Al & its Alloys

Introduction:

- Light alloys are characterized by low density (1.7 – 4.5) g/cm^3.
- Al density = 2.7 g/cm^3 $\cong$ 1/3 density of (Fe) which is equal to 7.9 g/cm^3.
- The Al's modulus of Elasticity (E) = 70 GPa $\cong$ 1/3 the Fe's modulus of Elasticity (210 GPa).
- σ / density $\Big|_{Al}$ = σ / density $\Big|_{Fe}$
- Pure Al is a weak, very ductile, electrical conductivity = 2/3 electrical conductivity of Cu.
- The relatively low value of strength for pure Al can be increased by:

  a – Strain hardening resulting from C. W.

  b – Solid – Solution strengthening due to alloying.

  c – Precipitation hardening.

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❖ Al has great affinity for O_2 ($Al + O_2 \longrightarrow Al_2O_3$) ⇒ thin layer of oxide on surface ⇒ protect the surface from further attack.

❖ Mechanical properties of Al & it's alloys depends not on purity but on the amount of work done to which it has subjected.

Classification of Al alloys

Wrought Alloys | Cast Alloy

❖ Four – digits of numerical designation is used to identify Wrought Al and Wrought Al alloy.

❖ The 1st digit indicate the alloy group as shown below:

- 1XXX Al, 99.00% min & greater
- 2XXX Cu, major alloying element
- 3XXX Mn,

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- 4XXX Si,
- 5XXX Mg,
- 6XXX Mg + Si
- 7XXX Zn,
- 8XXX other elements

❖ The composition designation for Cast alloys is somewhat different and consist of (2) or (3) digit designation.

❖ Al alloys may be classified as:

Non heat treatable alloys

(No significant strengthening can be achieved by heating & cooling)

Heat treatable alloys

(Capable of being Precipitation Hardening)

Both types use heating to decrease (σ) and increase ductility (annealing) → Full annealing. → Partial annealing.

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Precipitation hardening Treatment:

- (2XXX, 6XXX, 7XXX (except 7072)) Wrought alloys
- (2XX.0, 3XX.0, 7XX.0) Cast alloys

Solution H. T.
(dissolution of Soluble phases)

Quenching
Development of super-solution

Aging
Precipitation of soluble atoms either at RT^o (natural-aging) or elevated T^o (artificial-aging)

Temper Codes (for Work hardening):

- **F :** as manufactured (e.g. rolled)
- **O :** in the annealed or soft condition.
- **H :** worked hardened (The letter being followed by two no., the 1^{st} → the process.
  → the degree of hardening.

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- H1X	Cold worked only.
- H2X	Cold worked + partially annealed.
- H3X	Cold worked + Stabilized at low ^{0}T to prevent age hardening.

- HX2	¼ worked hardened.
- HX4	½ worked hardened.
- HX8	Fully worked hardened.
- HX9	Extra hard tempers.

Temper for Heat treatment Al alloys:

- T :	Heat treatment letter followed by digits or letter to form of heat treatment.
- T1 :	Cooled from fabrication ^{o}T & naturally aged.
- T2 :	Cooled from fabrication ^{o}T + C. W. + naturally aged.

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- T3 : Solution treated + C. W. + naturally aged.
- T4 : Solution treated + naturally aged.
- T5 : Cooled from fabrication T° + artificially aged.
- T6 : Solution treated + artificially aged.
- T7 : Solution treated + Stabilized by over aging.
- T8 : Solution treated + C. W. + artificially aged.
- T9 : Solution treated + artificially aged + C. W.
- T10: Cooled from fabrication T° + C. W. + artificially aged.

- W : Solution treated, this temper is unstable and aging occurs at RT°.

Adding digits 51, 52, 54, are used to indicate a stress relieving process.

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❖ One essential attribute of a precipitation – hardening alloy System is → Increasing solubility with increasing system (ex. Al – Cu system), see fig32 below:

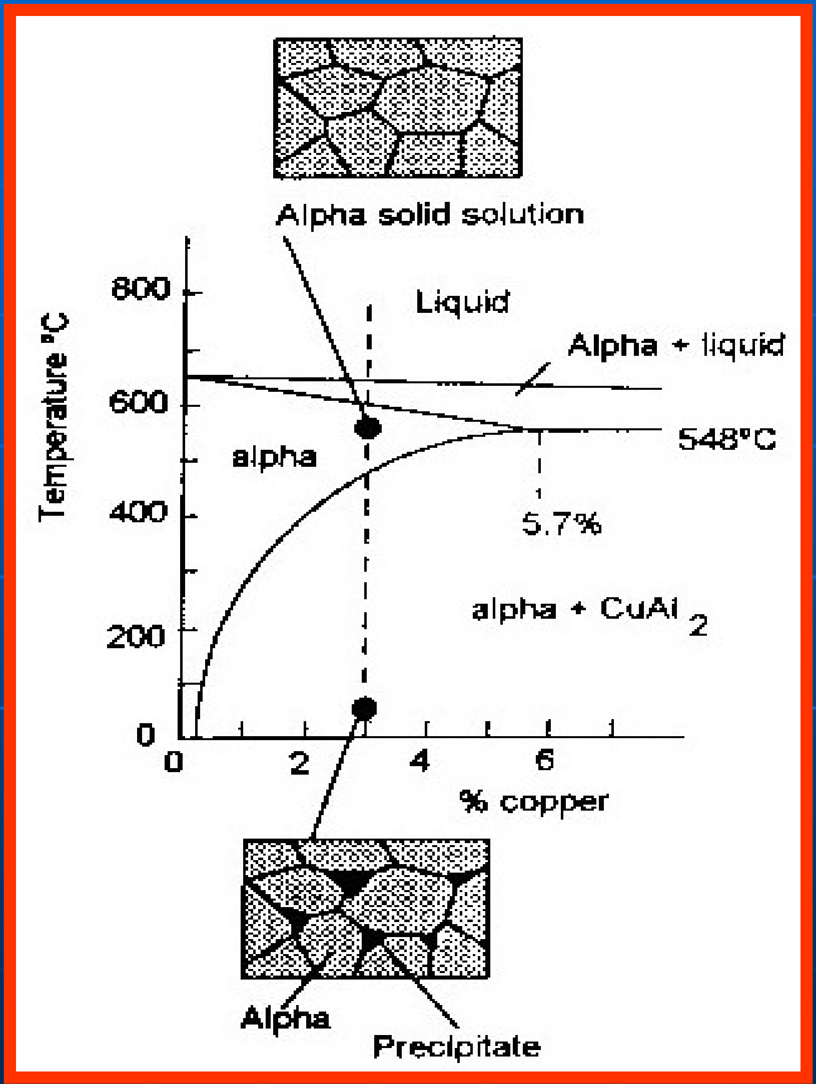

Fig. (32): Phase diagram for (Al – Cu) alloy.

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Precipitation hardening is accomplished by the following Heat Treatment:

Solution H. T. | **Quenching** | **Aging**

❖ In Solution heat treatment (fig. 32) all solute atoms are dissolved to form a single – phase solid solution (α).

❖ Consider alloy (Al – Cu)% of 4% Cu. This treatment consist of heating the alloy to T° within (α) phase field say (T°) and waiting until all the (θ) phase that may have been present is completely dissolved at this point the alloy consist of only (α) phase of 4% Cu, this procedure is followed by.

– Quenching (rapid cooling) to RT°.

– non equilibrium situation exist, in which only the (α) phase solid solution super-saturated with (Cu) atoms is present at T_1, in this case the alloy is relatively (soft + weak).

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❖ The super-saturated (α) solid solution is ordinary heated to intermediate T° (T_2) at which T° diffusion rates become appreciable.

– The (θ) precipitate phase begins to form as finely dispersed of 4% Cu. (The process called aging)

– After appropriate aging time the alloy is cooled to RT°. See fig. (33).

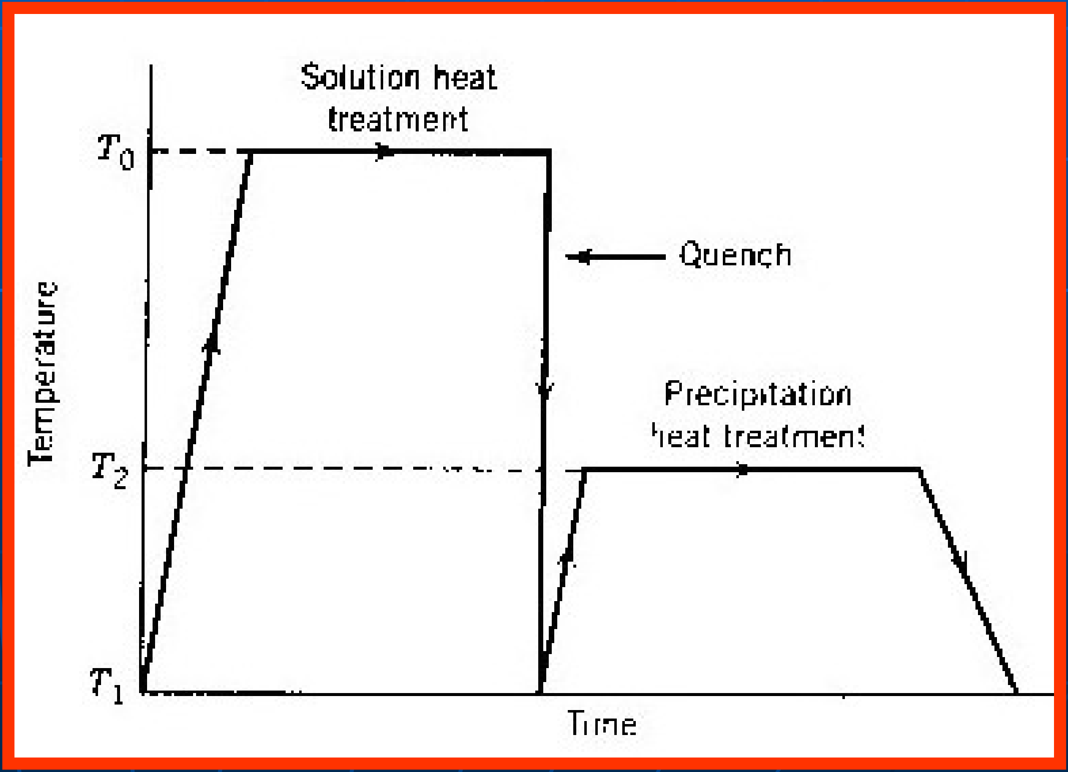

Fig. (33): Plot showing both solution H. T. quenching & precipitation H. T. for precipitation hardening.

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❖ The schematic diagram showing strength and hardness as a function of **log (t)** at constant T° is illustrated in **fig. (34).**

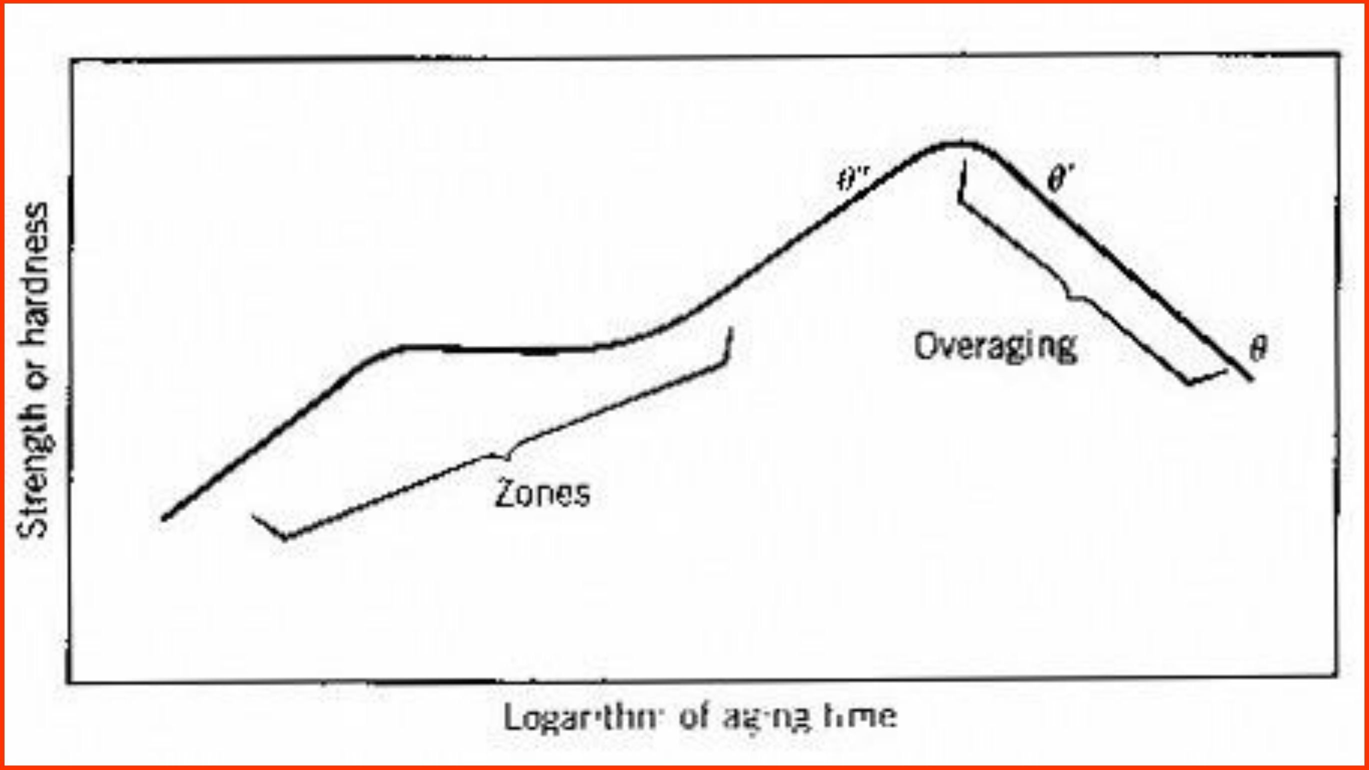

Fig. (34)

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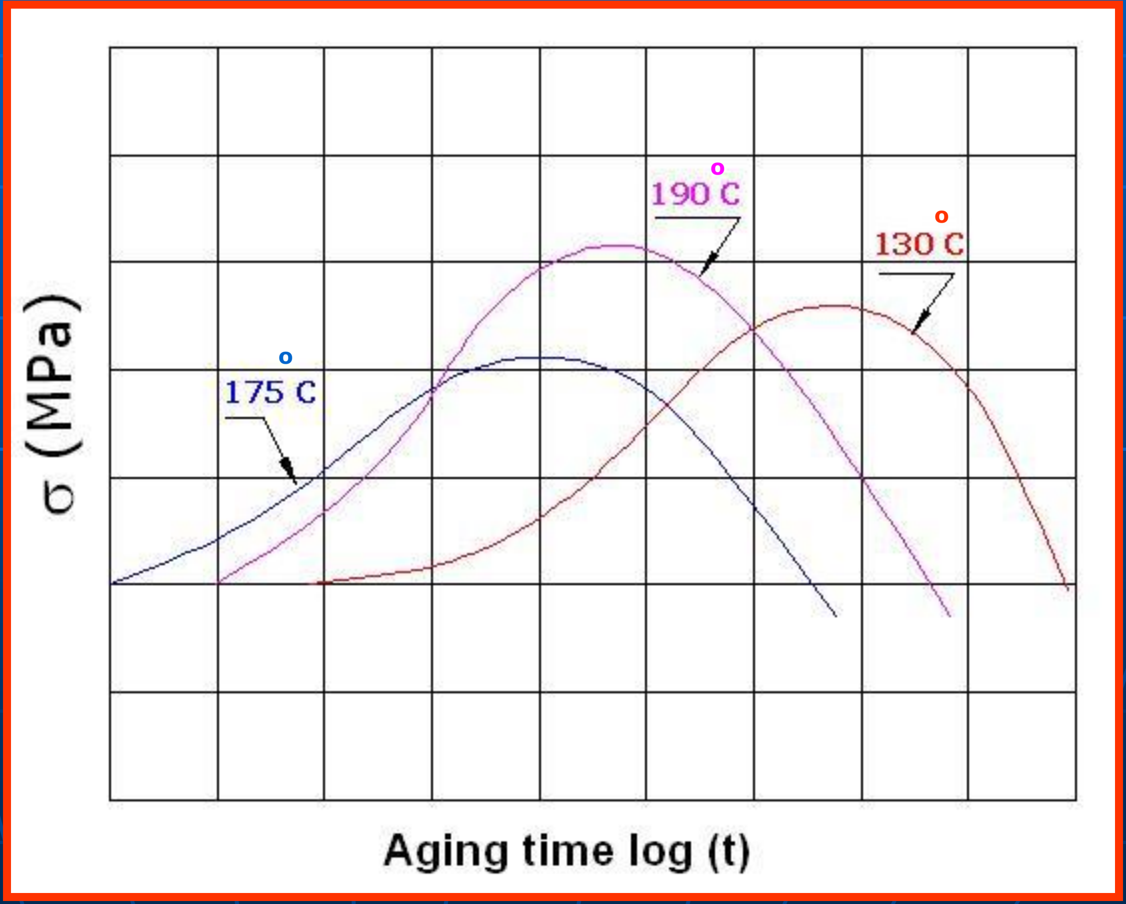
❖ Increasing time, the strength & hardness reaches a max. and finally diminishes, the reduction in strength & hardness that occurs after long period is known **"OVERAGING"** fig. (35).

Fig. (35)



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❖ Typical solution & precipitation heat treatment for Al alloys listed in table (1) below:

Table 1 Typical solution and precipitation heat treatments for aluminum alloy mill products

These times and temperatures are typical for various forms, sizes and methods of manufacture and may not exactly describe optimum treatments for specific items.

		Solution heat treatment(a)			Precipitation heat treatment			
		Metal temperature(b)			Metal temperature(b)			
Alloy	Product form	°C	°F	Temper designation	°C	°F	Time(c), h	Temper designation
2011	Rolled or cold finished rod and bar	525	975	T3(d)	160	320	14	T8(d)
				T4	...	...	...	...
				T451(e)	...	...	...	...
2014(f)	Flat sheet	500	935	T3(d)	160	320	18	T6
				T42	160	320	18	T62
	Coiled sheet	500	935	T4	160	320	18	T6
				T42	160	320	18	T62
	Plate	500	935	T42	160	320	18	T62
				T451(e)	160	320	18	T651(e)
	Rolled or cold finished wire, rod and bar	500	935	T4	160(g)	320(g)	18	T6
				T42	160(g)	320(g)	18	T62
				T451(e)	160(g)	320(g)	18	T651(e)
	Extruded rod, bar, shapes and tube	500	935	T4	160(g)	320(g)	18	T6
				T42	160(g)	320(g)	18	T62
				T4510(e)	160(g)	320(g)	18	T6510(e)
				T4511(e)	160(g)	320(g)	18	T6511(e)
	Drawn tube	500	935	T4	160(g)	320(g)	18	T6
				T42	160(g)	320(g)	18	T62
	Die forgings	500(h)	935(h)	T4	170	340	10	T6
	Hand forgings and rolled rings	500(h)	935(h)	T4	170	340	10	T6
				T452(j)	170	340	10	T652(j)
2017	Rolled or cold finished wire, rod and bar	500	935	T4	...	...	...	...
				T42	...	...	...	...
				T451(e)	...	...	...	...
2018	Die forgings	510(k)	950(k)	T4	170	340	10	T61
2024(f)	Flat sheet	495	920	T3(d)	190	375	12	T81(d)
				T361(d)	190	375	8	T861(d)
				T42	190	375	9	T62
					190	375	16	T72