Description

Image



Caption

1. Titanium Billet © Kirt Edblom at flickr (CC BY 2.0) 2. Titanium makes cool colors and patterns when it gets burned © David DeHetre at flickr (CC BY 2.0) 3. PowerBook G4 Titanium © Raneko at flickr (CC BY 2.0)

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	4.5e3	-	4.52e3	kg/m^3
Price	* 12.7	-	14.3	USD/kg
Date first used	1910			

Mechanical properties

Young's modulus	100	-	105	GPa
Shear modulus	36	-	51	GPa
Bulk modulus	110	-	135	GPa
Poisson's ratio	0.35	-	0.37	
Yield strength (elastic limit)	270	-	600	MPa
Tensile strength	450	-	650	MPa
Compressive strength	270	-	600	MPa
Elongation	5	-	25	% strain

Hardness - Vickers	155	-	165	HV
Fatigue strength at 10^7 cycles	* 200	-	300	MPa
Fracture toughness	55	-	60	MPa.m^0.5
Mechanical loss coefficient (tan delta)	0.002	-	0.003	

Thermal properties

Melting point	1.67e3	-	1.68e3	°C
Maximum service temperature	400	-	450	°C
Minimum service temperature	-273			°C
Thermal conductor or insulator?	Poor conductor			
Thermal conductivity	16	-	18	W/m.°C
Specific heat capacity	530	-	541	J/kg.°C
Thermal expansion coefficient	8.5	-	9.3	µstrain/°C

Electrical properties

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

Optical properties

Transparency	Opaque

Critical Materials Risk

High critical material risk?	No

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, principal component	2e5	tonne/yr
Reserves, principal component	7.25e8	tonne

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 548	-	606	MJ/kg
CO2 footprint, primary production	* 37.1	-	41	kg/kg
Water usage	* 103	-	114	l/kg
Eco-indicator 99	3.05e3			millipoints/kg

Material processing: energy

Casting energy	* 12.7	-	14.1	MJ/kg
Extrusion, foil rolling energy	* 9.11	-	10.1	MJ/kg
Rough rolling, forging energy	* 4.7	-	5.19	MJ/kg
Wire drawing energy	* 33.4	-	36.9	MJ/kg
Metal powder forming energy	* 45.7	-	50.4	MJ/kg
Vaporization energy	* 1.46e4	-	1.61e4	MJ/kg
Coarse machining energy (per unit wt removed)	* 1.14	-	1.26	MJ/kg
Fine machining energy (per unit wt removed)	* 7.09	-	7.84	MJ/kg
Grinding energy (per unit wt removed)	* 13.7	-	15.2	MJ/kg
Non-conventional machining energy (per unit wt removed)	146	-	161	MJ/kg

Material processing: CO2 footprint

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

Material recycling: energy, CO2 and recycle fraction

Recycle	✓			
Embodied energy, recycling	* 72.4	-	80.1	MJ/kg
CO2 footprint, recycling	* 5.69	-	6.29	kg/kg
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