) first widely used age hardening alloy (discovered accidentally in 1906 by Alfred Wilm)

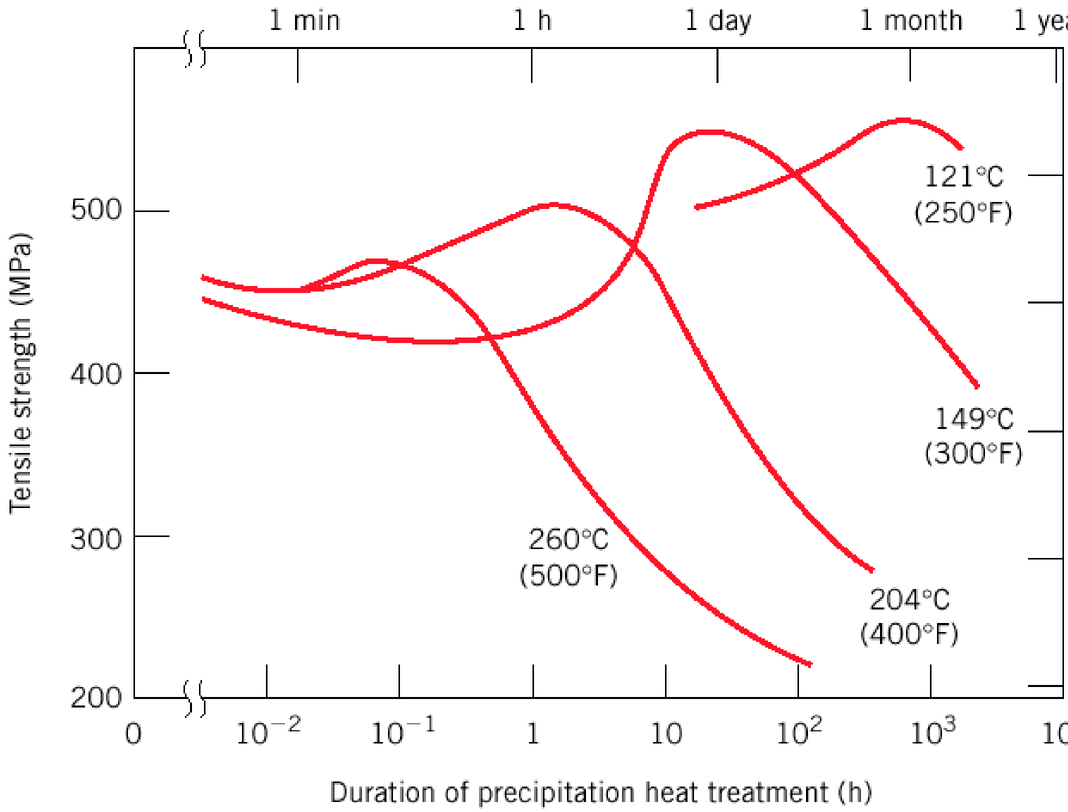
•Widely used for aircraft construction

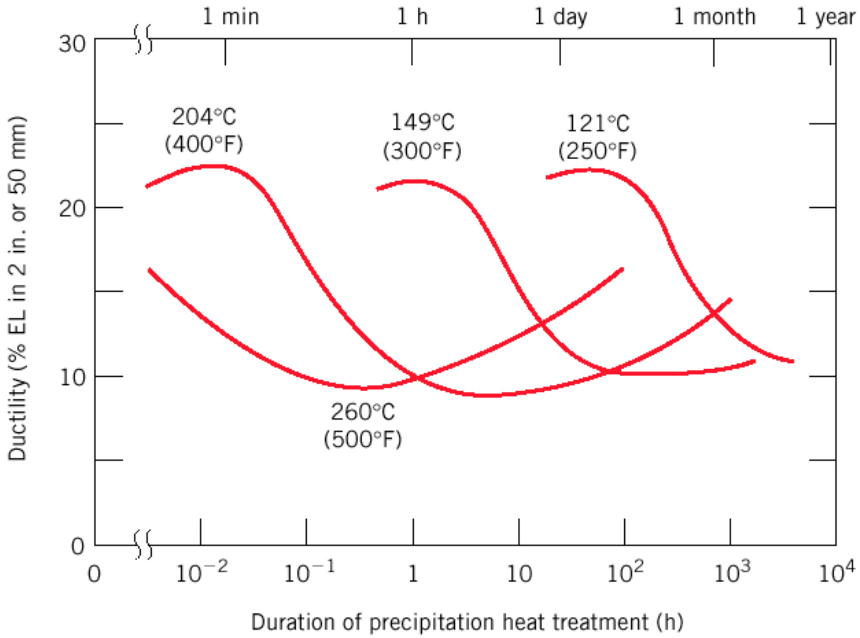
- •2618 Al-2.2Cu-1.5Mg-1Ni-1Fe developed for Concorde skin to withstand elevated temperature operation (T=130ºC at Mach 2)

•Normally roll clad with pure Al or Al-Zn to protect against corrosion

Strength and ductility during precipitation hardening

(Precipitation hardening characteristics of a 2014 aluminum alloy (0.9%Si, 4.4%Cu, 0.8%Mn, 0.5%Mg}





Strengthening of Aluminum

Material	Yield Strength ksi	%elongation
Pure annealed Al	2.5	60
Solid solution Strengthened with 1% Mn	6	45
Highly cold worked pure Al	22	15
Precipitation hardened alloy 7075	80	10