Description

Image

Caption

1. Silicon nitride bearing balls ranging from 1 to 20mm. © Lucasbosch at en.wikipedia - (CC BY-SA 3.0) 2. Detail of a ball bearing made of silicon nitride bearing balls. © Solaris2006 at en.wikipedia - (CC BY-SA 3.0)

The material

Silicon nitride, Si_3N_4, is a man made compound, synthesized as a powder through several different chemical reactions. Parts made from these powders are sintered by standard methods to produce a ceramic with a unique set of properties. High performance silicon nitrides were developed for automotive engine wear parts such as valves, cam followers and turbocharger vanes, and have proved effective although the cost has not yet dropped enough to allow widespread use. The very high quality bodies developed for these applications are now used for parts for other high temperature applications in chemically aggressive environments in which wear is a problem.

Composition (summary)

Si_3N_4

General properties

Density		3.1e3	-	3.4e3	kg/m^3
Price	*	35.3	-	53.9	USD/kg
Date first used		1958			

Mechanical properties

Young's modulus		290	-	318	GPa
Shear modulus	*	100	-	128	GPa
Bulk modulus	*	210	-	232	GPa
Poisson's ratio		0.26	-	0.28	
Yield strength (elastic limit)	*	600	-	720	MPa
Tensile strength		600	-	720	MPa
Compressive strength		524	-	5.5e3	MPa
Elongation		0			% strain
Hardness - Vickers		1.4e3	-	1.6e3	HV

Fatigue strength at 10^7 cycles	* 300	-	500	MPa
Fracture toughness	4	-	6.7	MPa.m^0.5
Mechanical loss coefficient (tan delta)	* 2e-5	-	5e-5	

Thermal properties

Melting point	2.39e3	-	2.5e3	°C
Maximum service temperature	1e3	-	1.2e3	°C
Minimum service temperature	-272	-	-271	°C
Thermal conductor or insulator?	Good conductor			
Thermal conductivity	22	-	30	W/m.°C
Specific heat capacity	670	-	800	J/kg.°C
Thermal expansion coefficient	3.2	-	3.6	µstrain/°C

Electrical properties

Electrical conductor or insulator?	Good insulator			
Electrical resistivity	1e20	-	1e21	µohm.cm
Dielectric constant (relative permittivity)	7.9	-	8.1	
Dissipation factor (dielectric loss tangent)	* 5e-4	-	7e-4	
Dielectric strength (dielectric breakdown)	* 11	-	13	1000000 V/m

Optical properties

Transparency	Translucent		
Refractive index	1.95	-	2

Critical Materials Risk

High critical material risk?	No

Processability

Moldability	2	-	3
Weldability	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%)	Excellent

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

Durability: alkalis

Sodium hydroxide (10%)	Excellent
Sodium hydroxide (60%)	Excellent

Durability: fuels, oils and solvents

Amyl acetate	Excellent
Benzene	Excellent
Carbon tetrachloride	Excellent
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
Methyl alcohol (methanol)	Excellent

Durability: halogens and gases

Chlorine gas (dry)	Excellent

Fluorine (gas)	Excellent
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)	Excellent
Tolerance above 850 C (1562 F)	Excellent

Primary material production: energy, CO2 and water

Embodied energy, primary production		116	-	128	MJ/kg
CO2 footprint, primary production		4.63	-	5.12	kg/kg
Water usage	*	41	-	123	l/kg

Material processing: energy

Grinding energy (per unit wt removed)	*	153	-	169	MJ/kg

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	*	11.4	-	12.6	kg/kg

Material recycling: energy, CO2 and recycle fraction

Recycle	✘	
Recycle fraction in current supply	0.1	%
Downcycle	✔	
Combust for energy recovery	✘	
Landfill	✔	
Biodegrade	✘	
Toxicity rating	Non-toxic	
A renewable resource?	✘	

Environmental notes

Technical ceramics that are used in the pure state, as Si3N4 usually is, are very energy intensive. The ingredients, silicon and nitrogen, are universally plentiful, but processing costs make the product expensive.

Supporting information

Design guidelines

Silicon carbide and silicon nitride are two of the emerging breed of high performance technical ceramics. Their extreme corrosion resistance and high hardness makes them a good choice for mechanical components that must withstand corrosive fluids - bearings, including ball bearings, and valve and pump parts in sewage systems, for example. Their other unique feature is their ability to carry significant loads at temperatures as high as 1800 C and to survive thermal shock well. The main drawbacks are their low toughness, requiring careful design and flaw-free fabrication, and their high cost, which has slowed their take up. Silicon nitride is dark gray or black in color. It can be polished to a very smooth, reflective surface, giving parts with a striking appearance. Technical ceramics are formed by the following steps.(a) Pressing, isostatic pressing, powder extrusion (for bars and tubes) or powder injection molding (for intricate, high-volume parts).(b) Green-machining in the unfired state, using standard tools.(c) Firing or "sintering" typically at 1550 - 1700 C for 12 to 20 hours; the part shrinks by about 20%.(d) Diamond grinding to achieve tighter tolerance and surface finish: +/- 10 microns is achievable. The cost of a ceramic part is greatly increased if it has to be diamond-ground. Thus design for net-shape sintering, eliminating step (d) is highly desirable. The standard tolerance for as-fired dimensions is +/- 1% or 125 microns, whichever is greater.

Technical notes

Silicon nitride can be synthesized by powder methods, and by CVD (Chemical vapor deposition), giving a degree of design flexibility. Its key features, shared with silicon carbide, are very high hardness outstanding wear resistance, outstanding corrosion resistance, a tolerance of thermal shock, and the ability to carry loads at temperature as high as 1700 C.

Typical uses

Rotating bearing balls and rollers, cutting tools, engine parts - valves, turbocharger rotors, cam followers, tappet shims, gas turbine blades, vanes, buckets, metal forming rolls and dies, precision shafts and axles in high wear environments, heaters and igniters, molten metal processing, particularly in the aluminum foundry industry.

Links

Reference

ProcessUniverse

Producers