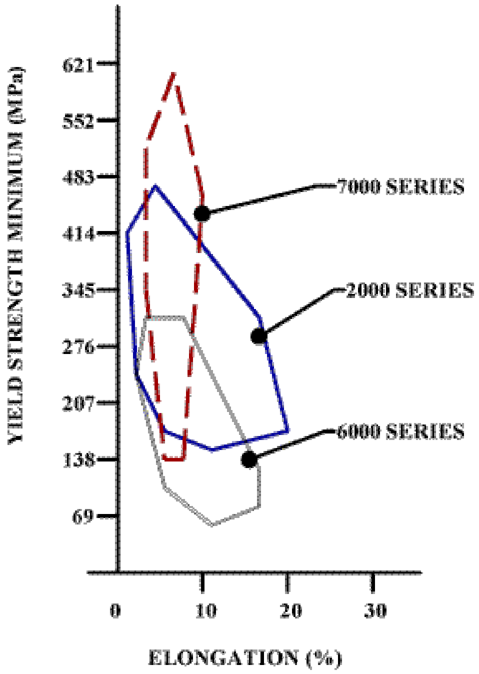
Lecture 17: Heat treatable aluminum alloys

MMat 380

Lecture outline

- Mechanical properties
- Age hardening
- Applications
- Corrosion
- Joining
- New Al alloys



Comparison of properties heat treatable Al alloys

Most of their strength due to PPT's

At peak aged condition we have optimum fine dispersion of second phase

$$\Delta\sigma \sim \frac{2Gb}{l}$$

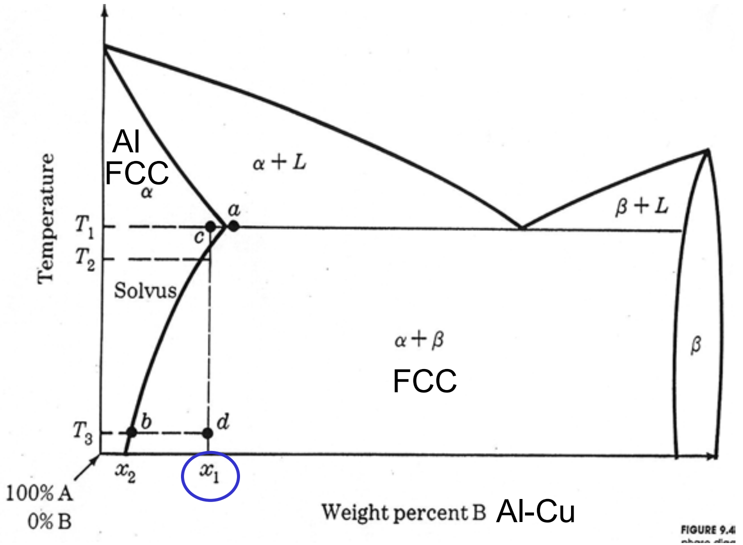
Overaging

Precipitates continue to grow i.e., small ppts are consumed and larger ppts continue to grow at their expense

Age hardening

- Solution treat in single phase α region
- Quench to room temperature (obtain a supersaturated single phase solid solution)
- Age at some intermediate T> RT to allow PPT to form

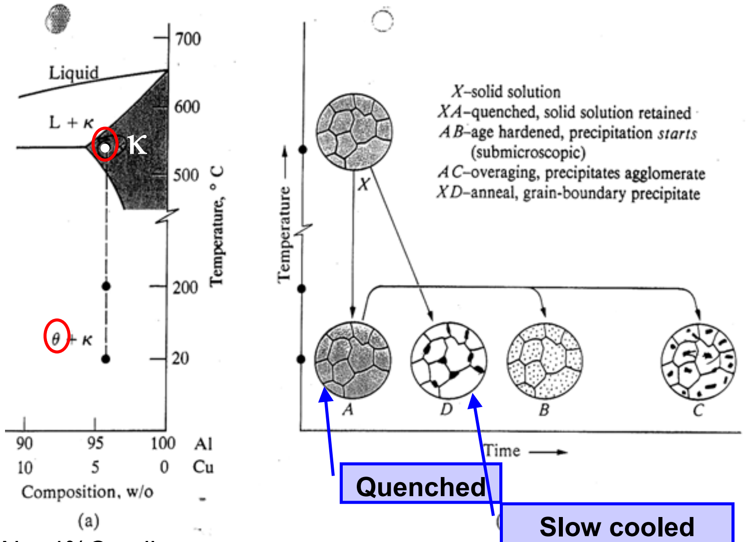
Binary phase diagram and solubility



Al-Cu

Al-Zn

Age Hardening Process



Quenched

Slow cooled

96%Al – 4%Cu alloy,
precipitates are still submicroscopic at time of max hardness

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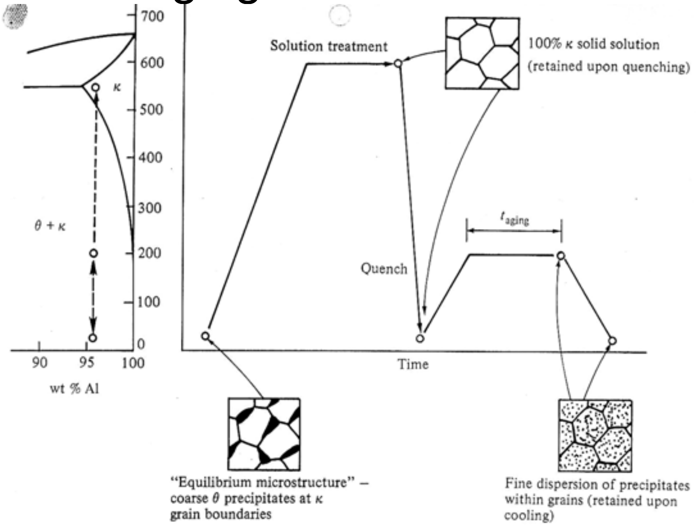
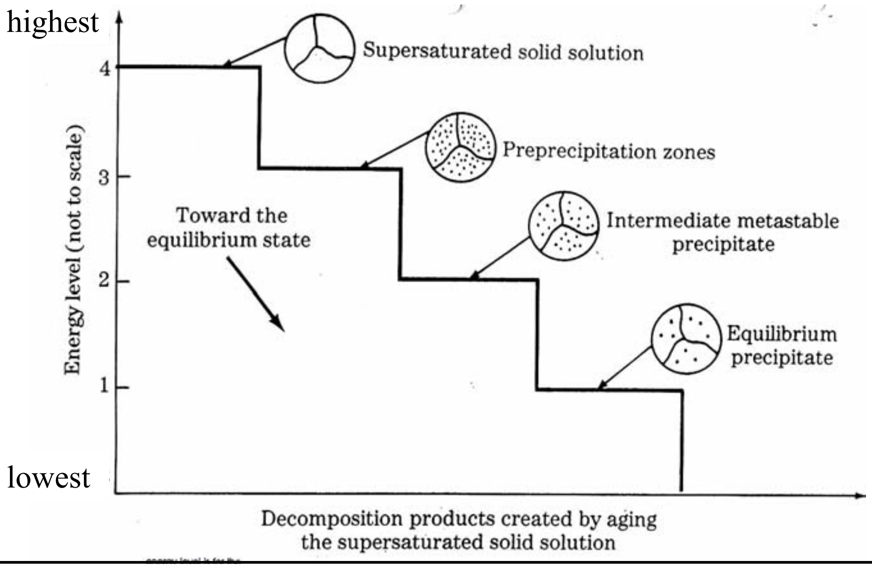
Aging heat treatment



By quenching and then reheating an Al-Cu (4.5 wt%) alloy, a fine dispersion of ppts forms within the κ grains.

Decomposition products



Age hardening

A Metastable solid solution after quenching

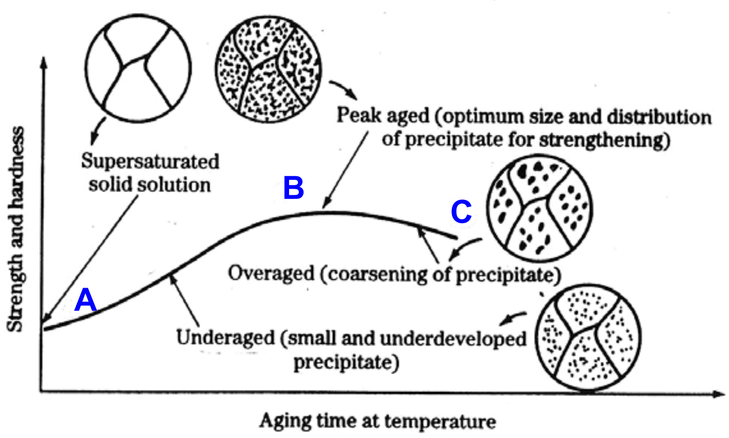
B Peak aged

- Coherent ppt zones
- Guinier Preston zones
- Dislocation and ppt zone stress fields interact

C Overaged

- Non-coherent ppts
- Usually stronger than A
- Precipitation coarsening

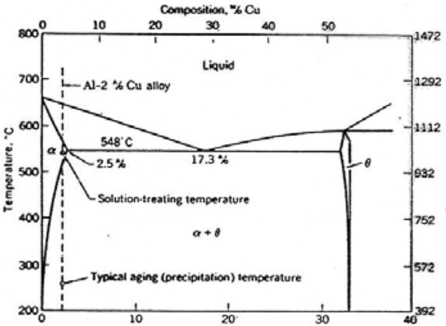
Schematic of aging curve



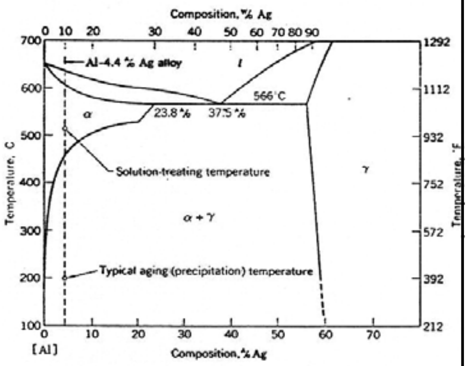
Age hardening

- Peak aged strength may be at uneconomically long times
- If T increases than decrease time to reach peak aged condition – get lower strength
- May deliberately overage for
    - a) Resistance to S.C.C.
    - b) Dimensional stability

Phase diagrams for Al alloys

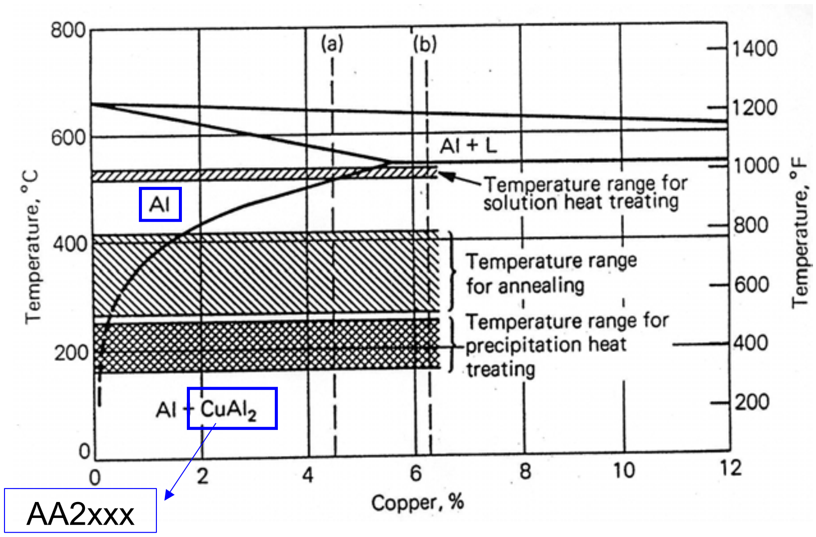


(a) Location of the Al-2 % Cu alloy in the aluminum end of the aluminum-copper phase diagram. The theta (θ) phase is C16 type structure, illustrated on inside back cover.

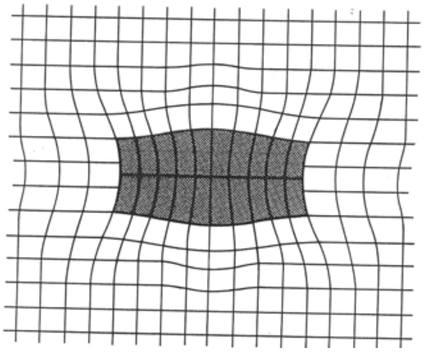


(b) Location of the Al-4.4 % Ag alloy in the aluminum end of the aluminum-silver phase diagram. The gamma (γ) phase has an HCP structure.

Partial phase diagram for Al-Cu alloys

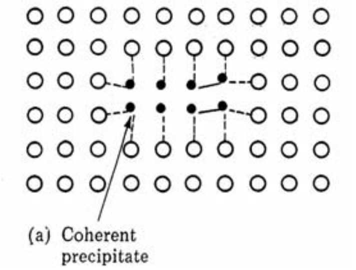


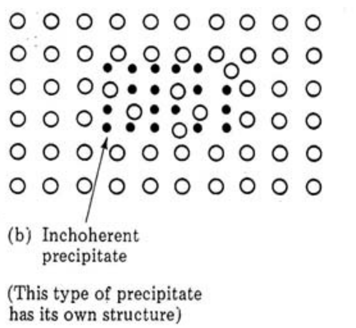
Schematic illustration of crystalline geometry of a Guiner-Preston (G.P.) zone



- Most effective for ppt hardening
- Structure developed at hardness maximum
- Coherent interfaces lengthwise along ppt.
- Precipitate is approx 15nm x 150nm

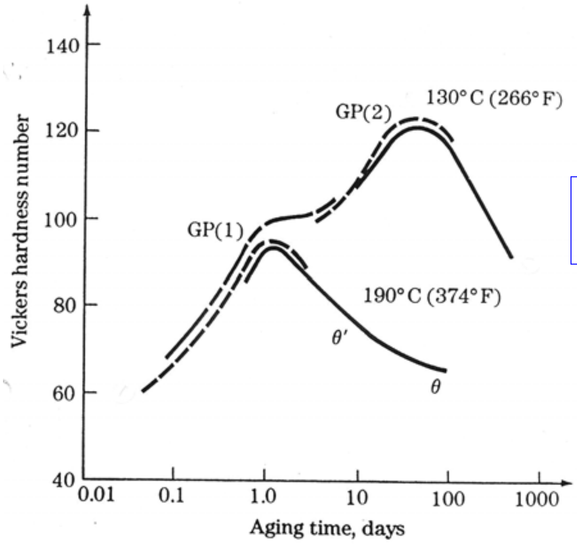
Schematic representation of the coherency of precipitates





- GP2 zones are coherent
  - Substitution
- GP1 zones are incoherent
  - Interstitial

Hardening of different zones



The general sequence of precipitation in binary Al-Cu alloys can be represented by:

Super saturated solid solution

GP1 zones

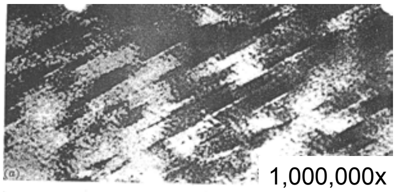
GP2 zones (θ" phase)

θ'

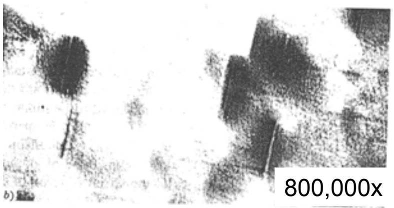
θ (Cu Al_2)

Microstructures of aged Al-4%Cu alloys

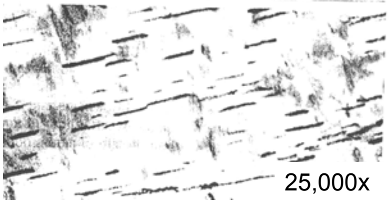
Heated to 540ºC, water-quenched and aged **16h at 130ºC**. The **GP zones** have been formed as disks parallel to the {100} planes of the FCC matrix and at this stage are a few atoms thick and about 100Å in diameter. Only disks lying on one crystallographic orientation are visible


1,000,000x

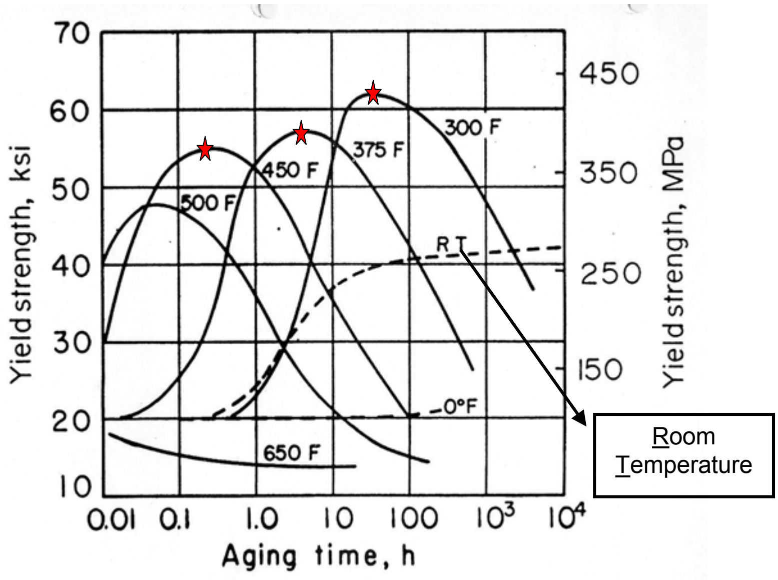
Solution treated at 540ºC, water-quenched and aged **1day at 130ºC**. This thin-foil micrograph shows strain fields due to **coherent GP2 zones**. The dark regions surrounding the zones are caused by strain fields.


800,000x

Solution treated at 540ºC, water-quenched and aged **3 days at 200ºC**. This thin-foil micrograph shows **incoherent and metastable phase θ'** which forms by heterogeneous nucleation and growth.

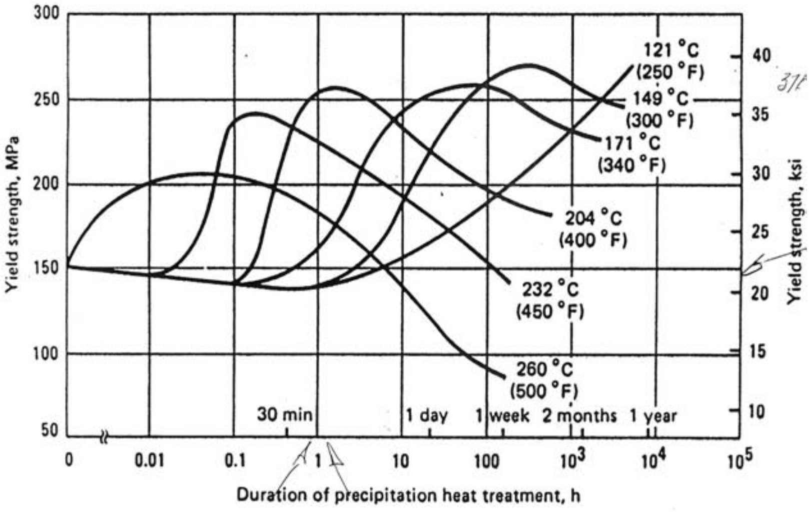

25,000x

Isothermal aging curves for 2014-T4

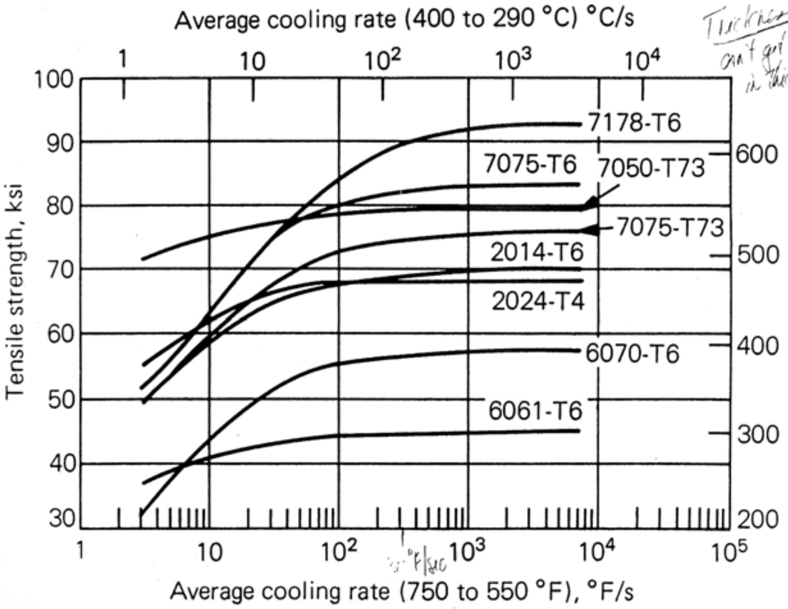


Room Temperature

Aging Curves for Alloy 6061



Effect of cooling rate on strength



Thickness
can't get hi str
in thick pla

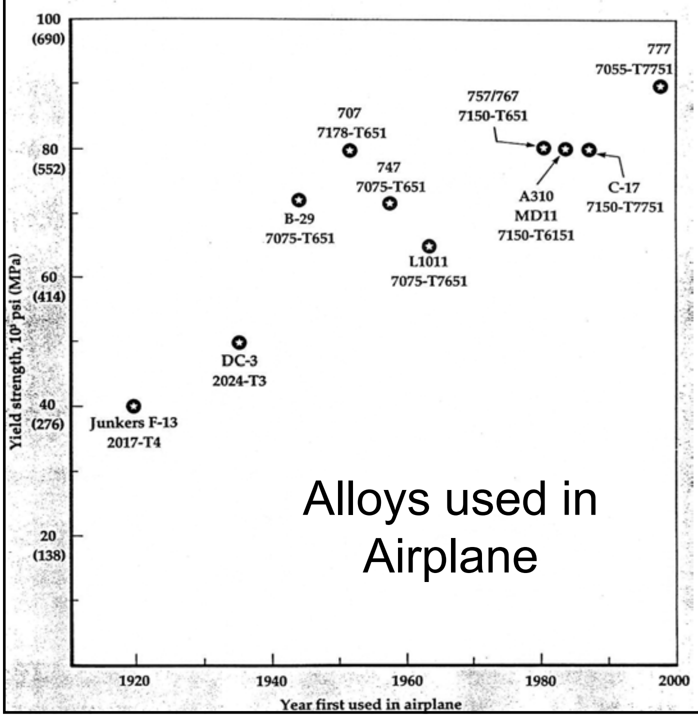
Heat treatable aluminum alloys

- AA6061
- Maximum strength – 235-268 MPa
- Most popular domestic age hardening alloys
  - **Ladders, tubing, bicycles (Cannondale)**
- Can be welded easily but loses strength to 165 MPa in the HAZ (have to re heat treat)
  - **Rivet construction truck panel bodies**
- Age hardening – higher strength – longer times but not economical
  - **1 hr at 200°C – 260 MPa**
- Not as strong as the 2xxx and 7xxx alloys (420-560 MPa)

Heat treatable aluminum alloys

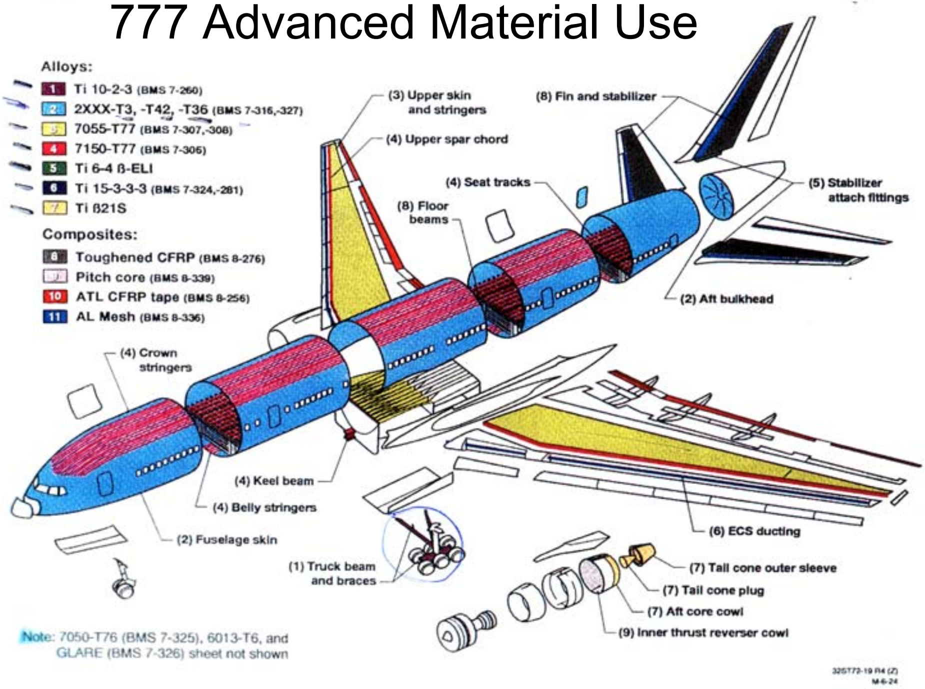
2xxx
7xxx
} aircraft alloys

High strength alloys **not weldable**



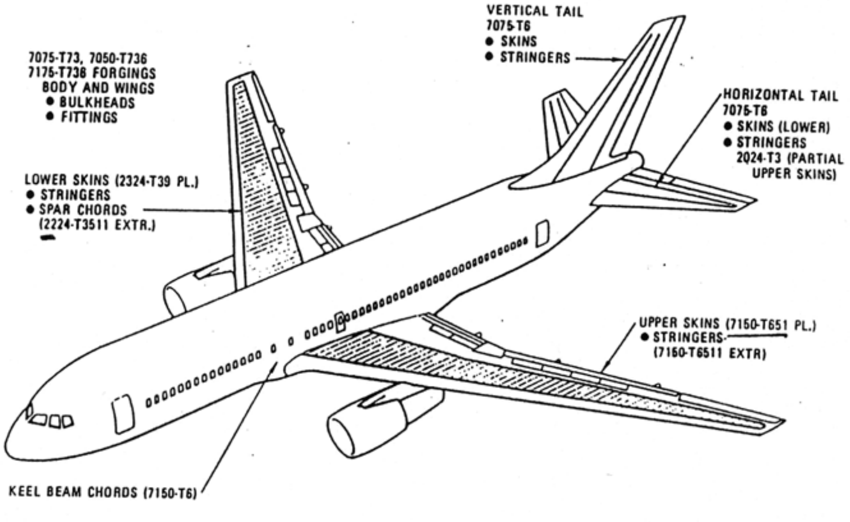
Alloys used in Airplane

777 Advanced Material Use



Note: 7050-T76 (BMS 7-325), 6013-T6, and GLARE (BMS 7-326) sheet not shown

Where Alloys used in 737



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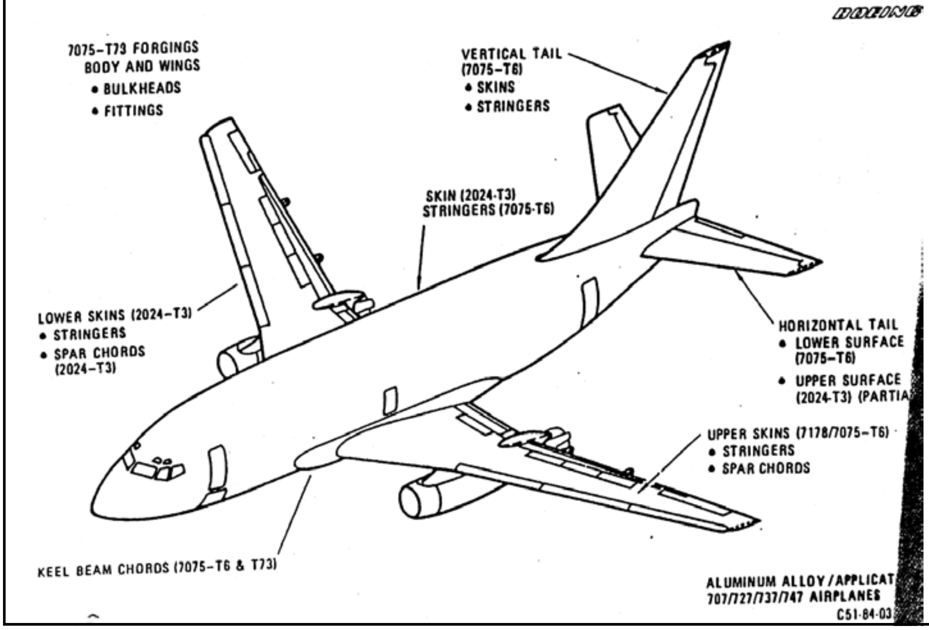
ALUMINUM ALLOY APPLICATIONS
737-300/757/767 AIRPLANES
C51-84-034-01C

Where Alloys used in 707



Concorde: Temperatures of body and wing

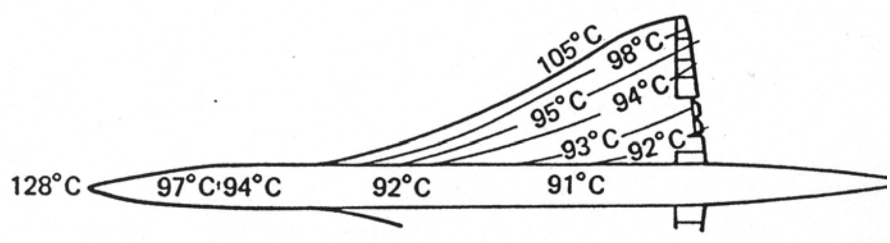


Figure 15.8 Concorde: temperatures of body and wing. (From Murphy[19]; reprod
Royal Society of Arts.)

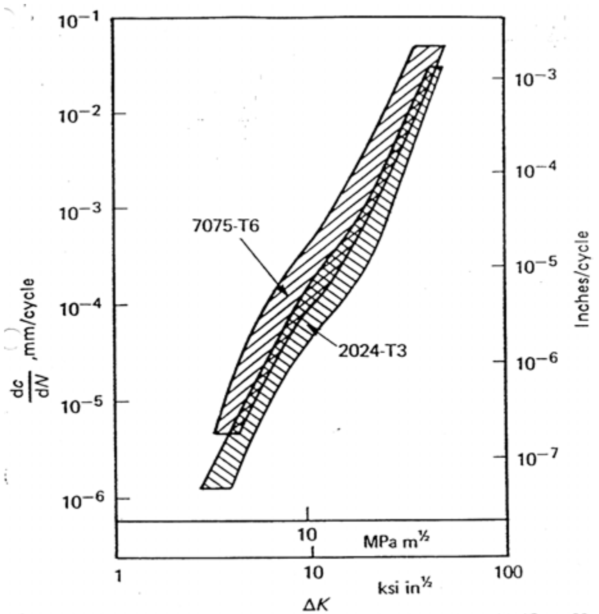


Figure 15.7 Fatigue crack growth rates for 2024-T3 and 7075-T6. (From Ha

Fatigue properties

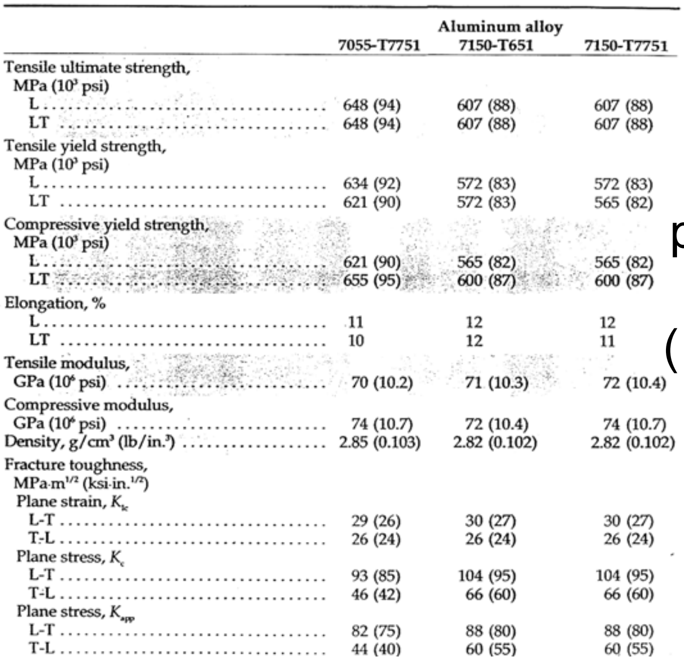
Applications AA7xxx alloys

weldable
Cu
low strgth

Aluminum-zinc-magnesium alloys						
Alloy	% Zn	% Mg	% Cr	% Mn	% Zr	Applications
7004	4.2	1.5		0.45	0.15	Truck bodies and trailer parts; portable bridges; railroad cars; extruded products
7005	4.5	1.4	0.13	0.40	0.14	

Aluminum-zinc-magnesium-copper alloys					
	% Zn	% Mg	% Cu	% Cr	Applications
7001	7.4	3.0	2.1	0.30	Missile structurals
7049	7.7	2.5	1.6	0.15	Aircraft and other structures; hydraulic fittings
7075	5.6	2.5	1.6	0.30	Aircraft and other structures; hydraulic fittings
7475	Lower impurity limits than 7075				Aircraft and other structures (good fracture toughness)
7178	6.8	2.7	2.0	0.30	Aircraft and other structures

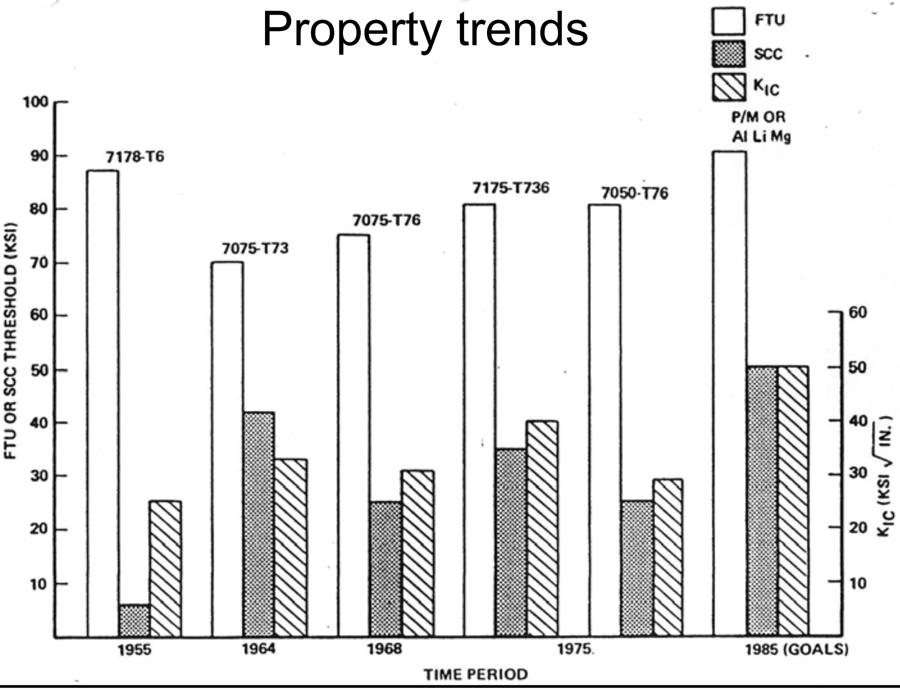
* After "ASM Databook," published in *Met. Prog.*, vol. 114, no. 1, mid-June 1978.



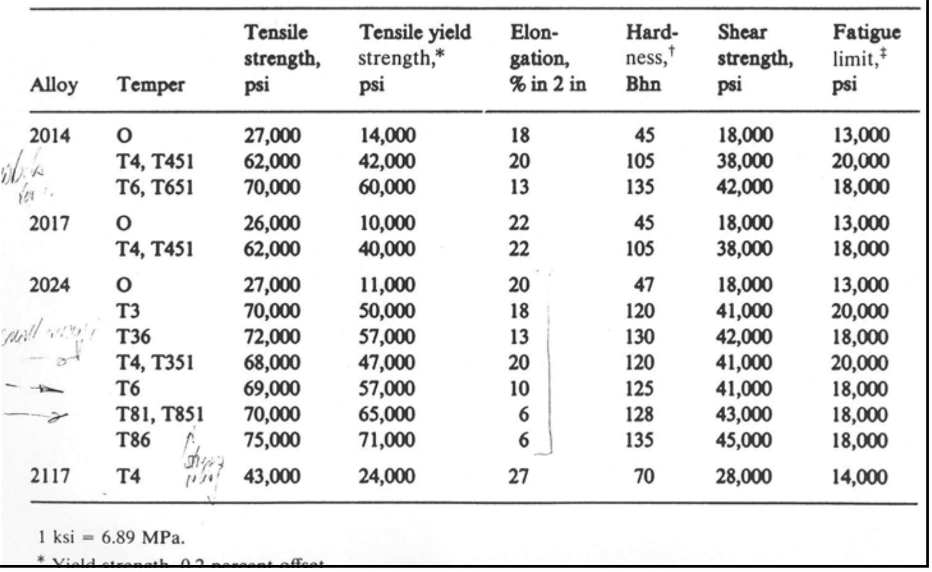
	Aluminum alloy		
	7055-T7751	7150-T651	7150-T7751
Tensile ultimate strength, MPa (10^3 psi)			
L	648 (94)	607 (88)	607 (88)
LT	648 (94)	607 (88)	607 (88)
Tensile yield strength, MPa (10^3 psi)			
L	634 (92)	572 (83)	572 (83)
LT	621 (90)	572 (83)	565 (82)
Compressive yield strength, MPa (10^3 psi)			
L	621 (90)	565 (82)	565 (82)
LT	655 (95)	600 (87)	600 (87)
Elongation, %			
L	11	12	12
LT	10	12	11
Tensile modulus, GPa (10^6 psi)	70 (10.2)	71 (10.3)	72 (10.4)
Compressive modulus, GPa (10^6 psi)	74 (10.7)	72 (10.4)	74 (10.7)
Density, g/cm³ (lb/in.³)	2.85 (0.103)	2.82 (0.102)	2.82 (0.102)
Fracture toughness, MPa·m$^{1/2}$ (ksi·in.$^{1/2}$)			
Plane strain, K_{Ic}			
L-T	29 (26)	30 (27)	30 (27)
T-L	26 (24)	26 (24)	26 (24)
Plane stress, K_c			
L-T	93 (85)	104 (95)	104 (95)
T-L	46 (42)	66 (60)	66 (60)
Plane stress, K_{app}			
L-T	82 (75)	88 (80)	88 (80)
T-L	44 (40)	60 (55)	60 (55)

Typical properties of 25mm (1in.) plate

Property trends



Mechanical properties AA2xxx alloys



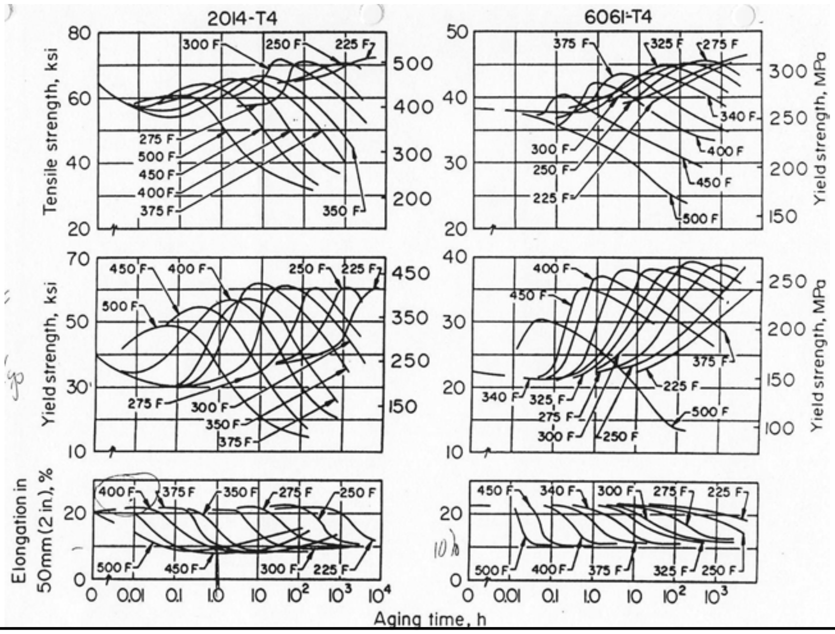
Alloy	Temper	Tensile strength, psi	Tensile yield strength,* psi	Elongation, % in 2 in	Hardness,† Bhn	Shear strength, psi	Fatigue limit,‡ psi
2014	O	27,000	14,000	18	45	18,000	13,000
	T4, T451	62,000	42,000	20	105	38,000	20,000
	T6, T651	70,000	60,000	13	135	42,000	18,000
2017	O	26,000	10,000	22	45	18,000	13,000
	T4, T451	62,000	40,000	22	105	38,000	18,000
2024	O	27,000	11,000	20	47	18,000	13,000
	T3	70,000	50,000	18	120	41,000	20,000
	T36	72,000	57,000	13	130	42,000	18,000
	T4, T351	68,000	47,000	20	120	41,000	20,000
	T6	69,000	57,000	10	125	41,000	18,000
	T81, T851	70,000	65,000	6	128	43,000	18,000
	T86	75,000	71,000	6	135	45,000	18,000
2117	T4	43,000	24,000	27	70	28,000	14,000

small [illegible]

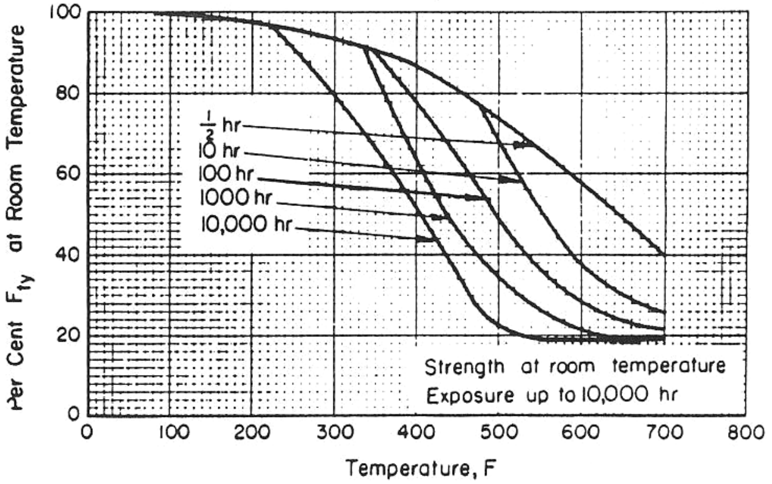
1 ksi = 6.89 MPa.

* Yield strength, 0.2 percent offset.

Aging of 2 sheet alloys at high temperature



Effect of exposure to high temperature on yield strength



Effect of exposure at elevated temperatures on the room-temperature tensile yield strength (F_{ty}) of 2024-T3, T351 and 2024-T4 aluminum alloy (all products except thick extrusions).

Corrosion resistance

- All alloys worse than pure Al
- Worst are highest strength 2xxx and 7xxx – these should be used in the clad condition
- Best are those with Mg present (5xxx and 6xxx)

Aluminum cladding

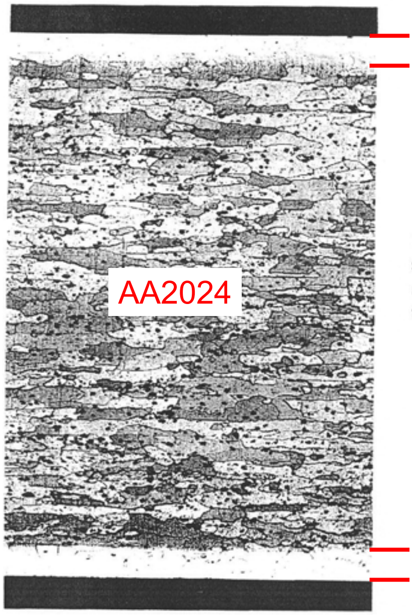


Fig. 12·30 Full cross section of Alclad 2024-T4 sheet showing white cladding layer of commercially pure aluminum on top and bottom of sheet, 125×. (Research Laboratory, Aluminum Company of America.)

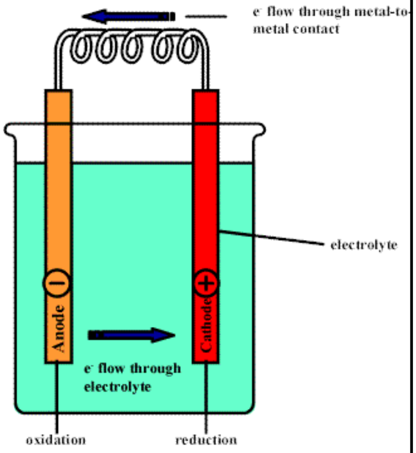
Anodizing aluminum alloys

- Conversion of the aluminum surface to aluminum oxide while the part is the anode in an electrolytic cell
  - 5-18 μm thick coating (most anodizing processes)
  - 25-100 μm thick coating (hard anodizing processes)

Anodizing Aluminum Alloys

Three principle types of anodizing processes

1. Chromic – 3-10% CrO_3
2. Sulfuric – 12-20% H_2SO_4
3. Hard processes – 10-15% H_2SO_4



Reasons for anodizing

- Increases corrosion resistance
- Increases paint adhesion
- Improves decorative appearance – organic dyes can be absorbed into the pores of the coating to provide different colours
- Provides electrical insulation
- Increases abrasion resistance

Joining Aluminum Alloys

Basic properties affecting welding of aluminum

1. Oxidizes readily
   - Oxide m.p. >> Al m.p. therefore it must be removed before a satisfactory welding bond can be made
2. High thermal conductivity (4x low carbon steel)
   - Heat must be applied 4x as fast as steel to raise the temperature locally by the same amount
3. High coefficient of linear expansion (2x that of steel)
   - must be considered when the material is constrained such as by fixturing or part design
4. Relatively low melting point (480-660 °C)
   - no warning just before it melts as aluminum won't change colour

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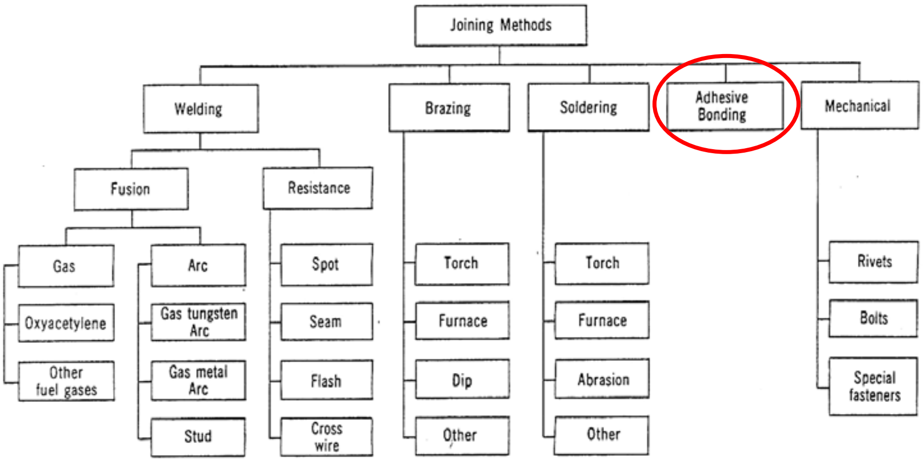
Joining Methods



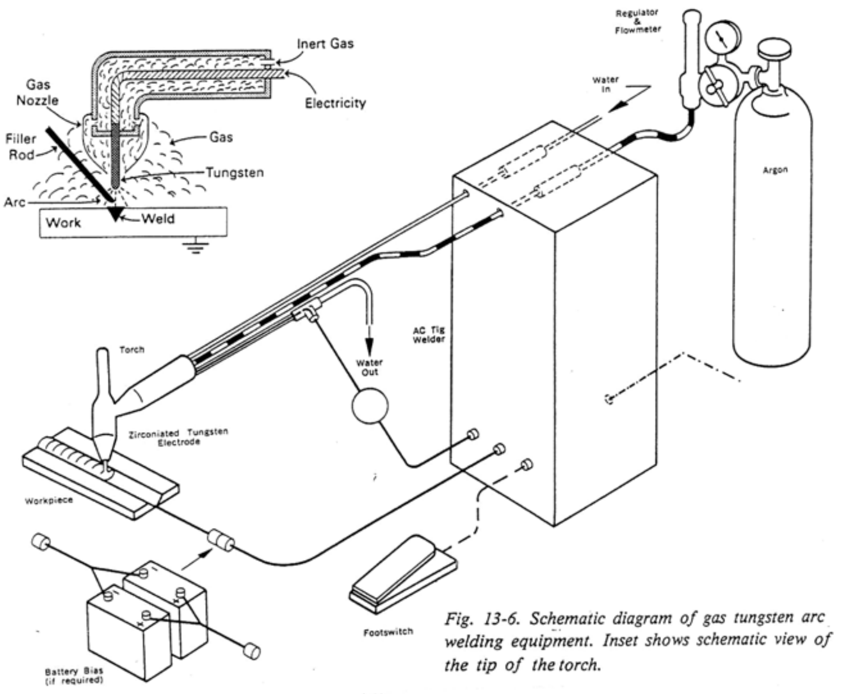


Fig. 13-6. Schematic diagram of gas tungsten arc welding equipment. Inset shows schematic view of the tip of the torch.

Summary of Relative Properties of Adhesive Classifications

Adhesive Classification	Shear Strength	Peel Strength	Flexi-bility	General Chemical Characteristics					Outdoor Resistance	High-Temperature Resistance	Low-Temperature Resistance	Creep at Elevated Temperature	Reference Page
				Water	Oil	Salt Spray	Fuels	Solvents					
Epoxy (High-Strength, Flexible)	A	A-B	C	B	A	B	A	A	B	C	A	A	
Epoxy (High-Strength, Semirigid)	A	D	D	A	A	A	A	A	A	A	A-B	A	
Epoxy (Multiple-Component)	B	C-D	D	C	A	C	B	A	B-C	C	B	A	
Phenolic (Thermoplastic-Modified)	A	B-C	C	A	A	A	A	A	A	B	A	A	
Phenolic (Elastomeric-Modified)	B	B	B	B	A	B	B	B	B	A	B	B	
Natural Rubber	D	C	A	B	D	C	D	D	C	C	B	D	
Chlorinated Rubber	D	C	B	B	C	C	C	D	C	B	B	C	
Cyclicized Rubber	D	C	B	B	D	C	D	D	C	D	C	D	
Rubber Hydrochloride	D	C	A	B	C	C	C	C	C	C	C	C	
GR-S (SBR) Rubber	D	C	B	B	D	C	D	D	B	C	C	C	
Neoprene Rubber	C	B	B	A	B	B	B	B	A	C	B	C	
Nitrile Rubber	C	B	B	A	A	B	A	B	A	B	B	C	
Butyl Rubber	D	C	B	B	D	C	D	B	B	D	C	D	
Polysulfide Rubber	D	C	B	A	B	B	A	B	A	D	B	D	
Silicone Rubber	C	A	A	A	C	A	C	C	A	A	A		
Reclaimed Rubber	C	C	B	B	D	C	D	D	C	C	C	C	
Polyvinyl Acetate	B	C	C	C	B	C	D	C	D	C	C		
Polyvinyl Chloride	C	B	B	C	C	C	C	C	C	D	C	D	
Acrylic	C	C	C	C	B	C	C	D	C	C	B	C	
Hot Melt	C-D	B-D	B-D	B-C	C-D	D	D	C-D	B-D	A-D	C-D	B-D	

New aluminum alloys

Aluminum–Lithium alloys

- Developed in the 1980’s for aircraft and aerospace structures
- Cost 3-5x conventional aluminum alloys (because of special equipment required for processing and high cost of Li)
- Al-Li tend to have low ductility and fracture toughness therefore add Cu and Cu+Mg to provide finer and more homogeneous ppts for strengthening
- Commercial Al-Li alloys have low density, high specific modulus and excellent fatigue and cryogenic properties