Level 2 Age-hardening wrought Al-alloys



The 2000 and 7000 series age-hardening aluminum alloys are the backbone of the aerospace industry. The 6000 series has lower strength but is more easily extruded: it is used for marine and ground transport systems.

THE MATERIAL

The high-strength aluminum alloys rely on age-hardening: a sequence of heat treatment steps that causes the precipitation of a nano-scale dispersion of intermetallics that impede dislocation motion and impart strength. This can be as high as 700 MPa giving them a strength-to-weight ratio exceeding even that of the strongest steels. This record describes for the series of wrought Al alloys that rely on age-hardening requiring a solution heat treatment followed by quenching and ageing. This is recorded by adding TX to the series number, where X is a number between 0 and 8 that records the state of heat treatment. They are listed below using the IADS designations (see Technical notes for details).2000 series: Al with 2 to 6% Cu -- the oldest and most widely used aerospace series.6000 series: Al with up to 1.2% Mg and 1.3% Si -- medium strength extrusions and forgings.7000 series: Al with up to 8% Zn and 3% Mg -- the Hercules of aluminum alloys, used for high strength aircraft structures, forgings and sheet. Certain special alloys also contain silver. So this record, like that for the non-age hardening alloys, is broad, encompassing all of these.

COMPOSITION

2000 series: Al + 2 to 6% Cu + Fe, Mn, Zn and sometimes Zr

6000 series: Al + up to 1.2%Mg + 0.25% Zn + Si, Fe and Mn

7000 series: Al + 4 to 9 % Zn + 1 to 3% Mg + Si, Fe, Cu and occasionally Zr and Ag

GENERAL PROPERTIES

Density	2500	-	2900	kg/m^3
Price	*1.99	-	2.13	USD/kg
Date First Used	1916			

MECHANICAL PROPERTIES

Young's modulus	68	-	80	GPa
Shear modulus	25	-	28	GPa
Bulk modulus	64	-	70	GPa
Poisson's ratio	0.32	-	0.36	
Yield strength (elastic limit)	95	-	610	MPa
Tensile strength	180	-	620	MPa
Compressive strength	95	-	610	MPa
Elongation	1	-	20	%
Hardness—Vickers	60	-	160	HV
Fatigue strength at 10^7 cycles	57	-	210	MPa
Fracture toughness	21	-	35	MPa.m^1/2
Mechanical loss coefficient (tan delta)	1e-4	-	1e-3	

THERMAL PROPERTIES

Melting point	495	-	640	°C
Maximum service temperature	120	-	200	°C
Minimum service temperature	-273			°C
Thermal conductor or insulator?	Good conductor			
Thermal conductivity	118	-	174	W/m.K
Thermal expansion coefficient	22	-	24	µstrain/°C
Specific heat capacity	890	-	1020	J/kg.K

ELECTRICAL PROPERTIES

Electrical conductor or insulator?	Good conductor			
Electrical resistivity	3.8	-	6	µohm.cm

OPTICAL PROPERTIES

Transparency	Opaque

CRITICAL MATERIALS RISK

High critical material risk?	No

PROCESSABILITY

Castability	4	-	5
Formability	3	-	4
Machinability	4	-	5
Weldability	3	-	4
Solder/brazability	2	-	3

ECO PROPERTIES

Embodied energy, primary production	*190	-	210	MJ/kg
CO_2 footprint, primary production	*12.5	-	13.8	kg/kg
Recycle	True			

SUPPORTING INFORMATION

Design guidelines

The age-hardening alloys have exceptional strength at low weight, but the origin of the strength -- age hardening -- imposes certain design constraints. At its simplest, age-hardening involves a three step heat treatment.

Step 1: the wrought alloy, as sheet, extrusion or forging, is solution heat treated -- held for about 2 hours at around 550 C (it depends on the alloys) to make the alloying elements (Cu, Zn, Mg, Si etc) dissolve.

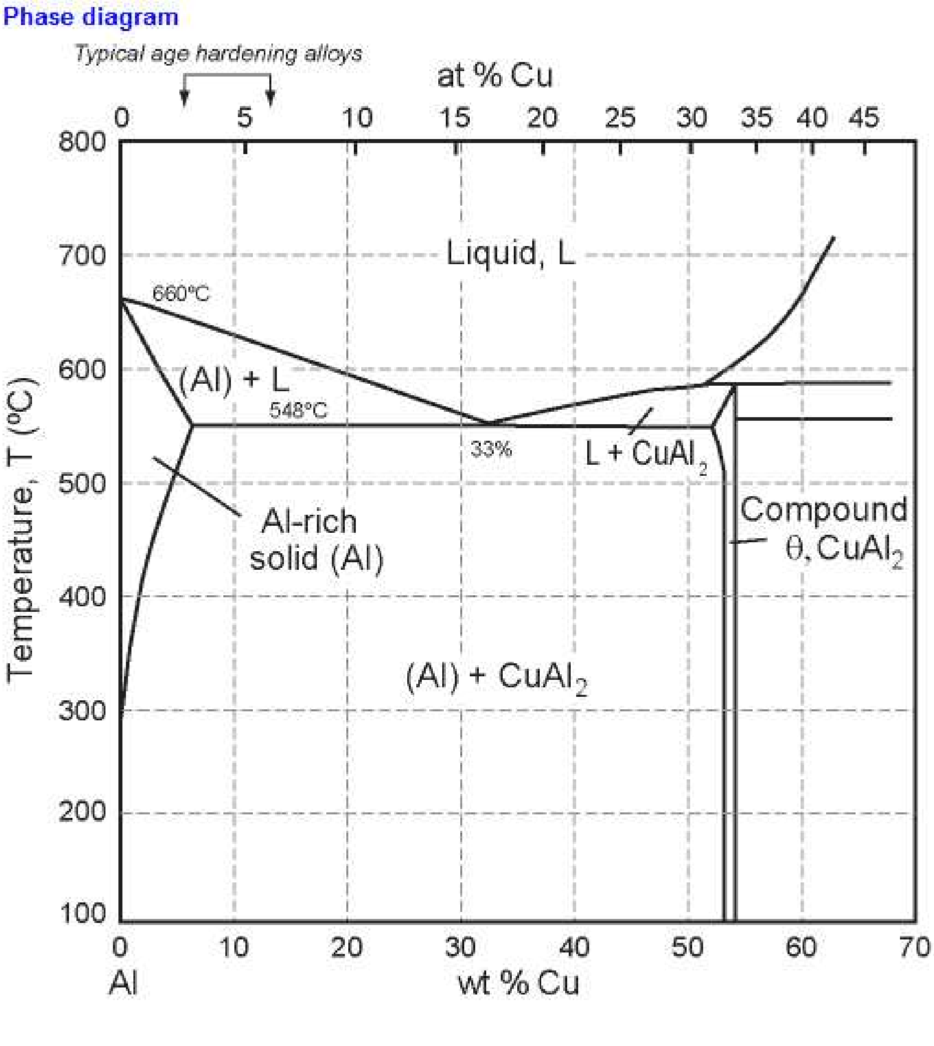
Step 2: the material is quenched from the solution-treatment temperature, typically by dunking or spraying it with cold water. This traps the alloying elements in solution. Quenching is a savage treatment that can cause distortion and create internal stresses that may require correction, usually by rolling.

Step 3: the material is aged, meaning that it is heated to between 120 and 190 C for about 8 hours during which the alloying elements condense into nano-scale dispersions of intermetallics (CuAl, CuAl2, Mg2Si and the like). It is this dispersion that gives the strength.

The result is a material that, for its weight, has remarkably high strength and corrosion resistance. But if it is heated above the solution treatment temperature -- by welding, for example -- the strength is lost. This means that assembly requires fasteners such as rivets, usual in airframe construction, or adhesives. Some 6000 series alloys can be welded, but they are of medium rather than high strength.

Technical notes

Until 1970, designations of wrought aluminum alloys were a mess; in many countries, they were simply numbered in the order of their development. The International Alloy Designation System (IADS), now widely accepted, gives each wrought alloy a 4-digit number. The first digit indicates the major alloying element or elements. Thus the series 1xxx describe unalloyed aluminum; the 2xxx series contain copper as the major alloying element, and so forth. The third and fourth digits are significant in the 1xxx series but not in the others; in 1xxx series they describe the minimum purity of the aluminum; thus 1145 has a minimum purity of 99.45%; 1200 has a minimum purity of 99.00%. In all other series, the third and fourth digits are simply serial numbers; thus 5082 and 5083 are two distinct aluminum-magnesium alloys. The second digit has a curious function: it indicates a close relationship: thus 5352 is closely related to 5052 and 5252; and 7075 and 7475 differ only slightly in composition. To these serial numbers are added a suffix indicating the state of hardening or heat treatment. The suffix F means 'as fabricated'. Suffix O means 'annealed wrought products'. The suffix H means that the material is 'cold worked'. The suffix T means that it has been 'heat treated'. More information on designations and equivalent grades can be found in the Users section of the Granta Design website, www.grantadesign.com



PHASE DIAGRAM DESCRIPTION

The 2000 series of wrought aluminum alloys are based on aluminum (Al) with 2.5-7% copper (Cu). This is the relevant part of the phase diagram.

TYPICAL USES

2000 and 7000 series: aerospace structures, ultralight land-based transport systems.6000 series: cladding and roofing; medium strength extrusions, forgings and welded structures for automotive and general engineering.

LINKS

Reference

ProcessUniverse

Producers

*No warranty is given for the accuracy of this data. Values marked * are estimates*