Description

Image

 

Caption

1. Zirconia disc © Roland DG Mid Europe Italia at flickr (CC BY-SA 2.0) 2. Zirconia knife © Jeff Nelson at flickr (CC BY-SA 2.0)

The material

Zirconia, ZrO2, is a ceramic with an exceptionally high melting point -- 2760 C when pure. It has the highest useful strength and toughness at room temperature of all the readily available ceramics. It is used (with 5% CaO) as a firebrick, and, in sintered form (with MgO or Y2O3 additives) for high strength, high temperature applications. The exceptional toughness is imparted by transformation toughening: a change in crystal structure from tetragonal to monoclinic, with an associated change in volume of the ZrO2 crystals when subjected to stress at a crack tip. The volume expansion squeezes the crack shut, impeding crack growth. Transformation toughening is made possible by additions of magnesia, MgO, or yttria, Y2O3, to give PSZ (partially stabilized zirconia) or TZP (tetragonal zirconia polycrystal). Zirconia is also available as foam for thermal insulation and filtration, and as fibers, used to make fabrics that can tolerate temperatures up to 2425 C.

Composition (summary)

ZrO2, usually with additions of Y2O3, MgO and other oxides to enhance

General properties

Density	368	-	384	lb/ft^3
Price	* 8.46	-	12.2	USD/lb
Date first used	1962			

Mechanical properties

Young's modulus	29	-	36.3	10^6 psi
Shear modulus	* 8.7	-	12.5	10^6 psi
Bulk modulus	* 23.2	-	30.7	10^6 psi
Poisson's ratio	0.3	-	0.32	
Yield strength (elastic limit)	72.5	-	103	ksi
Tensile strength	72.5	-	103	ksi
Compressive strength	* 522	-	754	ksi

Elongation		0			% strain
Hardness - Vickers		1e3	-	1.23e3	HV
Fatigue strength at 10^7 cycles	*	43.5	-	72.5	ksi
Fracture toughness		5.46	-	7.28	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	5e-4	-	0.001	

Thermal properties

Melting point		4.62e3	-	4.89e3	°F
Maximum service temperature		2.19e3	-	2.73e3	°F
Minimum service temperature		-459			°F
Thermal conductor or insulator?		Poor insulator			
Thermal conductivity		1.16	-	2.43	BTU.ft/h.ft^2.F
Specific heat capacity		0.115	-	0.124	BTU/lb.°F
Thermal expansion coefficient		5.83	-	6.11	µstrain/°F

Electrical properties

Electrical conductor or insulator?		Good insulator			
Electrical resistivity		2e18	-	3e21	µohm.cm
Dielectric constant (relative permittivity)		12	-	25	
Dissipation factor (dielectric loss tangent)	*	8e-4	-	0.002	
Dielectric strength (dielectric breakdown)	*	102	-	152	V/mil

Optical properties

Transparency		Opaque			
Refractive index		2.1	-	2.17	

Critical Materials Risk

High critical material risk?		No			

Processability

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

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%)	Unacceptable
Nitric acid (10%)	Excellent
Nitric acid (70%)	Excellent
Phosphoric acid (10%)	Excellent
Phosphoric acid (85%)	Excellent
Sulfuric acid (10%)	Excellent
Sulfuric acid (70%)	Limited use

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	* 9.21e3	-	1.02e4	kcal/lb
CO2 footprint, primary production	* 4.59	-	5.07	lb/lb
Water usage	* 5.58	-	6.17	gal(US)/lb

Material processing: energy

Grinding energy (per unit wt removed)	* 5.84e3	-	6.46e3	kcal/lb

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	* 4.04	-	4.47	lb/lb

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

Energy is consumed, and CO2 generated, in refining and firing zirconia components, but the processing is otherwise benign.

Supporting information

Design guidelines

Zirconia, ZrO2, has the highest useful strength and toughness at room temperature of all the readily available ceramics. The fine grain size allows extremely smooth surfaces and sharp edges. This, combined with its exceptionally high toughness, make it attractive for blades for paper cutting, engine components and wear plates. 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

Stabilization of stabilized Zirconias is slowly lost on holding between temperatures of 1050K and 1450K. At ~1150K zirconia ceramics become electrically conducting.

Typical uses

Bearing wear sleeves, microtools and tweezers, knife blades, replacement for steel in surgical applications, electrical and thermal insulation at high and low temperatures, cutting applications, extrusion and drawing dies, catalyst supports, cylinder liners, turbo-charger blades and other engine components for automotive applications, wear plates, thermal barrier coatings for turbine blades.

Links

Reference

ProcessUniverse

Producers