Description

Image

Caption

1. Jet engine. © Rolls-Royce plc 2. Cross section of a gas turbine showing its titanium blades. © iStockphoto 3. Titanium cladding for buildings. © John Fernandez

The material

Titan was a Greek god, remarkable for his size and strength. His name has been appropriated many times, not always aptly (think of the Titanic). But the alloys of titanium merit the association: the strongest of them have the highest strength-to-weight ratio of any structural metal, about 25% greater than the best alloys of aluminum or steel. Titanium alloys can be used at temperatures up to 500 C - compressor blades of aircraft turbines are made of them. They have unusually poor thermal and electrical conductivity, and low expansion coefficients. The alloy Ti 6%Al 4% V is used in quantities that exceed those of all other titanium alloys combined. The data in this record describes it and similar alloys.

Composition (summary)

Ti + alloying elements, e.g. Al, Zr, Cr, Mo, Si, Sn, Ni, Fe, V

General properties

Density	275	-	300	lb/ft^3
Price	* 9.39	-	10.3	USD/lb
Date first used	1952			

Mechanical properties

Young's modulus	16	-	17.4	10^6 psi
Shear modulus	5.8	-	6.53	10^6 psi
Bulk modulus	13.9	-	14.8	10^6 psi
Poisson's ratio	0.35	-	0.37	
Yield strength (elastic limit)	109	-	174	ksi
Tensile strength	116	-	210	ksi
Compressive strength	109	-	174	ksi
Elongation	5	-	10	% strain

Hardness - Vickers	267	-	380	HV
Fatigue strength at 10^7 cycles	* 85.4	-	89.5	ksi
Fracture toughness	50.1	-	63.7	ksi.in^0.5
Mechanical loss coefficient (tan delta)	5e-4	-	0.002	

Thermal properties

Melting point	2.69e3	-	3.06e3	°F
Maximum service temperature	842	-	932	°F
Minimum service temperature	-460			°F
Thermal conductor or insulator?	Poor conductor			
Thermal conductivity	4.04	-	8.09	BTU.ft/h.ft^2.F
Specific heat capacity	0.154	-	0.156	BTU/lb.°F
Thermal expansion coefficient	4.94	-	5.33	µstrain/°F

Electrical properties

Electrical conductor or insulator?	Good conductor			
Electrical resistivity	100	-	170	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)	Excellent
Citric acid (10%)	Acceptable

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

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)	Acceptable
Ethylene glycol	Limited use
Formaldehyde (40%)	Excellent
Glycerol	Excellent
Methyl alcohol (methanol)	Limited use

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)	Excellent
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	1.97e5	ton/yr
Reserves, principal component	7.14e8	I. ton

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 7.05e4	-	7.8e4	kcal/lb
CO2 footprint, primary production	* 44.1	-	48.7	lb/lb
Water usage	* 22.4	-	24.8	gal(US)/lb
Eco-indicator 99	3.45e3			millipoints/kg

Material processing: energy

Casting energy	* 1.37e3	-	1.51e3	kcal/lb
Extrusion, foil rolling energy	* 2.99e3	-	3.32e3	kcal/lb
Rough rolling, forging energy	* 1.52e3	-	1.67e3	kcal/lb
Wire drawing energy	* 1.12e4	-	1.24e4	kcal/lb
Metal powder forming energy	* 5.07e3	-	5.83e3	kcal/lb
Vaporization energy	* 1.58e6	-	1.74e6	kcal/lb
Coarse machining energy (per unit wt removed)	* 274	-	302	kcal/lb
Fine machining energy (per unit wt removed)	* 2.28e3	-	2.51e3	kcal/lb
Grinding energy (per unit wt removed)	* 4.5e3	-	4.97e3	kcal/lb
Non-conventional machining energy (per unit wt removed)				

	1.58e4	-	1.74e4	kcal/lb

Material processing: CO2 footprint

Casting CO2	* 0.942	-	1.04	lb/lb
Extrusion, foil rolling CO2	* 2.07	-	2.29	lb/lb
Rough rolling, forging CO2	* 1.05	-	1.16	lb/lb
Wire drawing CO2	* 7.72	-	8.53	lb/lb
Metal powder forming CO2	* 3.74	-	4.31	lb/lb
Vaporization CO2	* 1.09e3	-	1.21e3	lb/lb
Coarse machining CO2 (per unit wt removed)	* 0.19	-	0.209	lb/lb
Fine machining CO2 (per unit wt removed)	* 1.57	-	1.74	lb/lb
Grinding CO2 (per unit wt removed)	* 3.11	-	3.44	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	* 8.95e3	-	9.89e3	kcal/lb
CO2 footprint, recycling	* 6.49	-	7.17	lb/lb
Recycle fraction in current supply	20	-	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

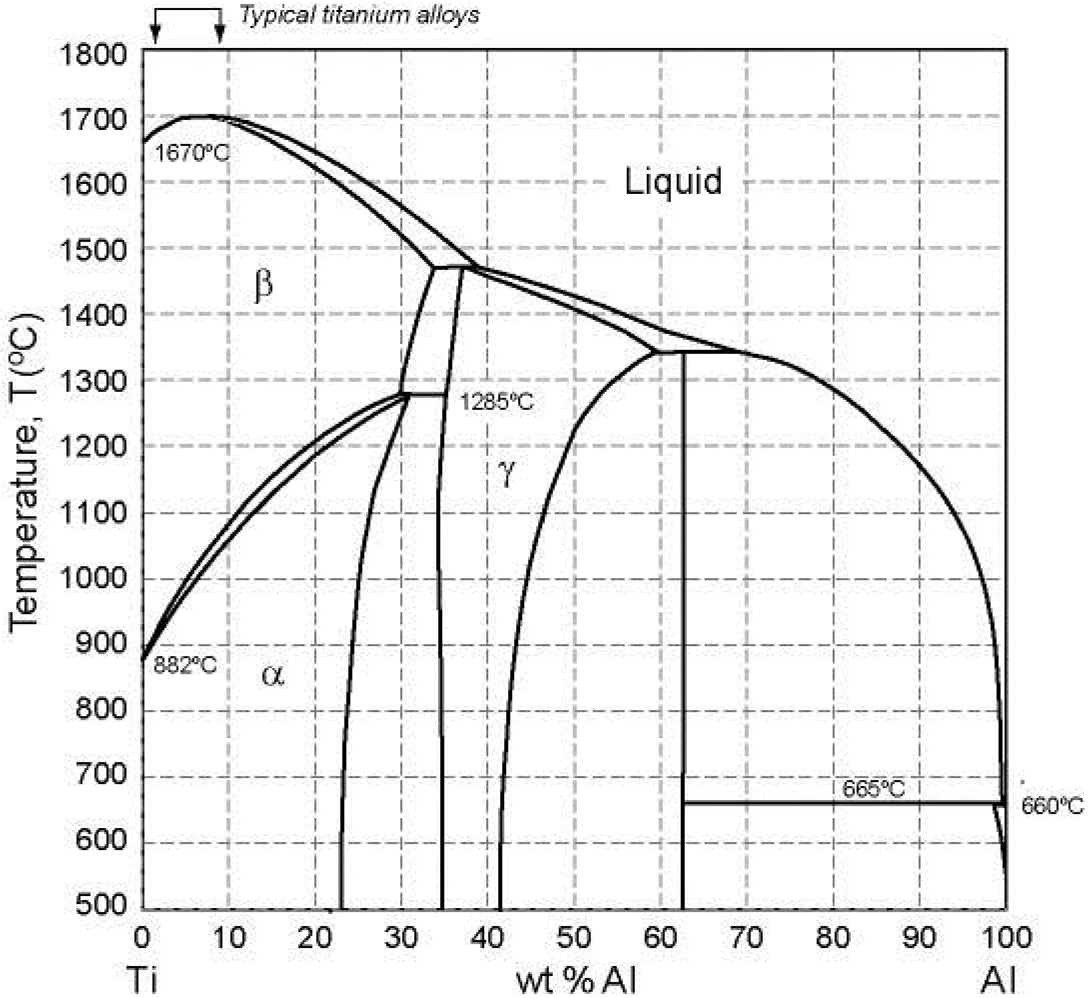
Design guidelines

Titanium alloys are expensive, requiring vacuum processing to prevent take up of oxygen, which makes them brittle. But they unusually strong, light and corrosion resistant, so much so that pure titanium can be implanted in the body to repair broken bones. More usually it is alloyed with aluminum and vanadium (Ti with 8% Al 6%V, or simply Ti - 6 - 4) to give a material that can be forged and worked yet has good resistance to creep. Titanium alloys have limited ductility - sheet cannot easily be bent to radii less than 1.5 times its thickness. They can - with difficulty - be welded, but are easy to diffusion bond.

Technical notes

There are four groups of titanium alloys: alpha alloys, near-alpha alloys, alpha-beta alloys, and beta alloys. The alpha alloys have an hcp crystal structure; the beta alloys are bcc. Alpha alloys are preferred for high temperature applications because of their creep resistance and for cryogenic applications because of their good toughness at low temperatures. A designation system with some logic to it simply lists the quantities of the principal alloying additions; thus 'Ti-8-1-1' contains 8% aluminum, 1% molybdenum and 1% vanadium; and 'Ti-6-4' means 6% aluminum and 4% vanadium. The alloy Ti 5% Al 2.5% Sn is the most widely used alpha alloy; it is used in space and aircraft structures. The alloy Ti 6% Al 4% V has a mixed alpha-beta structure; it is the most widely used of all titanium alloys. 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

Titanium alloys have complex compositions. Most are based on titanium (Ti) with 2 - 8% aluminum (Al) for which this is the phase diagram, with additions of vanadium, tin, zirconium and molybdenum.

Typical uses

Aircraft turbine blades, general aerospace applications, chemical engineering, heat exchangers, bioengineering, medical, missile fuel tanks, heat exchangers, compressors, valve bodies, light springs, surgical implants, marine hardware, paper-pulp equipment, sports equipment such as golf clubs and bicycles, casings for mobile phones and portable computers.

Links

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