

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 (Al_2O_3) 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

Al_2O_3 , often with some porosity and some glassy phase.

General properties

Density	237	-	248	lb/ft ³
Price	* 8.28	-	12.4	USD/lb
Date first used	1914			

Mechanical properties

Young's modulus	49.7	-	56.6	10 ⁶ psi
Shear modulus	* 19.9	-	22.6	10 ⁶ psi
Bulk modulus	* 32.8	-	37.4	10 ⁶ psi
Poisson's ratio	0.23	-	0.26	

Yield strength (elastic limit)	50.8	-	85.3	ksi
Tensile strength	50.8	-	85.3	ksi
Compressive strength	100	-	798	ksi
Elongation	0			% strain
Hardness - Vickers	1.2e3	-	2.06e3	HV
Fatigue strength at 10 ⁷ cycles	* 29	-	70.8	ksi
Fracture toughness	3	-	4.37	ksi.in ^{0.5}
Mechanical loss coefficient (tan delta)	* 1e-5	-	2e-4	

Thermal properties

Melting point	3.64e3	-	3.8e3	°F
Maximum service temperature	1.97e3	-	2.37e3	°F
Minimum service temperature	-460			°F
Thermal conductor or insulator?	Good conductor			
Thermal conductivity	15	-	22.2	BTU.ft/h.ft ² .F
Specific heat capacity	0.189	-	0.196	BTU/lb.°F
Thermal expansion coefficient	3.89	-	4.39	µstrain/°F

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)	254	-	508	V/mil

Optical properties

Transparency	Translucent			
Refractive index	1.64	-	1.68	

Processability

Moldability	2	-	3	
Machinability	1	-	2	

Eco properties

Embodied energy, primary production	5.36e3	-	5.93e3	kcal/lb
CO2 footprint, primary production	2.67	-	2.95	lb/lb
Recycle	✗			

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 and 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