Tungsten alloys

Description

Image

Caption

1. Filament of an incandescent lamp in pure tungsten. © Granta Design 2. Spark plug with tungsten electrodes, having to survive in the combustion chamber and tolerate spark discharges. © Granta Design

The material

Tungsten is remarkable for its melting point of 3410 ºC when pure. This is a problem if you want to process it, but an attraction if you want to use it at high temperatures. Processing is solved by using powder methods -- the same methods used to shape refractory ceramics. Its high melting point gives tungsten excellent creep resistance up to 1400 ºC (the temperature listed below as the maximum service temperature), but if not under load it can be used at much higher temperatures: photoflood bulbs reach 2200 ºC, though they have a short life.

Composition (summary)

> 99% W

General properties

Density		1.11e3	-	1.22e3	lb/ft^3
Price	*	23.3	-	25.6	USD/lb
Date first used		1783			

Mechanical properties

Young's modulus		45	-	55.1	10^6 psi
Shear modulus		17.4	-	21.5	10^6 psi
Bulk modulus		32.5	-	42.9	10^6 psi
Poisson's ratio		0.27	-	0.29	
Yield strength (elastic limit)		76.1	-	116	ksi
Tensile strength		104	-	435	ksi
Compressive strength		80.5	-	116	ksi
Elongation		1	-	17	% strain
Hardness - Vickers		280	-	600	HV
Fatigue strength at 10^7 cycles	*	38.4	-	71.8	ksi
Fracture toughness	*	45.5	-	54.6	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	1e-4	-	3e-4	

Thermal properties

Melting point		5.79e3	-	6.17e3	°F
Maximum service temperature		2.46e3	-	2.55e3	°F
Minimum service temperature		-459			°F
Thermal conductor or insulator?		Good conductor			
Thermal conductivity		57.8	-	82	BTU.ft/h.ft^2.F

Specific heat capacity	0.031	-	0.0334	BTU/lb.°F
Thermal expansion coefficient	2.22	-	3.11	µstrain/°F

Electrical properties

Electrical conductor or insulator?	Good conductor			
Electrical resistivity	10.2	-	13.6	µohm.cm

Optical properties

Transparency	Opaque

Processability

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

Durability: water and aqueous solutions

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

Durability: acids

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

Durability: alkalis

Sodium hydroxide (10%)	Acceptable
Sodium hydroxide (60%)	Acceptable

Durability: fuels, oils and solvents

Amyl acetate	Excellent
Benzene	Excellent
Carbon tetrachloride	Excellent
Chloroform	Excellent
Crude oil	Acceptable
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
Methyl alcohol (methanol)	Excellent

Durability: halogens and gases

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

Durability: built environments

Industrial atmosphere	Excellent
Rural atmosphere	Excellent
Marine atmosphere	Acceptable
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)	Excellent
Tolerance above 850 C (1562 F)	Excellent

Geo-economic data for principal component

Annual world production	5.71e4	ton/yr
Reserves	2.76e6	l. ton

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 5.54e4	-	6.11e4	kcal/lb
CO2 footprint, primary production	* 32.7	-	36.1	lb/lb
Water usage	* 17.6	-	19.4	gal(US)/lb

Material processing: energy

Casting energy	* 969	-	1.07e3	kcal/lb
Extrusion, foil rolling energy	* 1.09e3	-	1.21e3	kcal/lb
Rough rolling, forging energy	* 564	-	624	kcal/lb
Wire drawing energy	* 4.04e3	-	4.46e3	kcal/lb
Metal powder forming energy	* 6.03e3	-	6.65e3	kcal/lb
Vaporization energy	* 8.32e5	-	9.2e5	kcal/lb
Coarse machining energy (per unit wt removed)	* 131	-	145	kcal/lb
Fine machining energy (per unit wt removed)	* 853	-	943	kcal/lb
Grinding energy (per unit wt removed)	* 1.66e3	-	1.83e3	kcal/lb
Non-conventional machining energy (per unit wt removed)				

	8.32e3	-	9.2e3	kcal/lb

Material processing: CO2 footprint

Casting CO2	* 0.67	-	0.741	lb/lb
Extrusion, foil rolling CO2	* 0.761	-	0.841	lb/lb
Rough rolling, forging CO2	* 0.391	-	0.432	lb/lb
Wire drawing CO2	* 2.79	-	3.09	lb/lb
Metal powder forming CO2	* 4.45	-	4.91	lb/lb
Vaporization CO2	* 576	-	637	lb/lb
Coarse machining CO2 (per unit wt removed)	* 0.0911	-	0.101	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.59	-	0.652	lb/lb
Grinding CO2 (per unit wt removed)	* 1.14	-	1.27	lb/lb
Non-conventional machining CO2 (per unit wt removed)	5.76	-	6.37	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	✓			
Embodied energy, recycling	* 7.44e3	-	8.22e3	kcal/lb
CO2 footprint, recycling	* 5.4	-	5.97	lb/lb
Recycle fraction in current supply	34	-	38	%
Downcycle	✓			
Combust for energy recovery	✗			
Landfill	✓			
Biodegrade	✗			
Toxicity rating	Non-toxic			
A renewable resource?	✗			

Environmental notes

Tungsten is a skin and eye irritant and is noxious if ingested.

Supporting information

Design guidelines

Tungsten is heavy, relatively expensive and difficult to process -- it is a choice of last-resort. Most of its applications exploit its very high melting point (spark plug electrodes and lamp filament), its exceptional tensile strength when drawn to wire (reinforcement in metal, ceramic and polymer-matrix composites) or it very high density (armour-piercing penetrators). Because of the difficulty of processing tungsten it is generally available only as wire, rod or sheet.

Technical notes

Tungsten is produced by a chemical route that delivers the metal as a fine powder. The powder is pressed into billets, sintered and swaged to rod, then drawn to wire or rolled to sheet. Wires as fine as 5 microns in diameter are available. They can be woven into fabric or used as reinforcement in other metals, ceramics or polymers.

Typical uses

Applications are of four types.
1. Those using the high-temperature capability of tungsten: spark-plug electrodes, lamp filaments,heating elements and furnace windings and electrodes for TIG welding.
2. Those using the high density: balance weights; anti-vibration tooling; armour-piercing penetrators and radiation shielding; and X and gamma-ray shielding
3. Those using the high strength: reinforcement in composites, surface coatings for abrasion resistance
4. Those using its ability to harden steel: tool steels and armor.

Links

Reference

ProcessUniverse

Producers