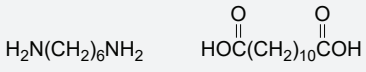
PA-6,12 polyamide-6,12

PARAMETER	UNIT	VALUE	REFERENCES
GENERAL			
Common name	-	polyamide-6,12, nylon-6,12; poly(iminohexamethyleneimino-dodecanedioyl)	
CAS name	-	poly[imino-1,6-hexanediylimino(1,12-dioxo-1,12-dodecanediyl)]	
Acronym	-	PA6,12	
CAS number	-	24936-74-1	
HISTORY			
Person to discover	-	Carothers, W H, 1937. Peterson, W R, 1939	Carothers, W H, US Patent 2,071,250, DuPont, Feb. 16, 1937. Peterson, W R, US Patent 2,174,527, DuPont, Oct. 3, 1939.
Date	-	1937; 1939	
Details	-	Carothers proposed basic synthesis; Peterson proposed process improvement	
SYNTHESIS			
Monomer(s) structure	-		
Monomer(s) CAS number(s)	-	124-09-4; 143-07-7	
Monomer(s) molecular weight(s)	dalton, g/mol, amu	116.21; 232.32	
Monomer ratio	-	0.5 (0.5:1)	
CH_2/CONH ratio		8	
Number average molecular weight, M_n	dalton, g/mol, amu	16,400	
Chain-end groups	meq g^{-1}	NH_2 – 0.036; COOH – 0.086	Koning, C; Teuwen, L; de Jong, R; Janssen, G; Coussens, B, High Perform. Polym., 11, 387-94, 1999.
STRUCTURE			
Crystallinity	%	7.7-28.4	Rhee, S; White, J L, Antec, 1690-94, 2000; Jones, N A; Atkins, E D T; Hill, M J; Cooper, S J; Franco, L, Polymer, 38, 11, 2689-99, 1997.
Cell type (lattice)	-	triclinic (α), pseudohexagonal (γ)	Jones, N A; Atkins, E D T; Hill, M J; Cooper, S J; Franco, L, Polymer, 38, 11, 2689-99, 1997; Menchaca, C; Manoun, B; Martinez-Barrera, G; Castado, V M; Lopez-Valdivia, H, J. Phys. Chem. Solids, 67, 2111-2118, 2006.
Cell dimensions	nm	a:b:c=0.49:0.533:2.48 (α); a:b:c=0.49:0.802:2.48 (γ)	Jones, N A; Atkins, E D T; Hill, M J; Cooper, S J; Franco, L, Polymer, 38, 11, 2689-99, 1997.
Unit cell angles	degree	α:β:γ=49:77:63.5 (α); α:β:γ=90:77:66.5 (β)	Jones, N A; Atkins, E D T; Hill, M J; Cooper, S J; Franco, L, Polymer, 38, 11, 2689-99, 1997.
Number of chains per unit cell	-	1/2	
Crystallite size	nm	20.4	Rajesh, J J; Bijwe, J, Wear, 661-68, 2005.
Polymorphs	-	α, γ	Menchaca, C; Manoun, B; Martinez-Barrera, G; Castado, V M; Lopez-Valdivia, H, J. Phys. Chem. Solids, 67, 2111-2118, 2006.

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Lamellae thickness	nm	23	Elzein, T; Brogly, M; Castelein, G; Schultz, J, J. Polym. Sci. B, 40, 1464-76, 2002.
Rapid crystallization temperature	°C	181	
Avrami constants, k/n	-	n=2.4-2.6	
PHYSICAL PROPERTIES			
Density at 20°C	g cm^{-3}	1.05-1.07; 1.32-1.42 (33-43% glass fiber, dry)	
Melting temperature, DSC	°C	215-218; 218 (33-43% glass fiber, dry)	
Decomposition temperature	°C	291	
Activation energy of thermal degradation	kJ mol^{-1}	164	Herrera, M; Matuschek, G; Kettrup, A, Chemosphere, 42, 601-7, 2001.
Thermal expansion coefficient, 23-80°C	$°C^{-1}$	9E-5-1.2E-4; 0.16-1.39E-4 (33-43% glass fiber, dry)	
Thermal conductivity, melt	W m^{-1} K^{-1}	0.22-0.25	
Glass transition temperature	°C	54-62 (dry); 42 (100% RH)	
Specific heat capacity	J K^{-1} kg^{-1}	1260	
Heat of fusion	kJ kg^{-1}	95	
Temperature index (50% tensile strength loss after 20,000 h/5000 h)	°C	65; 120 (33-43% glass fiber, dry)	
Heat deflection temperature at 0.45 MPa	°C	135-160 (dry); 216-217 (33-43% glass fiber, dry)	
Heat deflection temperature at 1.8 MPa	°C	62-80 (dry); 200-203 (33-43% glass fiber, dry)	
Vicat temperature VST/A/50	°C	181 (dry)	
Surface tension	mN m^{-1}	25-31	
Relative permittivity at 100 Hz	-	3.6 (dry); 6 (conditioned); 4.1 (33-43% glass fiber, dry)	
Relative permittivity at 1 MHz	-	3.2 (dry); 4 (conditioned); 3.6-3.8 (33-43% glass fiber, dry)	
Dissipation factor at 100 Hz	E-4	140 (dry); 1,500 (conditioned); 135 (33-43% glass fiber, dry)	
Dissipation factor at 1 MHz	E-4	165 (dry); 1,000 (conditioned); 150-200 (33-43% glass fiber, dry)	
Volume resistivity	ohm-m	1E13 (dry); 1E11-1E12 (saturation at 50% RH, 20°C); 1E11 (saturation at 100% RH, 20°C); 1E13 (33-43% glass fiber, dry)	
Surface resistivity	ohm	1E12 (dry); 1E12 (33-43% glass fiber)	
Electric strength K20/P50, d=0.60.8 mm	kV mm^{-1}	27 (33-43% glass fiber)	
Comparative tracking index, CTI, test liquid A	-	>600; >600 (33-43% glass fiber, dry)	
Arc resistance	MV/m	145 (33-43% glass fiber, dry)	
Coefficient of friction	-	0.35-0.55	
Surface free energy	mJ m^{-2}	67.0	
MECHANICAL & RHEOLOGICAL PROPERTIES			
Tensile strength	MPa	37; 168-200 (33-43% glass fiber, dry); 140-165 (33-43% glass fiber, conditioned)	
Tensile modulus	MPa	2,400-2,570 (dry); 1,500-1,680 (conditioned); 9,500-12,500 (33-43% glass fiber, dry); 7,90011,500 (33-43% glass fiber, conditioned)	

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PARAMETER	UNIT	VALUE	REFERENCES
Tensile stress at yield	MPa	62-63 (dry); 52-55 (conditioned)	
Elongation	%	7-35 (dry); 33 (conditioned); 3-3.2 (33-43% glass fiber, dry); 3.2-5 (33-43% glass fiber, conditioned)	
Tensile yield strain	%	4.3-4.5 (dry); 19 (conditioned)	
Flexural modulus	MPa	2,150 (dry); 8,200-11,000 (33-43% glass fiber, dry); 7,000 (33% glass fiber, conditioned)	
Young's modulus	MPa	672	
Charpy impact strength, unnotched, 23°C	kJ m^{-2}	no break; 80-100 (33-43% glass fiber, dry)	
Charpy impact strength, unnotched, -30°C	kJ m^{-2}	no break; 60-85 (33-43% glass fiber, dry)	
Charpy impact strength, notched, 23°C	kJ m^{-2}	4.2-5 (dry); 8 (conditioned); 13-17 (33-43% glass fiber, dry); 12 (33-43% glass fiber, conditioned)	
Charpy impact strength, notched, -30°C	kJ m^{-2}	4.2 (dry); 4 (conditioned); 11-17 (33-43% glass fiber, dry); 10 (33-43% glass fiber, conditioned)	
Izod impact strength, notched, 23°C	J m^{-1}	40	
Crack growth velocity	x 10^{-6} m s^{-1}	2077	Rajesh, J J; Bijwe, J, Tribology lett., 18, 3, 331-40, 2005.
Fracture energy	x 10^{4} J m^{-2}	3.78	Rajesh, J J; Bijwe, J, Tribology lett., 18, 3, 331-40, 2005.
Ductility factor	mm	14.52	Rajesh, J J; Bijwe, J, Tribology lett., 18, 3, 331-40, 2005.
Stress necessary to cause spontaneous fracture	MPa	110.95	Rajesh, J J; Bijwe, J, Tribology lett., 18, 3, 331-40, 2005.
Poisson's ratio	-	0.3-0.4; 0.39-0.42 (33-43% glass fiber, dry)	
Rockwell hardness	-	R114; R118 (33-43% glass fiber, dry)	
Shrinkage	%	1.1-1.5; 0.3-0.8 (33-43% glass fiber)	
Brittleness temperature (ASTM D746)	°C	-109	
Intrinsic viscosity, 25°C	dl g^{-1}	1.45	
Water absorption, equilibrium in water at 23°C	%	1.3-3.0; 1.7 (33-43% glass fiber)	
Moisture absorption, equilibrium 23°C/50% RH	%	1.3	
CHEMICAL RESISTANCE			
Acid dilute/concentrated	-	fair-poor	
Alcohols	-	good-fair	
Alkalis	-	good	
Aliphatic hydrocarbons	-	good	
Aromatic hydrocarbons	-	good	
Greases & oils	-	good	
Halogenated hydrocarbons	-	poor	
Ketones	-	good	
Good solvent	-	chloral hydrate, m-cresol, fluorinated alcohols, formic acid, mineral acids, phenols, trichloroethanol	

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PARAMETER	UNIT	VALUE	REFERENCES
FLAMMABILITY			
Ignition temperature	°C	420-430	
Autoignition temperature	°C	420-445	
Limiting oxygen index	% O_2	25-28; 23 (33-43% glass fiber)	
UL rating	-	HB; HB (33-43% glass fiber, dry)	
WEATHER STABILITY			
Products of degradation	-	CO,CO_2, H_2O, NO_x, caprolactam	
TOXICITY			
NFPA: Health, Flammability, Reactivity rating	-	1/1/0	
Carcinogenic effect	-	not listed by ACGIH, NIOSH, NTP	
PROCESSING			
Typical processing methods	-	blow molding, extrusion, injection molding	
Preprocess drying: temperature/ time/residual moisture	°C/h/%	80/2-6/<0.05; 80/2-4/<0.15 (33-43% glass fiber)	
Processing temperature	°C	230-290 (injection molding); 230-240 (extrusion); 280-300 (33-43% glass fiber)	
ANALYSIS			
FTIR (wavenumber-assignment)	cm^{-1}/-	N-H – 1539, 689, more in refs.	Yoshioka, Y; Tashiro, K; Ramesh, C, J. Polym. Sci. B, 41, 1294-1307, 2003; Rusu, G; Rusu, E, Mater. Design, 31, 4601-10, 2010.
Raman (wavenumber-assignment)	cm^{-1}/-	C=O – 1634; CH_2 – 2884, 1439; C-C – 1129	Olivares, M; Mondragon, M A; Vazquez-Polo, G; Martinez, E; Castano, V M, Intern. J. Polymeric Mater., 40, 213-18, 1998.