Wrought magnesium alloys

Description

Image

Caption

Super light luggage with magnesium sheet faces and extruded edging.

The material

Magnesium is a metal almost indistinguishable from aluminum in color, but of lower density. It is the lightest of the light-metal trio (with partners aluminum and titanium) and light it is: a computer case made from magnesium is barely two thirds as heavy as one made from aluminum. It, aluminum and magnesium are the mainstays of airframe engineering. Only beryllium is lighter, but its expense and potential toxicity limit its use to special applications only. Magnesium is flammable, but this is only a problem when it is in the form of powder or very thin sheet. It costs more than aluminum but nothing like as much as titanium. Magnesium and its alloys have a hexagonal crystal structure (unlike aluminum) restricting their ability to be rolled or forged at room temperature. They can however be extruded, forged and rolled above 350 C. This partly accounts for the low consumption of wrought products -- they account for about 25% of Mg alloy consumption.

Compositional summary

Mg+alloying elements, e.g. Al, Mn, Si, Zn, Cu, Li, rare earth elements

General properties

Density	1.5e3	-	1.95e3	kg/m^3
Price	* 3.04	-	3.18	USD/kg
Date first used	1950			

Mechanical properties

Young's modulus	42	-	47	GPa
Shear modulus	16	-	19	GPa
Bulk modulus	35	-	41	GPa
Poisson's ratio	0.29	-	0.31	
Yield strength (elastic limit)	115	-	410	MPa
Tensile strength	185	-	450	MPa
Compressive strength	115	-	410	MPa

Elongation		3.5	-	18	% strain
Hardness - Vickers		43	-	135	HV
Fatigue strength at 10^7 cycles	*	90	-	225	MPa
Fracture toughness	*	12	-	18	MPa.m^0.5
Mechanical loss coefficient (tan delta)		9e-4	-	0.02	

Thermal properties

Melting point	447	-	649	°C
Maximum service temperature	120	-	200	°C
Minimum service temperature	-83.2	-	-53.2	°C
Thermal conductor or insulator?	Good conductor			
Thermal conductivity	50	-	126	W/m.°C
Specific heat capacity	955	-	1.06e3	J/kg.°C
Thermal expansion coefficient	24.6	-	28	µstrain/°C

Electrical properties

Electrical conductor or insulator?	Good conductor			
Electrical resistivity	4.15	-	15	µohm.cm

Optical properties

Transparency	Opaque

Processability

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

Durability: water and aqueous solutions

Water (fresh)	Excellent
Water (salt)	Limited use
Soils, acidic (peat)	Limited use
Soils, alkaline (clay)	Limited use
Wine	Limited use

Durability: acids

Acetic acid (10%)	Limited use
Acetic acid (glacial)	Unacceptable
Citric acid (10%)	Limited use
Hydrochloric acid (10%)	Unacceptable
Hydrochloric acid (36%)	

	Unacceptable
Hydrofluoric acid (40%)	Acceptable
Nitric acid (10%)	Unacceptable
Nitric acid (70%)	Unacceptable
Phosphoric acid (10%)	Unacceptable
Phosphoric acid (85%)	Unacceptable
Sulfuric acid (10%)	Unacceptable
Sulfuric acid (70%)	Unacceptable

Durability: alkalis

Sodium hydroxide (10%)	Acceptable
Sodium hydroxide (60%)	Acceptable

Durability: fuels, oils and solvents

Amyl acetate	Excellent
Benzene	Excellent
Carbon tetrachloride	Excellent
Chloroform	Excellent
Crude oil	Limited use
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)	Excellent
Ethylene glycol	Excellent
Formaldehyde (40%)	Excellent
Glycerol	Excellent
Methyl alcohol (methanol)	Excellent

Durability: halogens and gases

Chlorine gas (dry)	Limited use
Fluorine (gas)	Acceptable

O2 (oxygen gas)	Unacceptable			
Sulfur dioxide (gas)	Excellent			

Durability: built environments

Industrial atmosphere	Acceptable			
Rural atmosphere	Excellent			
Marine atmosphere	Limited use			
UV radiation (sunlight)	Excellent			

Durability: flammability

Flammability	Non-flammable			

Durability: thermal environments

Tolerance to cryogenic temperatures	Unacceptable			
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	5.7e5			tonne/yr
Reserves, principal component	2.4e15	-	2.54e15	tonne

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 294	-	324	MJ/kg
CO2 footprint, primary production	* 33.6	-	37.1	kg/kg
Water usage	* 931	-	1.03e3	l/kg
Eco-indicator 99	790			millipoints/kg

Material processing: energy

Extrusion, foil rolling energy	* 11.7	-	12.9	MJ/kg
Rough rolling, forging energy	* 5.99	-	6.62	MJ/kg
Wire drawing energy	* 43.1	-	47.6	MJ/kg
Metal powder forming energy	* 20	-	24.2	MJ/kg
Vaporization energy	* 1.45e4	-	1.6e4	MJ/kg
Coarse machining energy (per unit wt removed)	* 1.33	-	1.47	MJ/kg
Fine machining energy (per unit wt removed)	* 9.03	-	9.99	MJ/kg
Grinding energy (per unit wt removed)	* 17.6	-	19.4	MJ/kg
Non-conventional machining energy (per unit wt removed)	145	-	160	MJ/kg

Material processing: CO2 footprint

Extrusion, foil rolling CO2	* 0.877	-	0.97	kg/kg
Rough rolling, forging CO2	* 0.449	-	0.497	kg/kg
Wire drawing CO2	* 3.23	-	3.57	kg/kg
Metal powder forming CO2	* 1.6	-	1.94	kg/kg
Vaporization CO2	* 1.08e3	-	1.2e3	kg/kg
Coarse machining CO2 (per unit wt removed)	* 0.0998	-	0.11	kg/kg
Fine machining CO2 (per unit wt removed)	* 0.678	-	0.749	kg/kg
Grinding CO2 (per unit wt removed)	* 1.32	-	1.46	kg/kg
Non-conventional machining CO2 (per unit wt removed)	10.8	-	12	kg/kg

Material recycling: energy, CO2 and recycle fraction

Recycle	✓			
Embodied energy, recycling	* 45.1	-	49.8	MJ/kg
CO2 footprint, recycling	* 3.54	-	3.92	kg/kg
Recycle fraction in current supply	9.2	-	11.4	%
Downcycle	✓			
Combust for energy recovery	✗			
Landfill	✓			
Biodegrade	✗			
Toxicity rating	Non-toxic			
A renewable resource?	✗			

Environmental notes

Magnesium is the fifth most abundant metal in the Earth's crust, and the third in its oceans - and it can be extracted economically from both (the Dead Sea, thick with dissolved salts - is the best source of all). But its extraction is very energy intensive, consuming three times more per unit weight than commodity polymers and nearly twice as much as aluminum. It can be recycled, and doing this uses barely one fifth as much energy.

Supporting information

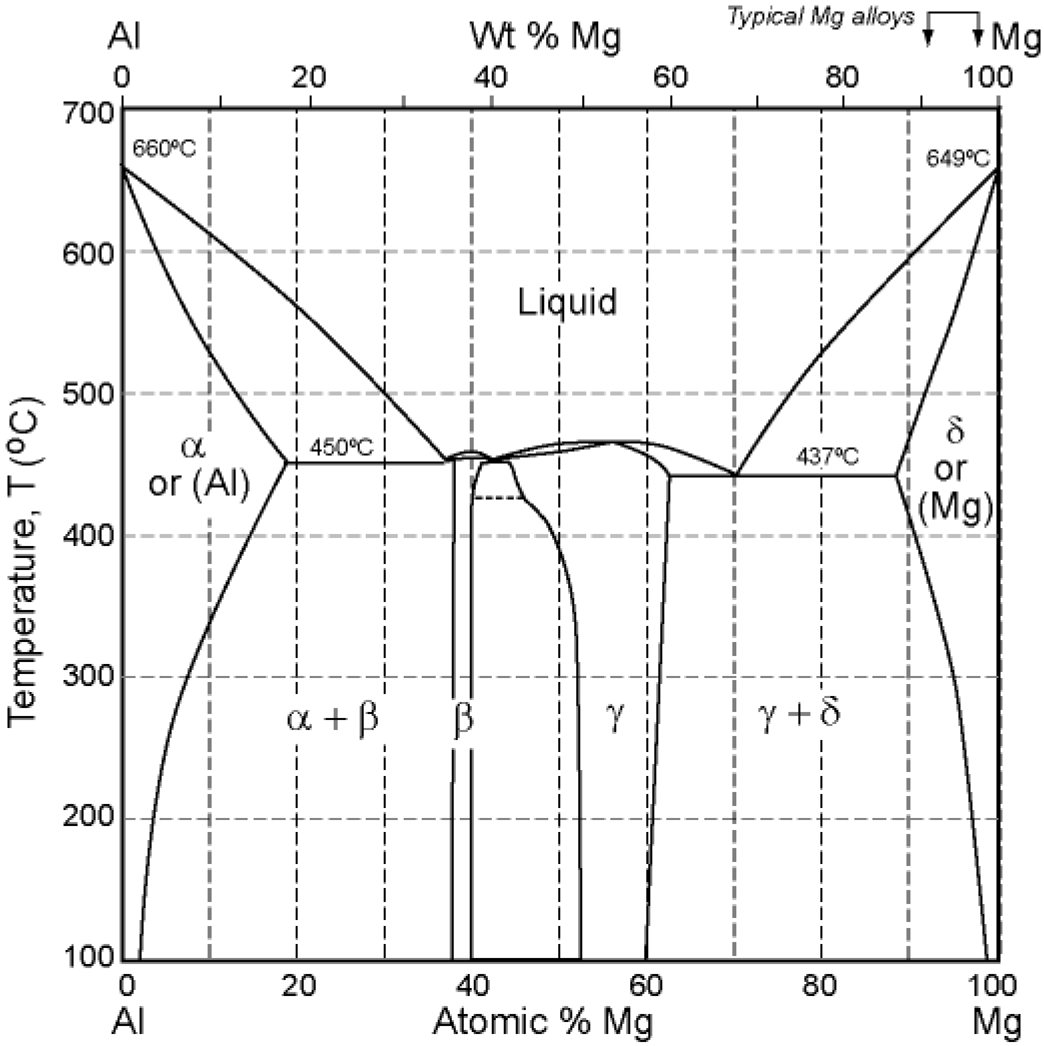
Design guidelines

Magnesium has a low density, good mechanical damping, much better thermal conductivity than steel, less good electrical conductivity than copper and aluminum, but still good. It survives well in the protected environment of a house or office, but it corrodes badly in salt water and acids; even sweat is enough to tarnish it, requiring coatings for protection. It is easy to machine, but because of its low stiffness, parts must be firmly clamped while doing so. Magnesium alloys are designed for specific forming purposes: AZ31B, for instance, is designed for extrusions. Most magnesium alloys can be welded using TIG or MIG methods; and soldering and adhesive bonding are both feasible. Spot and seam welds are possible but only in low stress applications; riveting is better, provided aluminum rivets are used to avoid galvanic corrosion.

Technical notes

The classification system of the American Society for Testing Materials (ASTM) is the most widely used. In this system, the first two letters indicate the principal alloying elements, thus: A = aluminum, C = copper, E = rare earths, K = zirconium, L = lithium, M = manganese, S = silicon, Z = zinc. The letter corresponding to the element present in the greatest quantity is used first; if they are equal, they are listed alphabetically. The letters are followed by numbers that list the amount of the principal alloying elements in weight % rounded to the nearest whole number; thus AZ91 means the alloy 90% Mg, 9% Al and 1% Zn; LA141 means the alloy 85% Mg, 14% Li and 1% Al.

Phase diagram



Phase diagram description

Wrought magnesium alloys are based on alloys of magnesium (Mg) with 3 - 8% aluminum (Al), some with additions of zinc, manganese or copper. This is the magnesium - aluminum phase diagram.

Typical uses

Aerospace; automotive; sports goods such as bicycles; nuclear fuel cans; vibration damping and shielding of machine tools; engine case castings; crank cases; transmission housings; automotive wheels; ladders; housings for electronic equipment, particularly mobile phone and portable computer chassis; camera bodies; office equipment; marine hardware and lawnmowers.

Tradenames

Electron, Dowmetal, Revere alloy, Eclipsalloy

Links

Reference	
ProcessUniverse	
Producers	