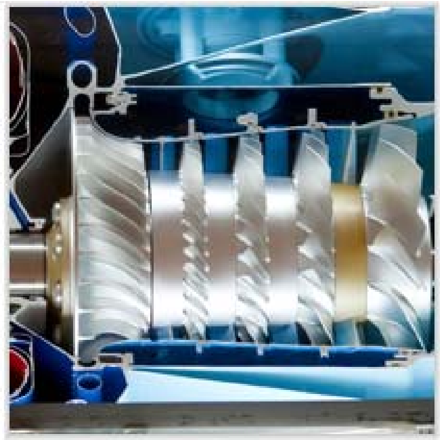
## Description

**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 | * | 10.1 | - | 11.1 | 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 |

## 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 | 1.97e5 | ton/yr |
| Reserves | 7.14e8 | l. 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

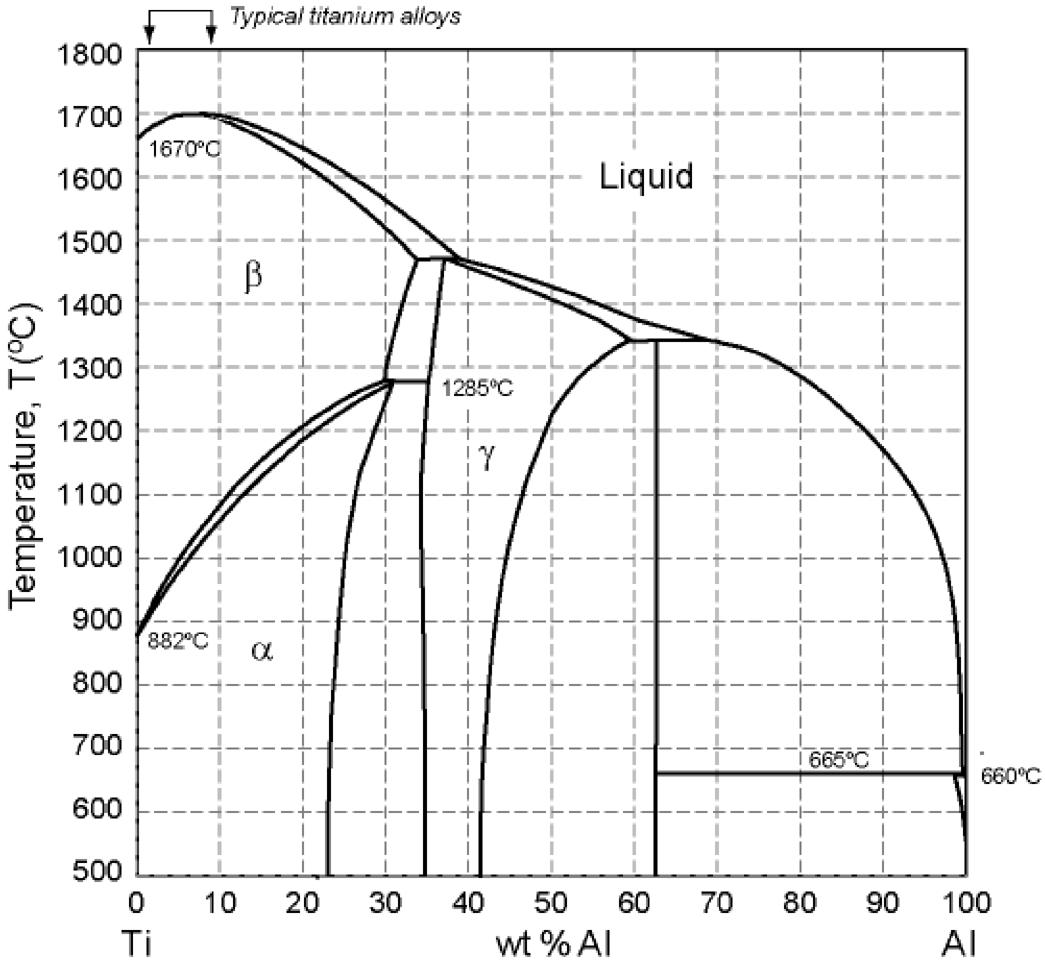
**Design guidelines**

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; 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