Description

Image

Caption

1. Ceramic knife made of zirconia. © SlonikkinolS at en.wikipedia - (CC BY-SA 3.0) 2. Zirconia components.

The material

Zirconia, ZrO_2, 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 Y_2O_3 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 ZrO_2 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, Y_2O_3, 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.

Compositional summary

ZrO_2, usually with additions of Y_2O_3, MgO and other oxides to enhance toughness.

General properties

Density		5.9e3	-	6.15e3	kg/m^3
Price	*	18.7	-	27	USD/kg
Date first used		1962			

Mechanical properties

Young's modulus		200	-	250	GPa
Shear modulus	*	60	-	86	GPa
Bulk modulus	*	160	-	212	GPa
Poisson's ratio		0.3	-	0.32	
Yield strength (elastic limit)		500	-	710	MPa
Tensile strength		500	-	710	MPa
Compressive strength	*	3.6e3	-	5.2e3	MPa
Elongation		0			% strain

Hardness - Vickers	1e3	-	1.23e3	HV
Fatigue strength at 10^7 cycles	* 300	-	500	MPa
Fracture toughness	6	-	8	MPa.m^0.5
Mechanical loss coefficient (tan delta)	* 5e-4	-	0.001	

Thermal properties

Melting point	2.55e3	-	2.7e3	°C
Maximum service temperature	1.2e3	-	1.5e3	°C
Minimum service temperature	-273			°C
Thermal conductor or insulator?	Poor insulator			
Thermal conductivity	2	-	4.2	W/m.°C
Specific heat capacity	480	-	520	J/kg.°C
Thermal expansion coefficient	10.5	-	11	µstrain/°C

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)	* 4	-	6	1000000 V/m

Optical properties

Transparency	Opaque		
Refractive index	2.1	-	2.17

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	* 85	-	94	MJ/kg
CO2 footprint, primary production	* 4.59	-	5.07	kg/kg
Water usage	* 46.6	-	51.5	l/kg

Material processing: energy

Grinding energy (per unit wt removed)	* 53.9	-	59.6	MJ/kg

Material processing: CO2 footprint

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

Energy is consumed, and CO_2 generated, in refining and firing zirconia components, but the processing is otherwise benign.

Supporting information

Design guidelines

Zirconia, ZrO_2, 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