Description

Image

Caption

1. 1950's telephone made using phenolics. © F_l_a_n_k_e_r at en.wikipedia - (CC BY 3.0) 2. Lamp made using phenolics. © Chris Lefteri

The material

Bakelite, commercialized in 1909, triggered a revolution in product design. It was stiff, fairly strong, could (to a muted degree) be colored, and - above all - was easy to mold. Products that, earlier, were handcrafted from woods, metals or exotics such as ivory, could now be molded quickly and cheaply. At one time the production of phenolics exceeded that of PE, PS and PVC combined. Now, although the ration has changed, phenolics still have a unique value. They are stiff, chemically stable, have good electrical properties, are fire-resistant and easy to mold - and they are cheap.

General properties

Density		1.24e3	-	1.32e3	kg/m^3
Price		1.76			USD/kg
Date first used		1909			

Mechanical properties

Young's modulus		2.76	-	4.83	GPa
Shear modulus	*	0.996	-	1.74	GPa
Bulk modulus		5.2	-	5.4	GPa
Poisson's ratio	*	0.378	-	0.394	
Yield strength (elastic limit)	*	27.6	-	49.7	MPa
Tensile strength		34.5	-	62.1	MPa
Compressive strength	*	30.4	-	54.6	MPa
Elongation		1.5	-	2	% strain
Hardness - Vickers		8.3	-	14.9	HV
Fatigue strength at 10^7 cycles	*	13.8	-	24.8	MPa
Fracture toughness	*	0.787	-	1.21	MPa.m^0.5
Mechanical loss coefficient (tan delta)	*	0.00828	-	0.0145	

Thermal properties

Glass temperature	167	-	267	°C
Maximum service temperature	* 200	-	230	°C
Minimum service temperature	* -123	-	-73.2	°C
Thermal conductor or insulator?	Good insulator			
Thermal conductivity	0.141	-	0.152	W/m.°C
Specific heat capacity	* 1.47e3	-	1.53e3	J/kg.°C
Thermal expansion coefficient	120	-	125	µstrain/°C

Electrical properties

Electrical conductor or insulator?	Good insulator			
Electrical resistivity	3.3e18	-	3e19	µohm.cm
Dielectric constant (relative permittivity)	* 4	-	6	
Dissipation factor (dielectric loss tangent)	* 0.005	-	0.01	
Dielectric strength (dielectric breakdown)	9.84	-	15.7	1000000 V/m

Optical properties

Transparency	Opaque			
Refractive index	1.59	-	1.6	

Processability

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

Durability: water and aqueous solutions

Water (fresh)	Excellent
Water (salt)	Excellent
Soils, acidic (peat)	Excellent
Soils, alkaline (clay)	Unacceptable
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%)	Unacceptable
Phosphoric acid (10%)	Excellent
Phosphoric acid (85%)	Excellent
Sulfuric acid (10%)	Excellent
Sulfuric acid (70%)	Limited use

Durability: alkalis

Sodium hydroxide (10%)	Unacceptable
Sodium hydroxide (60%)	Unacceptable

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	Acceptable
Toluene	Excellent
Turpentine	Excellent
Vegetable oils (general)	Excellent
White spirit	Acceptable

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

Durability: built environments

Industrial atmosphere	Acceptable
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

Geo-economic data for principal component

Annual world production, principal component		1e7	-	1.05e7	tonne/yr
Reserves, principal component	*	2.51e8	-	2.55e8	tonne

Primary material production: energy, CO2 and water

Embodied energy, primary production	*	75.3	-	83.3	MJ/kg
CO2 footprint, primary production	*	3.44	-	3.81	kg/kg
Water usage	*	49.2	-	54.4	l/kg

Material processing: energy

Polymer molding energy	*	26.6	-	29.4	MJ/kg
Coarse machining energy (per unit wt removed)	*	1.16	-	1.28	MJ/kg
Fine machining energy (per unit wt removed)	*	7.33	-	8.1	MJ/kg
Grinding energy (per unit wt removed)	*	14.2	-	15.7	MJ/kg

Material processing: CO2 footprint

Polymer molding CO2	*	2.13	-	2.35	kg/kg
Coarse machining CO2 (per unit wt removed)	*	0.087	-	0.0962	kg/kg
Fine machining CO2 (per unit wt removed)	*	0.55	-	0.607	kg/kg
Grinding CO2 (per unit wt removed)	*	1.06	-	1.18	kg/kg

Material recycling: energy, CO2 and recycle fraction

Recycle		✗			
Recycle fraction in current supply		0.5	-	1	%
Downcycle		✓			

Combust for energy recovery	✔			
Heat of combustion (net)	* 31.5	-	33.1	MJ/kg
Combustion CO2	* 2.86	-	3.01	kg/kg
Landfill	✔			
Biodegrade	✖			
Toxicity rating	Non-toxic			
A renewable resource?	✖			

Environmental notes

Thermosetting phenolics are recyclable, but by a different means than that for thermoplastics. Molded phenolic, ground into a fine powder, can be added to the raw material stream. 4% to 12% ground phenolic does not degrade properties.

http://www.phenolics.org/Publications/recycling2.htm

Supporting information

Design guidelines

Phenolic resins hard, tolerate heat and resist most chemicals except the strong alkalis. Phenolic laminates with paper have excellent electrical and mechanical properties and are cheap; filled with cotton the mechanical strength is increases and a machined surface is finer; filled with glass the mechanical strength increases again and there is improved chemical resistance. Fillers play three roles: extenders (such as wood flour and mica) are inexpensive and reduce cost; functional fillers add stiffness, impact resistance and limit shrinkage; reinforcements (such as glass, graphite and polymer fibers) increase strength, but cost increases too. Phenolic resins have creep resistance, and they self-extinguish in a fire. They can be cast (household light and switch fittings) and are available as rod and sheet. Impregnated into paper (Nomex) and cloth (Tufnol), they have exceptional durability, chemical resistance and bearing properties. Phenolics accept paint, electroplating, and melamine overlays.

Technical notes

Phenolic resins are formed by a condensation, generating water in the process, involving a reaction between phenol and formaldehyde to form the A-stage resin. Fillers, colorants, lubricants and chemicals to cause cross-linking are added to form the B-stage resin. This resin is then fused under heat and pressure converting to the final product - a C-stage resin - or completely cross-linked polymer.

Typical uses

Electrical parts - sockets, switches, connectors, general industrial, water-lubricated bearings, relays, pump impellers, brake pistons, brake pads, microwave cookware, handles, bottles tops, coatings, adhesives, bearings, foams and sandwich structures.

Tradenames

Bakelite, Durez, Ferropreg, Fiberite, Norsophen, Plaslok, Plenco, Polychem, Reliapreg, Resinoid, Texolite, Trolitan, Vyncolite, Tufnol

Links

Reference

ProcessUniverse

Producers