Description

Image

Caption

1. Alumina components for wear resistance and for high temperature use. © Kyocera Industrial Ceramics Corp. 2. Alumina spark plug insulator. © Norris Wong at Flickr - (CC BY 2.0) 3. Alumina insulator of a spark plug broken open. © Industry_shill at en.wikipedia - Public domain

The material

Alumina (Al2O3) is to technical ceramics what mild steel is to metals - cheap, easy to process, the workhorse of the industry. It is the material of spark plugs, electrical insulators and ceramic substrates for microcircuits. In single crystal form it is sapphire, used for watch faces and cockpit windows of high-speed aircraft. More usually it is made by pressing and sintering powder, giving grades ranging from 80 to 99.9% alumina - the rest is porosity, glassy impurities or deliberately added components. Pure aluminas are white; impurities make them pink or green. The maximum operating temperature increases with increasing alumina content. Alumina has a low cost and a useful and broad set of properties: electrical insulation, high mechanical strength, good abrasion and temperature resistance up to 1650 C, excellent chemical stability and moderately high thermal conductivity, but it has limited thermal shock and impact resistance. Chromium oxide is added to improve abrasion resistance; sodium silicate, to improve processability but with some loss of electrical resistance. Competing materials are magnesia, silica and borosilicate glass.

Compositional summary

Al2O3, often with some porosity and some glassy phase.

General properties

Density	3.8e3	-	3.98e3	kg/m^3
Price	* 18.3	-	27.4	USD/kg
Date first used	1914			

Mechanical properties

Young's modulus	343	-	390	GPa
Shear modulus	* 137	-	156	GPa
Bulk modulus	* 226	-	258	GPa
Poisson's ratio	0.23	-	0.26	
Yield strength (elastic limit)	350	-	588	MPa

Tensile strength	350	-	588	MPa
Compressive strength	690	-	5.5e3	MPa
Elongation	0			% strain
Hardness - Vickers	1.2e3	-	2.06e3	HV
Fatigue strength at 10^7 cycles	* 200	-	488	MPa
Fracture toughness	3.3	-	4.8	MPa.m^0.5
Mechanical loss coefficient (tan delta)	* 1e-5	-	2e-4	

Thermal properties

Melting point	2e3	-	2.1e3	°C
Maximum service temperature	1.08e3	-	1.3e3	°C
Minimum service temperature	-273			°C
Thermal conductor or insulator?	Good conductor			
Thermal conductivity	26	-	38.5	W/m.°C
Specific heat capacity	790	-	820	J/kg.°C
Thermal expansion coefficient	7	-	7.9	µstrain/°C

Electrical properties

Electrical conductor or insulator?	Good insulator			
Electrical resistivity	1e20	-	1e22	µohm.cm
Dielectric constant (relative permittivity)	6.5	-	6.8	
Dissipation factor (dielectric loss tangent)	1e-4	-	4e-4	
Dielectric strength (dielectric breakdown)	10	-	20	1000000 V/m

Optical properties

Transparency	Translucent		
Refractive index	1.64	-	1.68

Processability

Moldability	2	-	3
Machinability	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%)	Limited use
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

Geo-economic data for principal component

Annual world production, principal component		1.19e6	-	1.2e6	tonne/yr

Primary material production: energy, CO2 and water

Embodied energy, primary production		49.5	-	54.7	MJ/kg
CO2 footprint, primary production		2.67	-	2.95	kg/kg
Water usage	*	54	-	59.7	l/kg

Material processing: energy

Grinding energy (per unit wt removed)	*	103	-	114	MJ/kg

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	*	7.73	-	8.54	kg/kg

Material recycling: energy, CO2 and recycle fraction

Recycle		✗			
Recycle fraction in current supply		0.5	-	1	%
Downcycle		✓			
Combust for energy recovery		✗			

Landfill	✔
Biodegrade	✖
Toxicity rating	Non-toxic
A renewable resource?	✖

Environmental notes

Alumina, AL2O3, like silica, SiO2, is one of the most plentiful chemical compounds in the earths crust. Purifying it, and firing it to give a solid body, however, takes a great deal of energy.

Supporting information

Design guidelines

Alumina is available in a range of standard shapes: rods, tubes, plates. The lower-density grades with up to 10% porosity are easily cut and ground. Fully dense alumina is hard an abrasion resistant; it requires more specialized shaping methods. Aluminas offer excellent wear resistance, corrosion resistance and strength -- and all at a reasonable price. Their dielectric properties make them particularly attractive for electronic substrates. 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

All technical ceramics start as powders. The powders are mixed with a binder and, often, a glass-forming ingredient, and molded, extruded or pressed to the desired shape. The shaped body is fired, burning off the binder and causing the powder particles to fuse together, or -- if a glass-forming impurity is present -- to be bonded together by a thin film of glass. Most grades of alumina (including those used for electrical insulators) contain a good deal of silica (up to 10%). This forms a glassy phase when heated, allowing the easy forming and firing at a relatively low temperature. Pure alumina, required for substrates of microcircuits, contains no glass, and requires firing at a much higher temperature, making it expensive.

Typical uses

Electrical insulators and connector bodies; substrates; high temperature components; water faucet valves; mechanical seals; vacuum chambers and vessels; centrifuge linings; spur gears; fuse bodies; heating elements; plain bearings and other wear resistant components; cutting tools; substrates for microcircuits; spark plug insulators; tubes for sodium vapor lamps, thermal barrier coatings.

Links

Reference
ProcessUniverse
Producers