Aluminum alloys

The material. Aluminum was once so rare and precious that the Emperor Napoleon III of France had a set of cutlery made from it that cost him more than silver. But that was 1860; today, nearly 150 years later, aluminum spoons are things you throw away—a testament to our ability to be both technically creative and wasteful. Aluminum, the first of the "light alloys" (with magnesium and titanium), is the third most abundant metal in the earth's crust (after iron and silicon), but extracting it costs much energy. It has grown to be the second most important metal in the economy (steel comes first), and the mainstay of the aerospace industry.

Composition

Al + alloying elements, e.g., Mg, Mn, Cr, Cu, Zn, Zr, Li

General properties

Density	2,500	–	2,900	kg/m^3
Price	2.4	–	2.7	USD/kg

Mechanical properties

Young's modulus	68	–	82	GPa
Yield strength (elastic limit)	30	–	550	MPa
Tensile strength	58	–	550	MPa
Elongation	1	–	44	%
Hardness—Vickers	12	–	150	HV
Fatigue strength at 10^7 cycles	22	–	160	MPa
Fracture toughness	22	–	35	$MPa \cdot m^{1/2}$

Thermal properties

Melting point	495	–	640	°C
Maximum service temperature	120	–	200	°C
Thermal conductor or insulator?	Good conductor			
Thermal conductivity	76	–	240	$W/m \cdot K$
Specific heat capacity	860	–	990	$J/kg \cdot K$
Thermal expansion coefficient	21	–	24	µstrain/°C

Electrical properties

Electrical conductor or insulator?	Good conductor			
Electrical resistivity	2.5	–	6	$\mu ohm \cdot cm$

Cast and wrought aluminum alloys, examples of the wide range of properties of this, the most widely used light alloy

Eco properties: material

Global production, main component	37×10^6			metric ton/yr
Reserves	2.0×10^9			metric ton
Embodied energy, primary production	200	–	220	MJ/kg
CO_2 footprint, primary production	11	–	13	kg/kg
Water usage	495	–	1,490	L/kg
Eco-indicator	710			millipoints/kg

Eco properties: processing

Casting energy	11	–	12.2	MJ/kg
Casting CO_2 footprint	0.82	–	0.91	kg/kg
Deformation processing energy	3.3	–	6.8	MJ/kg
Deformation processing CO_2 footprint	0.19	–	0.23	kg/kg

End of life

Embodied energy, recycling	22	–	30	MJ/kg
CO_2 footprint, recycling	1.9	–	2.3	kg/kg
Recycle fraction in current supply	41	–	45	%

Typical uses. Aerospace engineering; automotive engineering—pistons, clutch housings, exhaust manifolds; sports equipment such as golf clubs and bicycles; die cast chassis for household and electronic products; siding for buildings; reflecting coatings for mirrors, foil for containers and packaging; beverage cans; electrical and thermal conductors.

CFRP (Isotropic)

The material. Carbon fiber reinforced polymer (CFRP) composites offer greater stiffness and strength than any other type, but they are considerably more expensive than glass fiber reinforced polymer (GFRP). Continuous fibers in a polyester or epoxy matrix give the highest performance. The fibers carry the mechanical loads, while the matrix material transmits loads to the fibers and provides ductility and toughness as well as protecting the fibers from damage caused by handling or the environment. It is the matrix material that limits the service temperature and processing conditions.

Composition

Epoxy + continuous HS carbon fiber reinforcement (0, + −45, 90), quasi-isotropic lay-up

General properties

Density	1,500	–	1,600	kg/m^3
Price	40.0	–	44.0	USD/kg

Mechanical properties

Young's modulus	69	–	150	GPa
Yield strength (elastic limit)	550	–	1,050	MPa
Tensile strength	550	–	1,050	MPa
Elongation	0.32	–	0.35	%
Hardness—Vickers	10.8	–	21.5	HV
Fatigue strength at 10^7 cycles	150	–	300	MPa
Fracture toughness	6.12	–	20	$MPa \cdot m^{1/2}$

Thermal properties

Maximum service temperature	140	–	220	°C
Thermal conductor or insulator?	Poor insulator			
Thermal conductivity	1.28	–	2.6	$W/m \cdot K$
Specific heat capacity	902	–	1,037	$J/kg \cdot K$
Thermal expansion coefficient	1	–	4	µstrain/°C

Electrical properties

Electrical conductor or insulator?	Poor conductor			
Electrical resistivity	1.65×10^5	–	9.46×10^5	$\mu ohm \cdot cm$

A CFRP bike frame, courtesy TREK

Eco properties: material

Global production, main component	2.8×10^4			metric ton/yr
Embodied energy, primary production	450	–	500	MJ/kg
CO_2 footprint, primary production	33	–	36	kg/kg
Water usage	360	–	1,367	L/kg

Eco properties: processing

Simple composite molding energy	9	–	12.9	MJ/kg
Simple composite molding CO_2	0.77	–	0.89	kg/kg
Advanced composite molding energy	21	–	23	MJ/kg
Advanced composite molding CO_2	1.7	–	1.8	kg/kg

End of life

Recycle fraction in current supply	0	–		%
Heat of combustion	31	–	33	MJ/kg
Combustion CO_2	3.1	–	3.3	kg/kg

Typical uses. Lightweight structural members in aerospace, ground transportation, and sports equipment such as bikes, golf clubs, oars, boats, and racquets; springs; pressure vessels.