

Description

Image



Caption

1. Low-density PE bottle. © Granta Design 2. Medium-density PE pipe. © Granta Design

The material

POLYETHYLENE, $(-CH_2)_n$, first synthesized in 1933, looks like the simplest of molecules, but the number of ways in which the $-CH_2-$ units can be linked is large. It is the first of the polyolefins, the bulk thermoplastic polymers that account for a dominant fraction of all polymer consumption. Polyethylene is inert, and extremely resistant to fresh and salt water, food, and most water-based solutions. Because of this it is widely used in household products, food containers like Tupperware and chopping boards. Polyethylene is cheap, and particularly easy to mold and fabricate. It accepts a wide range of colors, can be transparent, translucent or opaque, has a pleasant, slightly waxy feel, can be textured or metal coated, but is difficult to print on.

Composition (summary)

$(-CH_2-CH_2-)_n$

General properties

Density	58.6	-	59.9	lb/ft ³
Price	* 0.939	-	1.03	USD/lb
Date first used	1936			

Mechanical properties

Young's modulus	0.0901	-	0.13	10 ⁶ psi
Shear modulus	* 0.0316	-	0.0456	10 ⁶ psi
Bulk modulus	0.312	-	0.326	10 ⁶ psi
Poisson's ratio	* 0.418	-	0.434	
Yield strength (elastic limit)	2.6	-	4.21	ksi
Tensile strength	3	-	6.5	ksi
Compressive strength	2.86	-	4.63	ksi
Elongation	200	-	800	% strain
Hardness - Vickers	5.4	-	8.7	HV
Fatigue strength at 10 ⁷ cycles	3.05	-	3.34	ksi
Fracture toughness	* 1.31	-	1.57	ksi.in ^{0.5}
Mechanical loss coefficient (tan delta)	* 0.0446	-	0.0644	

Thermal properties

Melting point	257	-	269	°F
Glass temperature	-13.3	-	4.73	°F
Maximum service temperature	* 194	-	230	°F
Minimum service temperature	* -190	-	-99.7	°F

Thermal conductor or insulator?	Good insulator		
Thermal conductivity	0.233	-	0.251 BTU.ft/h.ft ² .F
Specific heat capacity	* 0.432	-	0.449 BTU/lb.°F
Thermal expansion coefficient	70	-	110 µstrain/°F

Electrical properties

Electrical conductor or insulator?	Good insulator		
Electrical resistivity	3.3e22	-	3e24 µohm.cm
Dielectric constant (relative permittivity)	2.2	-	2.4
Dissipation factor (dielectric loss tangent)	* 3e-4	-	6e-4
Dielectric strength (dielectric breakdown)	450	-	500 V/mil

Optical properties

Transparency	Translucent		
Refractive index	1.5	-	1.52

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)	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%)	Excellent
Nitric acid (10%)	Excellent
Nitric acid (70%)	Acceptable
Phosphoric acid (10%)	Excellent
Phosphoric acid (85%)	Excellent
Sulfuric acid (10%)	Excellent
Sulfuric acid (70%)	Excellent

Durability: alkalis

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

Durability: fuels, oils and solvents

Amyl acetate	Excellent
Benzene	Acceptable
Carbon tetrachloride	Acceptable
Chloroform	Limited use
Crude oil	Acceptable
Diesel oil	Excellent
Lubricating oil	Excellent

Paraffin oil (kerosene)	Excellent
Petrol (gasoline)	Excellent
Silicone fluids	Acceptable
Toluene	Acceptable
Turpentine	Excellent
Vegetable oils (general)	Excellent
White spirit	Excellent

Durability: alcohols, aldehydes, ketones

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

Durability: halogens and gases

Chlorine gas (dry)	Acceptable
Fluorine (gas)	Limited use
O2 (oxygen gas)	Unacceptable
Sulfur dioxide (gas)	Excellent

Durability: built environments

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

Durability: flammability

Flammability	Highly flammable
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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	6.69e7	-	6.79e7	ton/yr
Reserves	* 1.63e9	-	1.85e9	l. ton

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 8.34e3	-	9.22e3	kcal/lb
CO2 footprint, primary production	* 2.64	-	2.92	lb/lb
Water usage	* 6.63	-	7.32	gal(US)/lb
Eco-indicator 95	330			millipoints/kg
Eco-indicator 99	287			millipoints/kg

Material processing: energy

Polymer extrusion energy	* 639	-	706	kcal/lb
Polymer molding energy	* 2.25e3	-	2.49e3	kcal/lb
Coarse machining energy (per unit wt removed)	* 74.5	-	82.3	kcal/lb

Fine machining energy (per unit wt removed)	* 282	- 312	kcal/lb
Grinding energy (per unit wt removed)	* 512	- 567	kcal/lb

Material processing: CO2 footprint

Polymer extrusion CO2	* 0.442	- 0.489	lb/lb
Polymer molding CO2	* 1.56	- 1.73	lb/lb
Coarse machining CO2 (per unit wt removed)	* 0.0516	- 0.057	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.195	- 0.216	lb/lb
Grinding CO2 (per unit wt removed)	* 0.355	- 0.392	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	✓		
Embodied energy, recycling	* 5.1e3	- 5.63e3	kcal/lb
CO2 footprint, recycling	* 3.7	- 4.09	lb/lb
Recycle fraction in current supply	7.5	- 9.5	%
Downcycle	✓		
Combust for energy recovery	✓		
Heat of combustion (net)	* 4.76e3	- 5.01e3	kcal/lb
Combustion CO2	* 3.06	- 3.22	lb/lb
Landfill	✓		
Biodegrade	✗		
Toxicity rating	Non-toxic		
A renewable resource?	✗		

Environmental notes

PE is FDA compliant - indeed it is so non-toxic that it can be embedded in the human body (heart valves, hip-joint cups, artificial artery). PE, PP and PVC are made by processes that are relatively energy-efficient, making them the least energy-intensive of commodity polymers. The ethylene from which it is made at present is an oil derivative, but PE can be produced from renewable resources - from alcohol derived from the fermentation of sugar or starch, for instance. Its utility per kilogram far exceeds that of gasoline or fuel-oil (and its energy is stored and still accessible), so that production from oil will not disadvantage it in the near future. Polyethylene is readily recyclable if it has not been coated with other materials, and - if contaminated - it can be incinerated to recover the energy it contains.

Recycle mark



Supporting information

Design guidelines

PE is commercially produced as film, sheet, rod, foam and fiber. Drawn PE fiber has exceptional mechanical stiffness and strength, exploited in geo-textile and structural uses. PE is a good electrical insulator with low dielectric loss, so suitable for containers for microwave cooking. It has poor resistance to aromatics and chlorine; it is slow burning in fire. PE is cheap, easy to form, biologically inert and recyclable; it is one of the materials of the next 20 years.

Technical notes

Low density polyethylene (LDPE), used for film and packaging, has branched chains which do not pack well, making it less dense than water. Medium (MDPE) and High (HDPE) density polyethylenes have longer, less branched chains, making them stiffer and stronger; they are used for containers and pipes. Modern catalysis allows side-branching to be suppressed and molecular length to be controlled precisely, permitting precise tailoring both of the processing properties critical for drawing, blow molding, injection molding or extrusion and the use-properties of softening temperature, flexibility and toughness. Linear low-density polyethylene (LLPDE) is an example. In its pure form it is less resistant to organic solvents, but even this can be overcome by converting its surface to a fluoro-polymer by exposing it to fluorine gas. Treated in this way (when it is known as 'Super PE') it can be used for petrol tanks in cars and copes with oil, cleaning fluid, cosmetics and that most corrosive of substances: cola concentrate. Very low density polyethylene (VDLPE) is similar to EVA and plasticized PVC.

Typical uses

Oil container, street bollards, milk bottles, toys, beer crate, food packaging, shrink wrap, squeeze tubes, disposable clothing, plastic bags, paper coatings, cable insulation, artificial joints, and as fibers - low cost ropes and packing tape reinforcement.

Tradenames

Alathon, Aquathene, Bapolene, Dowlex, Eltex, Empee, Eraclene, Ferrene, Fortiflex, HiVal, Hid, Kemcor, Lacqtene, Lupolen, Marlex, Nortuff, Novapol, Paxon, Petrothene, Polyfort, Rigidex, Sclair, Stamylyn, Statoil, Unival, Zemid

Links

Reference

ProcessUniverse

Producers