Polyethylene terephthalate (PET)

Description

Image

Caption

PET drinks containers, pressurized and unpressurized. © Tee design and printing Ltd

The material

The name polyester derives from a combination of 'Polymerization' and 'esterification'. Saturated polyesters are thermoplastic - examples are PET and PBT; they have good mechanical properties to temperatures as high as 175 C. PET is crystal clear, impervious to water and CO2, but a little oxygen does get through. It is tough, strong, easy to shape, join and sterilize - allowing reuse. When its first life comes to an end, it can be recycled to give fibers and fleece materials for clothing and carpets. Unsaturated polyesters are thermosets; they are used as the matrix material in glass fiber/polyester composites. Polyester elastomers are resilient and stretch up to 45% in length; they have good fatigue resistance and retain flexibility at low temperatures.

Composition (summary)

(CO-(C6H4)-CO-O-(CH2)2-O)n

General properties

Density		80.5	-	87.4	lb/ft^3
Price	*	0.83	-	0.848	USD/lb
Date first used		1941			

Mechanical properties

Young's modulus		0.4	-	0.6	10^6 psi
Shear modulus	*	0.144	-	0.216	10^6 psi
Bulk modulus		0.718	-	0.754	10^6 psi
Poisson's ratio	*	0.381	-	0.396	
Yield strength (elastic limit)		8.19	-	9.04	ksi
Tensile strength		7.01	-	10.5	ksi
Compressive strength		9.01	-	9.94	ksi
Elongation		30	-	300	% strain
Hardness - Vickers		17	-	18.7	HV

Fatigue strength at 10^7 cycles	* 2.8	-	4.2	ksi
Fracture toughness	4.1	-	5.01	ksi.in^0.5
Mechanical loss coefficient (tan delta)	* 0.00966	-	0.0145	

Thermal properties

Melting point	413	-	509	°F
Glass temperature	154	-	176	°F
Maximum service temperature	152	-	188	°F
Minimum service temperature	* -190	-	-99.7	°F
Thermal conductor or insulator?	Good insulator			
Thermal conductivity	0.0797	-	0.0872	BTU.ft/h.ft^2.F
Specific heat capacity	* 0.339	-	0.352	BTU/lb.°F
Thermal expansion coefficient	63.7	-	66.3	µstrain/°F

Electrical properties

Electrical conductor or insulator?	Good insulator			
Electrical resistivity	3.3e20	-	3e21	µohm.cm
Dielectric constant (relative permittivity)	3.5	-	3.7	
Dissipation factor (dielectric loss tangent)	* 0.003	-	0.007	
Dielectric strength (dielectric breakdown)	419	-	551	V/mil

Optical properties

Transparency	Transparent		
Refractive index	1.57	-	1.58

Critical Materials Risk

High critical material risk?	No

Processability

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

Durability: water and aqueous solutions

Water (fresh)	Excellent
Water (salt)	Excellent
Soils, acidic (peat)	Acceptable
Soils, alkaline (clay)	Limited use
Wine	Excellent

Durability: acids

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

Durability: alkalis

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

Durability: fuels, oils and solvents

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

Durability: alcohols, aldehydes, ketones

Acetaldehyde	Excellent
Acetone	Limited use
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)	Unacceptable
O2 (oxygen gas)	Unacceptable
Sulfur dioxide (gas)	Excellent

Durability: built environments

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

Durability: flammability

Flammability	Highly flammable

Durability: thermal environments

Tolerance to cryogenic temperatures	Unacceptable
Tolerance up to 150 C (302 F)	Acceptable
Tolerance up to 250 C (482 F)	Unacceptable
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		8.86e6	-	9.05e6	ton/yr
Reserves, principal component	*	2.54e8	-	2.56e8	I. ton

Primary material production: energy, CO2 and water

Embodied energy, primary production	*	8.76e3	-	9.7e3	kcal/lb
CO2 footprint, primary production	*	3.76	-	4.15	lb/lb
Water usage	*	15.1	-	16.8	gal(US)/lb
Eco-indicator 95		380			millipoints/kg
Eco-indicator 99		276			millipoints/kg

Material processing: energy

Polymer extrusion energy	*	628	-	696	kcal/lb
Polymer molding energy	*	1.97e3	-	2.18e3	kcal/lb
Coarse machining energy (per unit wt removed)	*	117	-	129	kcal/lb
Fine machining energy (per unit wt removed)	*	709	-	782	kcal/lb
Grinding energy (per unit wt removed)	*	1.37e3	-	1.51e3	kcal/lb

Material processing: CO2 footprint

Polymer extrusion CO2	* 0.435	-	0.481	lb/lb
Polymer molding CO2	* 1.36	-	1.51	lb/lb
Coarse machining CO2 (per unit wt removed)	* 0.0811	-	0.0896	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.49	-	0.542	lb/lb
Grinding CO2 (per unit wt removed)	* 0.945	-	1.04	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	✓			
Embodied energy, recycling	* 4e3	-	4.41e3	kcal/lb
CO2 footprint, recycling	* 2.9	-	3.2	lb/lb
Recycle fraction in current supply	20	-	22	%
Downcycle	✓			
Combust for energy recovery	✓			
Heat of combustion (net)	* 2.49e3	-	2.62e3	kcal/lb
Combustion CO2	* 2.24	-	2.35	lb/lb
Landfill	✓			
Biodegrade	✗			
Toxicity rating	Non-toxic			
A renewable resource?	✗			

Environmental notes

PET bottles take less energy to make than glass bottles of the same volume, and they are much lighter - saving fuel in delivery. Thick-walled bottles can be reused; thin-walled bottles can be recycled - and are, particularly in the

Recycle mark

Supporting information

Design guidelines

There are four grades of thermoplastic polyesters: unmodified, flame retardant, glass-fiber reinforced and mineral-filled. Unmodified grades have high elongation; flame retardant grades are self -extinguishing; glass-fiber reinforced grades (like Rynite) are some of the toughest polymers but there are problems with dimensional stability; and mineral-filled grades are used to counter warping and shrinkage although some strength is lost. The PET used in carbonated drink containers is able to withstand pressure from within, it is recyclable and lighter than glass. The limits of the material's permeability to oxygen is overcome by sandwiching a layer of polyethylvinylidene-alcohol between two layers of PET giving a multi-layer material that can still be blow molded. Polyester can be optically transparent, clear, translucent, white or opaque; the resin is easily colored.

Technical notes

Polyesters are made by a condensation reaction of an alcohol like ethyl alcohol (the one in beer) and an organic acid like acetic acid (the one in vinegar). The two react, releasing water, and forming an ester. PET, PBT and PCT are not cross-linked and thus are thermoplastic. The polyesters that are used as the matrix polymer in bulk and sheet molding compounds are thermosets

Typical uses

Electrical fittings and connectors, blow molded bottles, packaging film, photographic and X-ray film, audio/visual tapes, industrial strapping, capacitor film, drawing office transparencies, fibers. Decorative film, metallized balloons, carbonated drink containers, ovenproof cookware, windsurfing sails, credit cards.

Tradenames

Arnite, Eastabond, Eastapak, Ektar, Grilpet, Impet, Kodapak, Melinar, Petra, Plenco, Polyclear, Rynite, Selar, Techster, Valox

Links

Reference

ProcessUniverse

Producers