Description

Image

Caption

1. Titanium bulkhead for F15 jet fighter before and after pressing by the Alcoa 50,000 ton press. © Jet Lowe, US National Park Service - Public domain 2. Titanium glasses. © Chris Lefteri

The material

Titanium is the seventh most abundant metal in the Earth's crust, but extracting the metal from the oxide in which it occurs naturally is unusually difficult. This makes titanium, third member of the light alloy trio, by far the most expensive of the three (more than ten times the price of aluminum). Despite this, the use of titanium is growing, propelled by its remarkable properties. It has a high melting point (1677 C), it is light, and - although reactive - its resists corrosion in most chemicals, protected by a thin film of oxide on its surface. Titanium has unusually low thermal and electrical conductivity, and low expansion coefficients.

Composition (summary)

> 99% Ti

General properties

Density		281	-	282	lb/ft^3
Price	*	4.55	-	5	USD/lb
Date first used		1910			

Mechanical properties

Young's modulus		14.5	-	15.2	10^6 psi
Shear modulus		5.22	-	7.4	10^6 psi
Bulk modulus		16	-	19.6	10^6 psi
Poisson's ratio		0.35	-	0.37	
Yield strength (elastic limit)		39.2	-	87	ksi
Tensile strength		65.3	-	94.3	ksi
Compressive strength		39.2	-	87	ksi
Elongation		5	-	25	% strain
Hardness - Vickers		155	-	165	HV
Fatigue strength at 10^7 cycles	*	29	-	43.5	ksi
Fracture toughness		50.1	-	54.6	ksi.in^0.5
Mechanical loss coefficient (tan delta)		0.002	-	0.003	

Thermal properties

Melting point		3.03e3	-	3.05e3	°F
Maximum service temperature		752	-	842	°F
Minimum service temperature		-460			°F

Thermal conductor or insulator?	Poor conductor			
Thermal conductivity	9.24	-	10.4	BTU.ft/h.ft^2.F
Specific heat capacity	0.127	-	0.129	BTU/lb.°F
Thermal expansion coefficient	4.72	-	5.17	µstrain/°F

Electrical properties

Electrical conductor or insulator?	Good conductor			
Electrical resistivity	55	-	57	µohm.cm

Optical properties

Transparency	Opaque

Processability

Castability	3		
Formability	2	-	4
Machinability	1	-	3
Weldability	4	-	5
Solder/brazability	1	-	2

Durability: water and aqueous solutions

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

Durability: acids

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

Durability: alkalis

Sodium hydroxide (10%)	Excellent
Sodium hydroxide (60%)	Excellent

Durability: fuels, oils and solvents

Amyl acetate	Excellent
Benzene	Excellent
Carbon tetrachloride	Limited use
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)	Excellent
Ethylene glycol	Excellent
Formaldehyde (40%)	Excellent
Glycerol	Excellent

Durability: halogens and gases

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

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

Geo-economic data for principal component

Annual world production	1.97e5	ton/yr
Reserves	7.14e8	l. ton

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 5.94e4	-	6.57e4	kcal/lb
CO2 footprint, primary production	* 37.1	-	41	lb/lb
Water usage	* 12.3	-	13.7	gal(US)/lb
Eco-indicator 99	3.05e3			millipoints/kg

Material processing: energy

Casting energy	* 1.38e3	-	1.53e3	kcal/lb
Extrusion, foil rolling energy	* 987	-	1.09e3	kcal/lb
Rough rolling, forging energy	* 509	-	562	kcal/lb
Wire drawing energy	* 3.62e3	-	4e3	kcal/lb
Metal powder forming energy	* 4.95e3	-	5.46e3	kcal/lb
Vaporization energy	* 1.58e6	-	1.74e6	kcal/lb
Coarse machining energy (per unit wt removed)	* 124	-	137	kcal/lb
Fine machining energy (per unit wt removed)				

	* 768	-	849	kcal/lb
Grinding energy (per unit wt removed)	* 1.48e3	-	1.65e3	kcal/lb
Non-conventional machining energy (per unit wt removed)	1.58e4	-	1.74e4	kcal/lb

Material processing: CO2 footprint

Casting CO2	* 0.955	-	1.06	lb/lb
Extrusion, foil rolling CO2	* 0.683	-	0.755	lb/lb
Rough rolling, forging CO2	* 0.352	-	0.389	lb/lb
Wire drawing CO2	* 2.5	-	2.77	lb/lb
Metal powder forming CO2	* 3.66	-	4.03	lb/lb
Vaporization CO2	* 1.09e3	-	1.21e3	lb/lb
Coarse machining CO2 (per unit wt removed)	* 0.0853	-	0.0943	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.532	-	0.588	lb/lb
Grinding CO2 (per unit wt removed)	* 1.03	-	1.14	lb/lb
Non-conventional machining CO2 (per unit wt removed)	10.9	-	12.1	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	✓			
Embodied energy, recycling	* 7.84e3	-	8.68e3	kcal/lb
CO2 footprint, recycling	* 5.69	-	6.29	lb/lb
Recycle fraction in current supply	22	-	24	%
Downcycle	✓			
Combust for energy recovery	✗			
Landfill	✓			
Biodegrade	✗			
Toxicity rating	Non-toxic			
A renewable resource?	✗			

Environmental notes

Extracting titanium from its ores is very energy intensive. It can be recycled provided it is not contaminated with oxygen.

Supporting information

Design guidelines

Titanium is expensive, requiring vacuum processing to prevent take up of oxygen, which makes it brittle. But it is unusually strong, light and corrosion resistant, so much so that pure titanium can be implanted in the body to repair broken bones. The drive to miniaturize consumer electronics gives titanium a growing importance in product design. The casings of mobile phones and portable computers are now so thin that polymers cannot take the strain - they are not stiff or strong enough. The strength and low density of titanium makes it - despite its cost - an attractive replacement.

Technical notes

Titanium is an allotropic metal that can exist in two different crystal structures (iron is another). At room temperature it is hexagonal, called alpha-titanium. At 884 C it transforms to a body-centered cubic structure called beta-titanium. Alloying elements stabilize one or other of the two structures giving great scope for manipulating properties by alloying and heat treatment. See the record for Titanium alloys for more.

Typical uses

Chemical engineering; heat exchangers; bioengineering; medical applications including surgical implants; eyeglass frames; sports equipment such as golf clubs and bicycles; casings for mobile phones and portable computers.

Links

Reference

ProcessUniverse

Producers