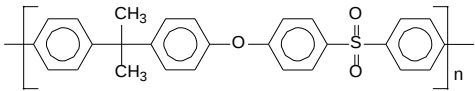
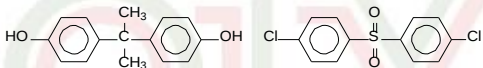


PES poly(ether sulfone)

PARAMETER	UNIT	VALUE	REFERENCES
GENERAL			
Common name	-	poly(ether sulfone)	
CAS name	-	poly(oxy-1,4-phenylenesulfonyl-1,4-phenylene)	
Acronym	-	PES, PESU (ISO)	
CAS number	-	25667-42-9	
Formula			
HISTORY			
Person to discover	-	Khattab, G	Khattab, G, US Patent 3,723,389, Allied Chemical, Mar. 27, 1973.
Date	-	1973	
Details	-	polymeric condensation products of p,p'-dihalodiphenyl sulfone with alkali metal bisphenates	
SYNTHESIS			
Monomer(s) structure	-		
Monomer(s) CAS number(s)	-	80-05-7; 80-07-9	
Monomer(s) molecular weight(s)	dalton, g/mol, amu	228.29; 287.16	
Method of synthesis	-	reaction between Bisphenol A and bis(4-chlorophenyl)sulfone in the presence of Na ₂ CO ₃ with elimination of NaCl, H ₂ O, and CO ₂	
Number average molecular weight, M _n	dalton, g/mol, amu	8,600-28,700	
Mass average molecular weight, M _w	dalton, g/mol, amu	10,100-38,800	
Polydispersity, M _w /M _n	-	1.17-1.55	
Molar volume at 298K	cm ³ mol ⁻¹	157	
Chain-end groups	-	NH ₂ , OH	
STRUCTURE			
Cell type (lattice)	-	orthorhombic	
Cell dimensions	nm	a:b:c=0.85:0.495:0.67	
Unit cell angles	degree	α:β:γ=90:90:90	
Number of chains per unit cell	-	2	
Chain conformation	-	glide 2/0	
COMMERCIAL POLYMERS			
Some manufacturers	-	BASF; Mitsui Chemical; Solvay	
Trade names	-	Ultrason E; PES; Veradel	
PHYSICAL PROPERTIES			
Density at 20°C	g cm ⁻³	1.37; 1.43; 1.50-1.61 (20-30% glass fiber); 1.23 (melt); 1.35-1.41 (20-30% glass fiber, melt)	

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PARAMETER	UNIT	VALUE	REFERENCES
Bulk density at 20°C	g cm ⁻³	0.7-0.8	
Color	-	transparent, amber	
Refractive index, 20°C	-	1.545-1.65	
Melting temperature, DSC	°C	220-238	
Decomposition temperature	°C	400-584	Duan, Y; Cong, P; Liu, X; Li, T, J. Macromol. Sci. B, 48, 604-16, 2009.
Thermal expansion coefficient, 23-200°C	°C ⁻¹	4.3-5.5E-5; 2.0-3.1E-5 (20-30% glass fiber)	
Thermal conductivity, melt	W m ⁻¹ K ⁻¹	0.18 (melt); 0.24; 0.30 (30% glass fiber)	
Glass transition temperature	°C	220-246; 220 (30% glass fiber)	
Specific heat capacity	J K ⁻¹ kg ⁻¹	1,950 (melt); 1,200 (23°C); 1,740 (20-30% glass fiber)	
Maximum service temperature	°C	218; 191 (NSF standard 51)	
Long term service temperature	°C	200 (at 180°C heat resistance is 20 years)	
Temperature index (50% tensile strength loss after 20,000 h/5000 h)	°C	190	Padey, D; Walling, J; Wood A, Polymers in Defence and Aerospace 2007, Rapra, 2007, paper 15.
Heat deflection temperature at 0.45 MPa	°C	214-218; 218-224 (20-30% glass fiber)	
Heat deflection temperature at 1.8 MPa	°C	204-207; 214-216 (20-30% glass fiber)	
Vicat temperature VST/A/50	°C	214-215; 217-218 (20-30% glass fiber)	
Hansen solubility parameters, δ_D , δ_P , δ_H	MPa ^{0.5}	18.3, 8.2, 6.4; 19.6, 10.8, 9.2	Yune, P S; Kilduff, J E; Belfort, G, J. Membrane Sci., in press, 2011.
Interaction radius		6.3; 6.2	Yune, P S; Kilduff, J E; Belfort, G, J. Membrane Sci., in press, 2011.
Hildebrand solubility parameter	MPa ^{0.5}	calc.=23.12-24.4; exp.=21.0-22.9	
Dielectric constant at 60 Hz/1 MHz	-	3.51/3.54; 3.7-4.11/3.7-4.17 (20-30% glass fiber)	
Relative permittivity at 100 Hz	-	3.9 (conditioned); 4.2-4.3 (20-30% glass fiber, conditioned)	
Relative permittivity at 1 MHz	-	3.8 (conditioned); 4.2-4.3 (20-30% glass fiber, conditioned)	
Dissipation factor at 100 Hz	E-4	17; 15-20 (20-30% glass fiber)	
Dissipation factor at 1 MHz	E-4	56; 81-100 (20-30% glass fiber)	
Volume resistivity	ohm-m	>1.7E13; 1E14 (20-30% glass fiber)	
Surface resistivity	ohm	>1E15	
Electric strength K20/P50, d=0.60.8 mm	kV mm ⁻¹	15; 17 (20-30% glass fiber)	
Comparative tracking index	-	125 (conditioned); 125 (20-30% glass fiber, conditioned)	
Coefficient of friction	-	0.15-0.45 (air); 0.3 (water)	Duan, Y; Cong, P; Liu, X; Li, T, J. Macromol. Sci. B, 48, 604-16, 2009.
Contact angle of water, 20°C	degree	68.5-69.0	Kim, Y; Rana, D; Matsuura, T; Chung, W-J, J. Membrane Sci., 338, 84-91, 2009.
Surface free energy	mJ m ⁻²	47.0	
Speed of sound	m s ⁻¹	2260	
MECHANICAL & RHEOLOGICAL PROPERTIES			
Tensile strength	MPa	83-95, 105-137 (20-30% glass fiber)	

PES poly(ether sulfone)

PARAMETER	UNIT	VALUE	REFERENCES
Tensile modulus	MPa	2,650; 5,700-9,800 (20-30% glass fiber); 20,900 (30% carbon fiber)	
Tensile stress at yield	MPa	90 (conditioned)	
Tensile creep modulus, 1000 h, elongation 0.5 max	MPa	2,300-2,700; 5,600-8,300 (20-30% glass fiber)	
Elongation	%	25-75; 1.9-3.2 (20-30% glass fiber); 1.7 (30% carbon fiber)	
Tensile yield strain	%	5.2; 6.7 (conditioned)	
Flexural strength	MPa	111; 145-190 (20-30% glass fiber)	
Flexural modulus	MPa	2,900; 5,170-8,800 (20-30% glass fiber)	
Compressive strength	Mpa	100; 151-177 (20-30% glass fiber)	
Young's modulus	MPa	4,950	Grunzinger, S J; Watanabe, M; Fukagawa, K; Kikuchi, R; Tominaga, Y; Hayakawa, T; Kakimoto, M, J. Power Sources, 175, 120-26, 2008.
Charpy impact strength, unnotched, 23°C	kJ m ⁻²	no break (conditioned); 42-47 (20-30% glass fiber, conditioned)	
Charpy impact strength, unnotched, -30°C	kJ m ⁻²	no break (conditioned); 45 (20-30% glass fiber, conditioned)	
Charpy impact strength, notched, 23°C	kJ m ⁻²	6.5 (conditioned); 6.5-8 (20-30% glass fiber, conditioned)	
Charpy impact strength, notched, -30°C	kJ m ⁻²	7 (conditioned); 7.5-8 (20-30% glass fiber, conditioned)	
Izod impact strength, unnotched, 23°C	J m ⁻¹	no break; 530-640 (20-30% glass fiber)	
Izod impact strength, notched, 23°C	J m ⁻¹	85, 59-75 (20-30% glass fiber)	
Shear strength	MPa	55; 61-65 (20-30% glass fiber)	
Poisson's ratio	-	0.41; 0.42 (20-30% glass fiber)	
Shore D hardness	-	88	
Rockwell hardness	R	127; 121 (30% glass fiber)	
Shrinkage	%	0.8-1.4; 0.28-0.58 (20-30% glass fiber)	
Viscosity number	ml g ⁻¹	48-52; 56 (20-30% glass fiber)	
Melt viscosity, shear rate=1000 s ⁻¹	Pa s	240-800; 350-700 (20-30% glass fiber)	
Melt volume flow rate (ISO 1133, procedure B), 360°C/10 kg	cm ³ /10 min	35-150; 25-29 (20-30% glass fiber)	
Melt index, 380°C/2.16 kg	g/10 min	12-30; 10-18 (20-30% glass fiber)	
Water absorption, 24h at 23°C	%	2.2; 1.6 (20-30% glass fiber)	
Moisture absorption, equilibrium 23°C/50% RH	%	0.8; 0.6 (20-30% glass fiber)	
CHEMICAL RESISTANCE			
Acid dilute/concentrated	-	good/poor	
Alcohols	-	good	
Alkalis	-	good	
Aliphatic hydrocarbons	-	good	
Aromatic hydrocarbons	-	good to fair	
Esters	-	poor	
Greases & oils	-	good	
Halogenated hydrocarbons	-	poor	

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PARAMETER	UNIT	VALUE	REFERENCES
Ketones	-	poor	
⊖ solvent, ⊖-temp.=25°C	-	DMF/methanol=83/17	
FLAMMABILITY			
Flammability according to UL-standard; thickness 1.6/0.8 mm	class	V-0 to V-1; V-0 (20-30% glass fiber)	
Autoignition temperature	°C	580-600	
Limiting oxygen index	% O ₂	39; 40-44.5 (20-30% glass fiber)	
NBS smoke chamber, Ds, 4 min	-	1.0	
Char at 500°C	%	12.4-29.3 (air); 48 (nitrogen)	Lyons, R E; Walters, R N, J. Anal. Appl. Pyrolysis, 71, 27-46, 2004; Chen, H; Zhang, K; Xu, J, Polym. Deg. Stab., 96, 197-203, 2011.
Heat of combustion	J g ⁻¹	25,420	Walters, R N; Hackett, S M; Lyons, R E, Fire Mater., 24, 5, 245-52, 2000.
Activation energy of decomposition	kJ mol ⁻¹	280	Swallowe, G M; Dawson, P C; Tang, T B; Xu, Q L, J. Mater. Sci., 30, 3853-55, 1995.
Volatile products of combustion	-	CO	
TOXICITY			
HMIS: Health, Flammability, Reactivity rating	-	1/1/0	
Carcinogenic effect	-	not listed by ACGIH, NIOSH, NTP	
PROCESSING			
Typical processing methods	-	blow molding, casting, compression molding, film extrusion, injection molding, machining, profile extrusion, spinning, thermoforming, wire and cable extrusion	
Preprocess drying: temperature/time/residual moisture	°C/h/%	140-150/4/0.02-0.05	
Processing temperature	°C	340-390 (injection molding)	
Additives used in final products	-	carbon fiber, glass fiber, graphite	
Applications	-	aircraft interiors, automotive fuses, coatings, coil bobbins, dip switches, fiber optics connectors, hollow fiber, integrated circuits sockets, medical applications (due to the resistance to different methods of sterilization), membranes, microwave cookware, multipin connectors, printed circuit boards, transformer wire coatings, sight glasses	
BLENDS			
Suitable polymers	-	epoxy, PBI, PC, PEEK, PEO	