Description

Image

Caption

PHB containers. © Kumar and Minocha, Trangenic Plant Research, Harwood Publishers

The material

Polyhydroxyalkanoates (PHAs) are linear polyesters produced in nature by bacterial fermentation of sugar or lipids derived from soybean oil, corn oil or palm oil. They are fully biodegradable. More than 100 different monomers can be combined within this family to give materials with a wide range of properties, from stiff and brittle thermoplastics to flexible elastomers. The most common type of PHAs is PHB (poly-3-hydroxybutyrate) with properties similar to those of PP, though it is stiffer and more brittle. A copolymer of PHB, polyhydroxybutyrate-valerate (PBV) is less stiff and tougher. It is used as a packaging material. The data below are for PHB.

Compositional summary

(CH(CH3)-CH2-CO-O)n

General properties

Density		1.23e3	-	1.25e3	kg/m^3
Price	*	6	-	7	USD/kg
Date first used		1982			

Mechanical properties

Young's modulus		0.8	-	4	GPa
Shear modulus	*	2.2	-	2.5	GPa
Bulk modulus	*	5.8	-	6.8	GPa
Poisson's ratio	*	0.38	-	0.4	
Yield strength (elastic limit)		35	-	40	MPa
Tensile strength		35	-	40	MPa
Compressive strength	*	40	-	45	MPa
Elongation		6	-	25	% strain
Hardness - Vickers	*	11	-	13	HV
Fatigue strength at 10^7 cycles	*	12	-	17	MPa

Fracture toughness	* 0.7	-	1.2	MPa.m^0.5
Mechanical loss coefficient (tan delta)	* 0.03	-	0.15	

Thermal properties

Melting point	115	-	175	°C
Glass temperature	4	-	15	°C
Maximum service temperature	* 60	-	80	°C
Minimum service temperature	* -70	-	-60	°C
Thermal conductor or insulator?	Good insulator			
Thermal conductivity	* 0.13	-	0.23	W/m.°C
Specific heat capacity	* 1.4e3	-	1.6e3	J/kg.°C
Thermal expansion coefficient	* 180	-	240	µstrain/°C

Electrical properties

Electrical conductor or insulator?	Good insulator			
Electrical resistivity	* 1e16	-	1e18	µohm.cm
Dielectric constant (relative permittivity)	* 3	-	5	
Dissipation factor (dielectric loss tangent)	* 0.05	-	0.15	
Dielectric strength (dielectric breakdown)	* 12	-	16	1000000 V/m

Optical properties

Transparency	Transparent

Processability

Moldability	4	-	5
Machinability	4	-	5
Weldability	3	-	4

Durability: water and aqueous solutions

Water (fresh)	Excellent
Water (salt)	Excellent
Soils, acidic (peat)	Unacceptable
Soils, alkaline (clay)	Unacceptable
Wine	Excellent

Durability: acids

Acetic acid (10%)	Unacceptable
Acetic acid (glacial)	Unacceptable
Citric acid (10%)	Excellent
Hydrochloric acid (10%)	Excellent
Hydrochloric acid (36%)	Unacceptable
Hydrofluoric acid (40%)	

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

Durability: alkalis

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

Durability: fuels, oils and solvents

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

Durability: alcohols, aldehydes, ketones

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

Durability: halogens and gases

Chlorine gas (dry)	Unacceptable
Fluorine (gas)	Unacceptable
O2 (oxygen gas)	Unacceptable

Sulfur dioxide (gas)	Unacceptable

Durability: built environments

Industrial atmosphere	Acceptable
Rural atmosphere	Acceptable
Marine atmosphere	Acceptable
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

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 81.2	-	89.8	MJ/kg
CO2 footprint, primary production	* 4.14	-	4.58	kg/kg
Water usage	* 100	-	300	l/kg

Material processing: energy

Polymer extrusion energy	* 5.75	-	6.35	MJ/kg
Polymer molding energy	* 16.6	-	18.4	MJ/kg
Coarse machining energy (per unit wt removed)	* 0.8	-	0.884	MJ/kg
Fine machining energy (per unit wt removed)	* 3.73	-	4.12	MJ/kg
Grinding energy (per unit wt removed)	* 6.98	-	7.71	MJ/kg

Material processing: CO2 footprint

Polymer extrusion CO2	* 0.431	-	0.476	kg/kg
Polymer molding CO2	* 1.25	-	1.38	kg/kg
Coarse machining CO2 (per unit wt removed)	* 0.06	-	0.0663	kg/kg
Fine machining CO2 (per unit wt removed)	* 0.279	-	0.309	kg/kg
Grinding CO2 (per unit wt removed)	* 0.523	-	0.578	kg/kg

Material recycling: energy, CO2 and recycle fraction

Recycle	✓			
Embodied energy, recycling	* 36.8	-	40.7	MJ/kg
CO2 footprint, recycling	* 2.89	-	3.2	kg/kg

Recycle fraction in current supply	0.5	-	1	%
Downcycle	✓			
Combust for energy recovery	✓			
Heat of combustion (net)	* 22.9	-	24.1	MJ/kg
Combustion CO2	* 2	-	2.1	kg/kg
Landfill	✓			
Biodegrade	✓			
Toxicity rating	Non-toxic			
A renewable resource?	✓			

Environmental notes

PHAs are bio-polyesters made from renewable resources and are biodegradable -- both excellent eco-qualifications. If combusted, the CO2 footprint rises to 3.6 kg/kg. Embodied energy and CO2 footprint are from Doi, Y. (2007) Riken Institute, Japan.

Recycle mark

Supporting information

Design guidelines

The physical properties of PHA biopolymers resemble those of synthetic plastics. Their biodegradability makes them an attractive alternative, meeting the growing problems of pollution by plastic waste. The drawback of PHAs is their high costs, making them substantially more expensive than synthetic plastic.
PHB is insoluble in water, and has good oxygen permeability and UV resistance. It is soluble in chloroform and other chlorinated hydrocarbons, which can be used to bond it. It is non-toxic and biocompatible. It can blow-molded, injection molded or extruded.

Technical notes

Polyhydroxyalkanoates (PHAs) are a family of polyesters produced in bacteria as a carbon and energy reserve. Bacterial PHAs are classified into two groups according to the number of carbon atoms in the monomer units: short-chain-length (SCL) PHAs consist of 3-5 carbon chains, and medium-chain-length (MCL) PHAs consist of 6-14 carbon chains. The physical properties of PHAs are dependent upon their monomer units. The most commonly used PHA is Poly-3-hydroxybutyrate (PHB).

Typical uses

Packaging, containers, bottles

Tradenames

Biopol, Biomer

Further reading

1. Biopol http://members.rediff.com/jogsn/BP6.htm
2. Biomer http://www.biomer.de/MechDatE.html#mechanical
3.Price, Embodied energy and CO2 footprint are from Doi, Y. (2007) Riken Institute, Japan

Links

Reference	
ProcessUniverse	