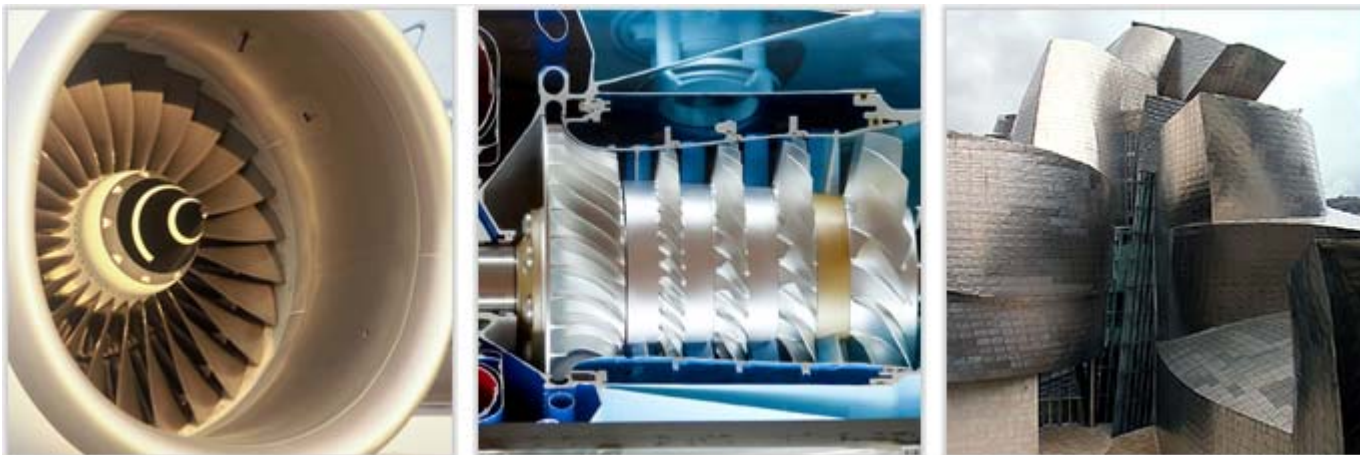


## Description

### 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.

### Compositional summary

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

### General properties

Density	4.4e3	-	4.8e3	kg/m <sup>3</sup>
Price	* 20.3	-	22.5	USD/kg
Date first used	1952			

### Mechanical properties

Young's modulus	110	-	120	GPa
Shear modulus	40	-	45	GPa
Bulk modulus	96	-	102	GPa
Poisson's ratio	0.35	-	0.37	
Yield strength (elastic limit)	750	-	1.2e3	MPa
Tensile strength	800	-	1.45e3	MPa
Compressive strength	750	-	1.2e3	MPa
Elongation	5	-	10	% strain

Hardness - Vickers	267	-	380	HV
Fatigue strength at 10 <sup>7</sup> cycles	* 589	-	617	MPa
Fracture toughness	55	-	70	MPa.m <sup>0.5</sup>
Mechanical loss coefficient (tan delta)	5e-4	-	0.002	

### Thermal properties

Melting point	1.48e3	-	1.68e3	°C
Maximum service temperature	450	-	500	°C
Minimum service temperature	-273			°C
Thermal conductor or insulator?	Poor conductor			
Thermal conductivity	7	-	14	W/m.°C
Specific heat capacity	645	-	655	J/kg.°C
Thermal expansion coefficient	8.9	-	9.6	µstrain/°C

### Electrical properties

Electrical conductor or insulator?	Good conductor			
Electrical resistivity	100	-	170	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)	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
O <sub>2</sub> (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	2e5	tonne/yr
Reserves, principal component	7.25e8	tonne

### Primary material production: energy, CO2 and water

Embodied energy, primary production	* 651	-	720	MJ/kg
CO2 footprint, primary production	* 44.1	-	48.7	kg/kg
Water usage	* 187	-	207	l/kg
Eco-indicator 99	3.45e3			millipoints/kg

### Material processing: energy

Casting energy	* 12.6	-	13.9	MJ/kg
Extrusion, foil rolling energy	* 27.6	-	30.6	MJ/kg
Rough rolling, forging energy	* 14	-	15.4	MJ/kg
Wire drawing energy	* 103	-	114	MJ/kg
Metal powder forming energy	* 46.8	-	53.8	MJ/kg
Vaporization energy	* 1.46e4	-	1.61e4	MJ/kg
Coarse machining energy (per unit wt removed)	* 2.53	-	2.79	MJ/kg
Fine machining energy (per unit wt removed)	* 21	-	23.2	MJ/kg
Grinding energy (per unit wt removed)	* 41.5	-	45.9	MJ/kg
Non-conventional machining energy (per unit wt removed)	146	-	161	MJ/kg

### Material processing: CO2 footprint

Casting CO2	* 0.942	-	1.04	kg/kg
Extrusion, foil rolling CO2	* 2.07	-	2.29	kg/kg
Rough rolling, forging CO2	* 1.05	-	1.16	kg/kg
Wire drawing CO2	* 7.72	-	8.53	kg/kg
Metal powder forming CO2	* 3.74	-	4.31	kg/kg
Vaporization CO2	* 1.09e3	-	1.21e3	kg/kg
Coarse machining CO2 (per unit wt removed)	* 0.19	-	0.209	kg/kg
Fine machining CO2 (per unit wt removed)	* 1.57	-	1.74	kg/kg
Grinding CO2 (per unit wt removed)	* 3.11	-	3.44	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	* 82.6	-	91.3	MJ/kg
CO2 footprint, recycling	* 6.49	-	7.17	kg/kg
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

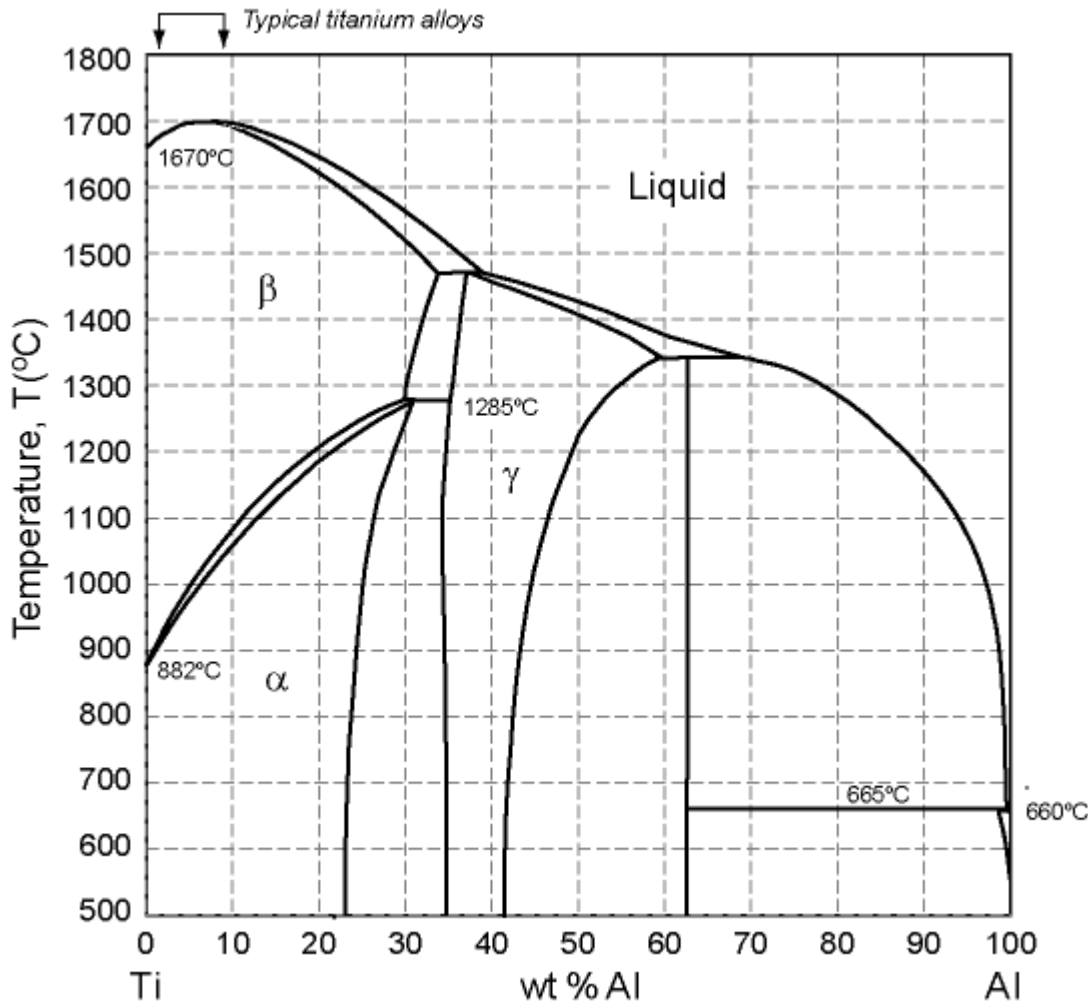
#### Design guidelines

Titanium alloys are expensive, requiring vacuum processing to prevent take up of oxygen, which makes them brittle. But they are 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](http://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; pressure vessels; high-performance automotive parts such as connecting rods; heat exchangers; bioengineering; medical; missile fuel tanks; compressors; valve bodies; light springs, surgical implants; marine hardware, paper-pulp equipment; sports equipment such as golf clubs and bicycles.

---

## Links

Reference

ProcessUniverse

Producers

---