Silicone elastomers (SI, Q)

Description

Image

Caption

The silicone elastomer seal and strap of these swimming goggles resist chemical attack by bleaches and other chemicals. © Justus Blümer at Flickr - (CC BY 2.0)

The material

Silicones are high-performance, high cost materials. Silicone and fluoro-silicone elastomers have long chains of linked O-Si-O-Si- groups (replacing the -C-C-C-C- chains in carbon-based elastomers), with methyl (CH3) or fluorine (F) side chains. They have poor strength, but can be used over an exceptional range of temperature (-100 C to + 300 C), have great chemical stability, and an unusual combination of properties (Silly Putty is a silicone elastomer - it bounces when dropped but flows if simple left on the desk).

Composition (summary)

Most common version: (O-Si(CH3)2)n

General properties

Density		1.3e3	-	1.8e3	kg/m^3
Price	*	3.17	-	5.92	USD/kg
Date first used		1943			

Mechanical properties

Young's modulus		0.005	-	0.02	GPa
Shear modulus		0.002	-	0.0066	GPa
Bulk modulus	*	1.25	-	1.35	GPa
Poisson's ratio		0.47	-	0.49	
Yield strength (elastic limit)		2.4	-	5.5	MPa
Tensile strength		2.4	-	5.5	MPa
Compressive strength		10	-	30	MPa
Elongation		80	-	300	% strain
Fatigue strength at 10^7 cycles		2.28	-	4	MPa
Fracture toughness		0.03	-	0.5	MPa.m^0.5

Mechanical loss coefficient (tan delta)	0.06	-	0.15	

Thermal properties

Glass temperature	-123	-	-73.2	°C
Maximum service temperature	227	-	287	°C
Minimum service temperature	-73.2	-	-48.2	°C
Thermal conductor or insulator?	Good insulator			
Thermal conductivity	0.3	-	1	W/m.°C
Specific heat capacity	1.05e3	-	1.3e3	J/kg.°C
Thermal expansion coefficient	250	-	300	µstrain/°C

Electrical properties

Electrical conductor or insulator?	Good insulator			
Electrical resistivity	3.16e19	-	1e22	µohm.cm
Dielectric constant (relative permittivity)	2.9	-	4	
Dissipation factor (dielectric loss tangent)	0.002	-	0.008	
Dielectric strength (dielectric breakdown)	15	-	25	1000000 V/m

Optical properties

Transparency	Translucent			
Refractive index	1.4	-	1.44	

Critical Materials Risk

High critical material risk?	No

Processability

Castability	4	-	5
Moldability	4	-	5
Machinability	2	-	3
Weldability	1		

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)	Limited use
Citric acid (10%)	Excellent

Hydrochloric acid (10%)	Limited use
Hydrochloric acid (36%)	Unacceptable
Hydrofluoric acid (40%)	Unacceptable
Nitric acid (10%)	Limited use
Nitric acid (70%)	Unacceptable
Phosphoric acid (10%)	Excellent
Phosphoric acid (85%)	Excellent
Sulfuric acid (10%)	Limited use
Sulfuric acid (70%)	Unacceptable

Durability: alkalis

Sodium hydroxide (10%)	Excellent
Sodium hydroxide (60%)	Excellent

Durability: fuels, oils and solvents

Amyl acetate	Unacceptable
Benzene	Unacceptable
Carbon tetrachloride	Unacceptable
Chloroform	Unacceptable
Crude oil	Limited use
Diesel oil	Unacceptable
Lubricating oil	Unacceptable
Paraffin oil (kerosene)	Unacceptable
Petrol (gasoline)	Unacceptable
Silicone fluids	Limited use
Toluene	Unacceptable
Turpentine	Unacceptable
Vegetable oils (general)	Limited use
White spirit	Unacceptable

Durability: alcohols, aldehydes, ketones

Acetaldehyde	Excellent
Acetone	Limited use
Ethyl alcohol (ethanol)	Excellent
Ethylene glycol	Excellent
Formaldehyde (40%)	Limited use
Glycerol	Excellent
Methyl alcohol (methanol)	Excellent

Durability: halogens and gases

Chlorine gas (dry)	Unacceptable

Fluorine (gas)	Unacceptable			
O2 (oxygen gas)	Acceptable			
Sulfur dioxide (gas)	Excellent			

Durability: built environments

Industrial atmosphere	Excellent			
Rural atmosphere	Excellent			
Marine atmosphere	Excellent			
UV radiation (sunlight)	Good			

Durability: flammability

Flammability	Self-extinguishing

Durability: thermal environments

Tolerance to cryogenic temperatures	Unacceptable
Tolerance up to 150 C (302 F)	Excellent
Tolerance up to 250 C (482 F)	Acceptable
Tolerance up to 450 C (842 F)	Unacceptable
Tolerance up to 850 C (1562 F)	Unacceptable
Tolerance above 850 C (1562 F)	Unacceptable

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 118	-	131	MJ/kg
CO2 footprint, primary production	* 7.55	-	8.34	kg/kg
Water usage	* 190	-	571	l/kg
Eco-indicator 99	207			millipoints/kg

Material processing: energy

Polymer molding energy	* 14.1	-	15.5	MJ/kg
Grinding energy (per unit wt removed)	* 2.31	-	2.55	MJ/kg

Material processing: CO2 footprint

Polymer molding CO2	* 1.13	-	1.24	kg/kg
Grinding CO2 (per unit wt removed)	* 0.173	-	0.191	kg/kg

Material recycling: energy, CO2 and recycle fraction

Recycle	✗			
Recycle fraction in current supply	0.1			%
Downcycle	✓			
Combust for energy recovery	✓			
Heat of combustion (net)	* 13.1	-	14.2	MJ/kg
Combustion CO2	* 1.3	-	1.37	kg/kg

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

Environmental notes

Silicones are energy intensive - although they are not oil-derivatives. They cannot be recycled.

Supporting information

Design guidelines

Silicone resins are the most expensive thermosetting resin to use in composite materials and they are difficult to process. They feel like natural rubber, but have a completely different structure. Glass fibers and other fillers are commonly used as reinforcement. The resulting parts are relatively low in strength but have high heat resistance. For glass fiber composites, the mechanical properties are better with a phenolic or melamine resin, but the electrical properties are better with silicone. Electrical and high temperature applications dominate their use. They are chemically inert, do not absorb water and can be used in surgical or food processing equipment and seals. Silicones can be produced as fluids, adhesives, coatings, elastomers, molding resins and release agents. But each suffers from a short shelf life (3-6 months). Silicone fluids were the earliest commercial silicones, used as lubricants over a wide range of temperature (-75 C to 450 C). Silicone adhesives can be made as liquids or pastes, they can be non-curing, self-curing or heat-curing. RTV silicone was first developed for its rapid mold filling - a few seconds at high temperatures. Silicone elastomers can be air-curing, cold-curing by the addition of a catalyst or heat-curing; they may be pure or loaded with carbon black to give conductivity. Silicone molding resins are compounded with inert fillers to allow the production of flexible parts with high heat resistance. Silicones are the most chemically stable of all elastomers, with useful properties from -110 C to +310 C, good electrical properties, but relatively low strength (8MPa).

Technical notes

Silicone and fluoro-silicone elastomers have long chains of linked O-Si-O-Si- groups (replacing the -C-C-C-C- chains in carbon-based elastomers), with methyl (CH_3) or fluorine (F) side chains. Silicones are based on the repetition of silicon and oxygen in the polymer chain; it can be used as an elastomer or a thermoset.

Typical uses

Wire and cable insulation, mold release agents and flexible molds, lens cleaning tissue coatings, seals, gaskets, adhesives, o-rings, insulation, encapsulation and potting of electronic circuitry, surgical and food processing equipment, baby bottle tips, breast implants.

Links

Reference
ProcessUniverse
Producers