Description

Image

Caption

Open-cell alumina foam sample. © Granta Design

The material

If you wanted to filter dross out of a molten metal at -- say -- 1800 C, how would you do it? The answer is to pour it through a ceramic foam. A range of such foams is now available with relative densities between 5% and 40% (the volume fraction of solid in the foam), with pore sizes between 0.05 and 2 mm. They are available in alumina, zirconia, and a number of other ceramics including the bio-ceramic hydroxyapatite. Their great merit is their stability at high temperatures: zirconia foams, for instance, can be use at up to 2000 Cathie data given here is for a medium-density alumina foam

Composition (summary)

Al2O3, ZrO2 and many other compositions.

General properties

Density	392	-	670	kg/m^3
Price	* 35.1	-	52.9	USD/kg
Date first used	1970			

Mechanical properties

Young's modulus	1.9	-	3.8	GPa
Shear modulus	* 0.6	-	1.4	GPa
Bulk modulus	* 1.9	-	3.8	GPa
Poisson's ratio	0.26	-	0.27	
Yield strength (elastic limit)	* 0.6	-	2.1	MPa
Tensile strength	* 0.6	-	2.1	MPa
Compressive strength	0.8	-	2.8	MPa
Elongation	0			% strain
Hardness - Vickers	0.08	-	0.3	HV
Fatigue strength at 10^7 cycles	* 0.5	-	1.8	MPa

Fracture toughness	0.03	-	0.1	MPa.m^0.5
Mechanical loss coefficient (tan delta)	* 0.003	-	0.01	

Thermal properties

Melting point	1.98e3	-	2.1e3	°C
Maximum service temperature	1.5e3	-	1.8e3	°C
Minimum service temperature	-273			°C
Thermal conductor or insulator?	Good insulator			
Thermal conductivity	0.5	-	0.7	W/m.°C
Specific heat capacity	780	-	960	J/kg.°C
Thermal expansion coefficient	6.94	-	8.9	µstrain/°C

Electrical properties

Electrical conductor or insulator?	Good insulator			
Electrical resistivity	1e20	-	1e23	µohm.cm
Dielectric constant (relative permittivity)	1.7	-	2.4	
Dissipation factor (dielectric loss tangent)	0.001	-	0.02	
Dielectric strength (dielectric breakdown)	10	-	17	1000000 V/m

Optical properties

Transparency	Translucent

Critical Materials Risk

High critical material risk?	No

Processability

Machinability	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%)	Acceptable

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	* 121	-	134	MJ/kg
CO2 footprint, primary production	* 6.53	-	7.22	kg/kg
Water usage	* 167	-	185	l/kg

Material processing: energy

Grinding energy (per unit wt removed)	* 1.71	-	1.89	MJ/kg

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	* 0.128	-	0.142	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

Ceramics, once fired, are inert. Some can even be used for human implants.

Supporting information

Design guidelines

Most ceramic foams are used as high-temperature filters for liquids and gasses (removing carbon particulates from diesel exhaust, for instance), and for high temperature thermal insulation, replacing materials like asbestos. They can be cut with saws, but this leaves an uneven surface. Better is the use of abrasive water-jet cutting. Interpenetrating composites ("3-3 composites") are made by infiltrating the ceramic with a polymer or a metal, giving a fully dense body. They have potential for wear-resistant parts and as armor to resist projectiles. Hydroxyapatite foams are biocompatible and have a pore size that encourages attachment and in-growth of cell.

Technical notes

Ceramic foams are made in a number of ways. Typical of them is co-foaming of a ceramic-polymer slurry. Fine ceramic powder is mixed with an acrylate monomer, a catalyst and a foaming agent. The concoction foams then polymerizes in much the same way that polymer foams are made, but the cell edges are full of ceramic powder. When this is sintered (heated at 1500 to 2000 C) the polymer burns off and the powder particles bond to give a consolidated ceramic foam.

Typical uses

High temperature filters for liquids and gases, catalyst carriers for chemical processing and catalytic converters, high temperature thermal insulation, as a first step in making 3-dimensionally interpenetrating composites, as a bioactive medium for cell attachment in implants.

Links

Reference

ProcessUniverse

Producers