Description

Image



Caption

1. Aluminum foil. © images-of-elements.com - (CC BY 3.0) 2. Block of crushed, recycled aluminum cans. © Lance Cpl. Miranda Blackburn, United States Marine Corps - Public domain 3. Aluminum drinking can. © Thinkstock

The material

Aluminum is the most important of the light alloys, second only to steel in the volume of its use. When pure it is extremely ductile (it can be rolled to foil only a few microns thick) and corrosion resistant. Pure aluminum has a thermal and electrical conductivity about 60% that of copper (alloying reduces both), and it is only one third as dense. This record is for the series of wrought Al alloys that rely on solution hardening and do not exploit heat treatment. Here they are, using the IADS designations (see Technical notes for details).1000 series: pure Al (99+%) -- familiar as kitchen foil and electrical conductors.3000 series: Al with up to 1.5% Mn -- it can be found in the bodies of drink cans.5000 series: Al with up to 5% Mg -- peel off tops of drink cans, welded structures and pressure vessels; certain variants are superplastic.8000 series: a hodge-podge of special alloys used developed for aerospace and the nuclear industry. So this record is broad, encompassing all of these. None are particularly strong: the 1000 series have strengths around 90 MPa and the strongest 5000 series only reach 300 MPa; but they are robust, not requiring carefully controlled heat treatments that are destroyed by welding.

Composition (summary)

1000 series: 99% Al, some with a little Si
3000 series: Al + 0.3 to 1.5% Mn + Cu, Mg, Si and Fe
5000 series: Al + 0.5 to 5.5% Mg + Mn, Si, Fe and Zn
8000 series: Al + Sn, Ni, Si, Fe

General properties

Density		2.5e3	-	2.9e3	kg/m^3
Price	*	1.9	-	2	USD/kg
Date first used		1914			

Mechanical properties

Young's modulus	68	-	72	GPa
Shear modulus	25	-	28	GPa
Bulk modulus	64	-	69	GPa

Poisson's ratio	0.32	-	0.36	
Yield strength (elastic limit)	30	-	286	MPa
Tensile strength	70	-	360	MPa
Compressive strength	30	-	286	MPa
Elongation	2	-	41	% strain
Hardness - Vickers	30	-	100	HV
Fatigue strength at 10^7 cycles	42	-	160	MPa
Fracture toughness	26	-	42	MPa.m^0.5
Mechanical loss coefficient (tan delta)	2e-4	-	0.002	

Thermal properties

Melting point	570	-	670	°C
Maximum service temperature	130	-	220	°C
Minimum service temperature	-273			°C
Thermal conductor or insulator?	Good conductor			
Thermal conductivity	119	-	240	W/m.°C
Specific heat capacity	886	-	995	J/kg.°C
Thermal expansion coefficient	22	-	25	µstrain/°C

Electrical properties

Electrical conductor or insulator?	Good conductor			
Electrical resistivity	2.5	-	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

Durability: water and aqueous solutions

Water (fresh)	Excellent
Water (salt)	Acceptable
Soils, acidic (peat)	Unacceptable
Soils, alkaline (clay)	Excellent
Wine	

	Excellent

Durability: acids

Acetic acid (10%)	Limited use
Acetic acid (glacial)	Unacceptable
Citric acid (10%)	Acceptable
Hydrochloric acid (10%)	Limited use
Hydrochloric acid (36%)	Unacceptable
Hydrofluoric acid (40%)	Unacceptable
Nitric acid (10%)	Limited use
Nitric acid (70%)	Acceptable
Phosphoric acid (10%)	Unacceptable
Phosphoric acid (85%)	Unacceptable
Sulfuric acid (10%)	Limited use
Sulfuric acid (70%)	Unacceptable

Durability: alkalis

Sodium hydroxide (10%)	Unacceptable
Sodium hydroxide (60%)	Unacceptable

Durability: fuels, oils and solvents

Amyl acetate	Excellent
Benzene	Excellent
Carbon tetrachloride	Excellent
Chloroform	Excellent
Crude oil	Excellent
Diesel oil	Excellent
Lubricating oil	Excellent
Paraffin oil (kerosene)	Excellent
Petrol (gasoline)	Excellent
Silicone fluids	Excellent
Toluene	Excellent
Turpentine	Excellent
Vegetable oils (general)	Excellent
White spirit	Excellent

Durability: alcohols, aldehydes, ketones

Acetaldehyde	Excellent
Acetone	Excellent
Ethyl alcohol (ethanol)	Acceptable
Ethylene glycol	Excellent

Formaldehyde (40%)	Excellent
Glycerol	Excellent
Methyl alcohol (methanol)	Acceptable

Durability: halogens and gases

Chlorine gas (dry)	Limited use
Fluorine (gas)	Unacceptable
O2 (oxygen gas)	Excellent
Sulfur dioxide (gas)	Acceptable

Durability: built environments

Industrial atmosphere	Excellent
Rural atmosphere	Excellent
Marine atmosphere	Excellent
UV radiation (sunlight)	Excellent

Durability: flammability

Flammability	Non-flammable

Durability: thermal environments

Tolerance to cryogenic temperatures	Excellent
Tolerance up to 150 C (302 F)	Acceptable
Tolerance up to 250 C (482 F)	Unacceptable
Tolerance up to 450 C (842 F)	Unacceptable
Tolerance up to 850 C (1562 F)	Unacceptable
Tolerance above 850 C (1562 F)	Unacceptable

Geo-economic data for principal component

Annual world production, principal component		3.69e7			tonne/yr
Reserves, principal component		4.74e10	-	5.24e10	tonne

Primary material production: energy, CO2 and water

Embodied energy, primary production	*	200	-	221	MJ/kg
CO2 footprint, primary production	*	12.5	-	13.8	kg/kg
Water usage	*	1.14e3	-	1.26e3	l/kg
Eco-indicator 95		780			millipoints/kg
Eco-indicator 99		710			millipoints/kg

Material processing: energy

Extrusion, foil rolling energy	*	9.24	-	10.2	MJ/kg
Rough rolling, forging energy	*	4.76	-	5.27	MJ/kg
Wire drawing energy	*	33.9	-	37.5	MJ/kg

Metal powder forming energy	* 22	-	26.6	MJ/kg
Vaporization energy	* 1.55e4	-	1.71e4	MJ/kg
Coarse machining energy (per unit wt removed)	* 1.15	-	1.27	MJ/kg
Fine machining energy (per unit wt removed)	* 7.19	-	7.95	MJ/kg
Grinding energy (per unit wt removed)	* 13.9	-	15.4	MJ/kg
Non-conventional machining energy (per unit wt removed)	155	-	171	MJ/kg

Material processing: CO2 footprint

Extrusion, foil rolling CO2	* 0.693	-	0.766	kg/kg
Rough rolling, forging CO2	* 0.357	-	0.395	kg/kg
Wire drawing CO2	* 2.54	-	2.81	kg/kg
Metal powder forming CO2	* 1.76	-	2.13	kg/kg
Vaporization CO2	* 1.16e3	-	1.28e3	kg/kg
Coarse machining CO2 (per unit wt removed)	* 0.086	-	0.0951	kg/kg
Fine machining CO2 (per unit wt removed)	* 0.54	-	0.596	kg/kg
Grinding CO2 (per unit wt removed)	* 1.04	-	1.15	kg/kg
Non-conventional machining CO2 (per unit wt removed	11.6	-	12.8	kg/kg

Material recycling: energy, CO2 and recycle fraction

Recycle	✔			
Embodied energy, recycling	* 33.7	-	37.2	MJ/kg
CO2 footprint, recycling	* 2.65	-	2.93	kg/kg
Recycle fraction in current supply	10	-	12	%
Downcycle	✔			
Combust for energy recovery	✖			
Landfill	✔			
Biodegrade	✖			
Toxicity rating	Non-toxic			
A renewable resource?	✖			

Environmental notes

Aluminum ore is abundant. It takes a lot of energy to extract aluminum, but it is easily recycled at low energy cost.

Supporting information

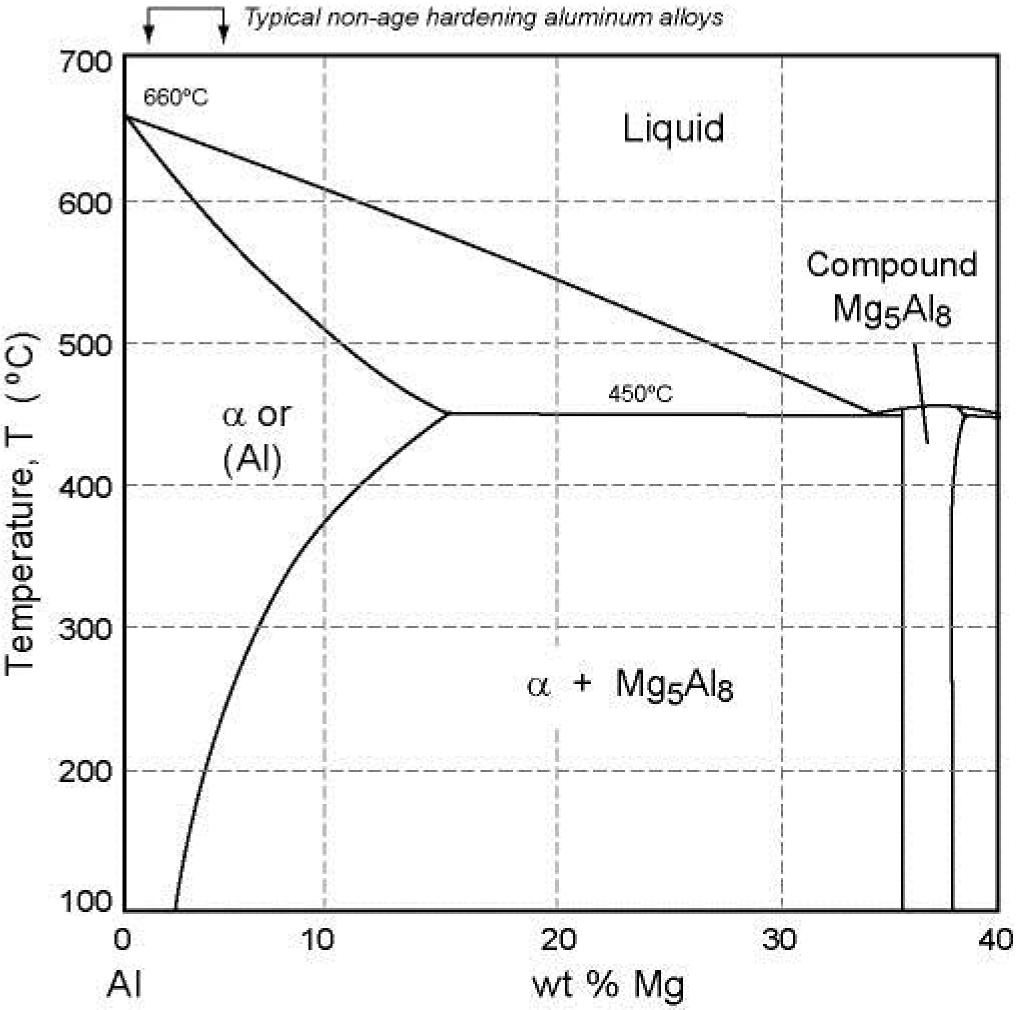
Design guidelines

Aluminum alloys are light, can be strong, and are easily worked. Pure 1000 series aluminum is soft and extremely ductile, allowing it to be rolled to thin sheet. It has outstanding electrical and thermal conductivity (copper is the only competition here). The 3000 series are stronger but still ductile, allowing sheet that can be deep drawn or spun. The 5000 series are stronger still, but at the sacrifice of ductility. Aluminum is relatively cheap, though still more than twice the price of steel. It is a reactive metal - in powder form it can explode - but in bulk an oxide film (Al2O3) forms on its surface, protecting it from corrosion in water and acids but not strong alkalis. The oxide film is thickened and its structure controlled by the process of anodizing; the anodized film will absorb dyes, giving vivid surface colors. Aluminum alloys are not good for sliding surfaces - they scuff - and the fatigue strength of the high-strength alloys is poor.

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 on the Granta Design website at www.grantadesign.com/designations

Phase diagram



Phase diagram description

The 5000 series of wrought aluminum alloys are based on alloys of aluminum (Al) with 1 - 5% magnesium (Mg), for which this is the phase diagram.

Typical uses

1000 series: foil, sheet, wire, food equipment, electrical conductors and bus-bars, coatings for mirrors and reflectors. 3000 series: sheet, beverage can-stock, siding and roofing, cooking utensils, extrusions. 5000 series: sheet and tubing, extrusions for marine and transport applications.

Links

Reference

ProcessUniverse

Producers