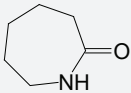


PA-6 polyamide-6

PARAMETER	UNIT	VALUE	REFERENCES
GENERAL			
Common name	-	polyamide-6, nylon 6, poly(ϵ -caprolactam)	
IUPAC name	-	poly[imino(1-oxohexane-1,6-diyl)]	
CAS name	-	poly[imino(1-oxo-1,6-hexanediy)]	
Acronym	-	PA-6	
CAS number	-	25038-54-4	
RTECS number	-	TQ9800000	
HISTORY			
Person to discover	-	Paul Schlack	Schlack, P, US Patent 2,241,321, IG Farben, May 6, 1941.
Date	-	1941	
Details	-	preparation of polyamides	
SYNTHESIS			
Monomer(s) structure	-		
Monomer(s) CAS number(s)	-	105-60-2	
Monomer(s) molecular weight(s)	dalton, g/mol, amu	113.2	
CH ₂ /CONH ratio		5	
Method of synthesis	-	caprolactam is melted and polymerized in the presence of catalyst and dulling agent	
Temperature of polymerization	°C	190-275	
Time of polymerization	h	24+22	
Catalyst	-	AH-salt	
Heat of polymerization	J g ⁻¹	137-146	Riedel, O; Wittmer, P, Makromol. Chem., 97, 1, 1966.
Number average molecular weight, M _n	dalton, g/mol, amu	20,800-48,100	Robert, E C; Bruessau, R; Dubois, J; Jacques, B; Meijerink, N; Nguye, T Q; Niehaus, D E; Tobisch, W A, Pure Appl. Chem., 76, 11, 2009-25, 2004; Farina, H; Yuan, C M; Ortenzi, M; Di Silvestro, G, Macromol. Symp., 218, 51-60, 2004.
Mass average molecular weight, M _w	dalton, g/mol, amu	17,000-94,000	Farina, H; Yuan, C M; Ortenzi, M; Di Silvestro, G, Macromol. Symp., 218, 51-60, 2004.
Polydispersity, M _w /M _n	-	1.7-2.4	
Polymerization degree (number of monomer units)	-	130-250	
Molar volume at 298K	cm ³ mol ⁻¹	calc.=103.7; 92.0 (crystalline); 104.4 (amorphous); exp.=104.4	
Van der Waals volume	cm ³ mol ⁻¹	68.06; 64.2 (crystalline); 64.2 (amorphous)	
Chain-end groups	micro-equivalent g ⁻¹	COOH – 28.8; NH ₂ – 34.5; COOH – 0; NH ₂ – 0.84	Fornes, T D; Paul, D R, Macromolecules, 37, 7698-7709, 2004; Davis, R D; Jarrett, W L; Mathias, L J, Polymer, 42, 2621-26, 2001.

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PARAMETER	UNIT	VALUE	REFERENCES
STRUCTURE			
Crystallinity	%	26-50; 42 (dry); 34 (wet)	Extrand, C W, J. Colloid Interface Sci., 248, 136-42, 2002; Yebra-Rodriguez, A; Alvarez-Lloret, P; Cardell, C; Rrodriguez-Navarro, A B, Appl. Clay Sci., 43, 91-97, 2009.
Cell type (lattice)	-	monoclinic	Holmes, D R; Bunna, C W; Smith, C J, J. Polym. Sci., 17, 159, 1955.
Cell dimensions	nm	a:b:c=0.956:0.801:1.724	Holmes, D R; Bunna, C W; Smith, C J, J. Polym. Sci., 17, 159, 1955.
Unit cell angles	degree	$\gamma=67.5$	Holmes, D R; Bunna, C W; Smith, C J, J. Polym. Sci., 17, 159, 1955.
Number of chains per unit cell	-	8	Holmes, D R; Bunna, C W; Smith, C J, J. Polym. Sci., 17, 159, 1955.
Crystallite size	nm	23.3	Rajesh, J J; Bijwe, J, Wear, 661-68, 2005.
Cis content	%	1.64	Davis, R D; Jarrett, W L; Mathias, L J, Polymer, 42, 2621-26, 2001.
Entanglement molecular weight	dalton, g/mol, amu	calc.=1988-2490	
Crystallization temperature	°C	191.8-193.2	Faghihi, M; Shojaei, A; Bagheri, R, Composites: Part B, 78, 50-64, 2015.
Rapid crystallization temperature	°C	173-180	Adriaensens, P; Pollaris, A; Carleer, R; Vanderzande, D; Gelan, J; Litvinov, V M; Tijssen, J, Polymer, 42, 7943-52, 2001.
COMMERCIAL POLYMERS			
Some manufacturers	-	BASF, DSM; EMS; DuPont; Kolon Plastics; Eurotec; Zig Shen	
Trade names	-	Ultramid B; Aculon; Grilon; Zytel; Kopa; Tecomid; Zisamide	
PHYSICAL PROPERTIES			
Density at 20°C	g cm ⁻³	1.06-1.16; 1.23-1.56 (12-50% glass fiber, dry); 0.96-1.07 (melt); 1.34 (50% glass fiber)	
Bulk density at 20°C	g cm ⁻³	0.5-0.8	
Color	-	colorless to white	
Refractive index, 20°C	-	calc.=1.513-1.530; exp.=1.53	
Birefringence	-	1.580/1.582	
Transmittance	%	85	
Odor	-	odorless	
Melting temperature, DSC	°C	220-260; 218.6-220	Faghihi, M; Shojaei, A; Bagheri, R, Composites: Part B, 78, 50-64, 2015.
Heat of melting	J g ⁻¹	53.8-62.1	Faghihi, M; Shojaei, A; Bagheri, R, Composites: Part B, 78, 50-64, 2015.
Thermal decomposition temperature	°C	>300	
Activation energy of thermal degradation	kJ mol ⁻¹	162	Herrera, M; Matuschek, G; Kettrup, A, Chemosphere, 42, 601-7, 2001.
Thermal expansion coefficient, 23-80°C	°C ⁻¹	0.83-0.93E-4 (dry); 0.12-0.78E-4 (12-50% glass fiber, dry)	
Thermal conductivity, melt	W m ⁻¹ K ⁻¹	0.1968-0.23; 0.23 (melt)	

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PARAMETER	UNIT	VALUE	REFERENCES
Glass transition temperature	°C	calc.=49-61; exp.=50-75 (dry); 3-20 (exposed to 50% RH); -22 to -32 (exposed to 100% RH)	
Specific heat capacity	J K ⁻¹ kg ⁻¹	1,400; 2,680-2,730 (melt); 1,950 (50% glass fiber)	
Heat of fusion	kJ kg ⁻¹	188-280	
Heat deflection temperature at 0.45 MPa	°C	117-190 (dry); 217-250 (12-50% glass fiber, dry)	
Heat deflection temperature at 1.8 MPa	°C	42-65 (dry); 190-250 (12-50% glass fiber, dry)	
Vicat temperature VST/A/50	°C	195-204 (dry); 210-250 (12-50% glass fiber, conditioned)	
Hansen solubility parameters, δ_D , δ_P , δ_H	MPa ^{0.5}	17.0, 3.4, 10.6	
Interaction radius		5.1	
Hildebrand solubility parameter	MPa ^{0.5}	calc.=21.5; exp.=20.3	
Surface tension	mN m ⁻¹	calc.=33.9-47.6; exp.=40.0-47.0	
Dielectric constant at 100 Hz/1 MHz	-	-/3.8	
Relative permittivity at 100 Hz	-	3.2-4.1 (dry); 3.6-14 (12-50% glass fiber, dry)	
Relative permittivity at 1 MHz	-	3.0-3.5 (dry); 4.5-7 (conditioned); 3.4-3.8 (12-50% glass fiber, dry)	
Dissipation factor at 100 Hz	E-4	50-100 (dry); 100-250 (12-50% glass fiber, dry); 1,700-3,000 (12-50% glass fiber, conditioned)	
Dissipation factor at 1 MHz	E-4	150-310 (dry); 1,200-3,000 (conditioned); 0.02-250 (12-50% glass fiber, dry); 1,700-2,400 (12-50% glass fiber, conditioned)	
Volume resistivity	ohm-m	1E13 (dry), 2E9 (saturated at 50% RH, 20°C), 4E6 (saturated at 100% RH, 20°C)	
Surface resistivity	ohm	1E15 (dry); 1E10 to 1E14 (conditioned)	
Electric strength K20/P50, d=0.60.8 mm	kV mm ⁻¹	25-460; 20 (conditioned)	
Comparative tracking index	-	600 (conditioned); 550 (12-50% glass fiber, conditioned)	
Power factor	-	0.02-0.06	
Coefficient of friction	ASTM D1894	0.32-0.43 (static), 0.16-0.8 (dynamic); 0.26 (chrom steel), 0.44-0.47 (aluminum)	Maldonado, J E, Antec, 3431-35, 1998.
Diffusion coefficient of water vapor	cm ² s ⁻¹ x10 ⁶	0.004/0.055	
Contact angle of water, 20°C	degree	62.6-65.5; 69.2/42.4 (ascending/receding)	
Surface free energy	mJ m ⁻²	45.4	
MECHANICAL & RHEOLOGICAL PROPERTIES			
Tensile strength	MPa	74-106; 130-240 (12-50% glass fiber, dry); 70-180 (12-50% glass fiber, conditioned)	Jia, N; Kagan, V A, Antec, 1706-12, 1998.
Tensile modulus	MPa	780-3,800 (dry); 570-1,200 (conditioned); 5,800-16,800 (12-50% ; 2,640-12,500 (12-50% glass fiber, conditioned)	
Tensile stress at yield	MPa	36-95 (dry); 32-55 (conditioned)	
Tensile creep modulus, 1000 h, elongation 0.5 max	MPa	700-1,100 (conditioned); 2,100-7,800 (12-50% glass fiber, conditioned)	
Elongation	%	10-160 (dry); 327 (conditioned); 2.5-4 (12-50% glass fiber, dry); 3.5-18 (12-50% glass fiber, conditioned)	
Tensile yield strain	%	3.5-7 (dry); 15-25 (conditioned)	
Flexural strength	MPa	100 (dry)	
Flexural modulus	MPa	2,600 (dry)	

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PARAMETER	UNIT	VALUE	REFERENCES
Elastic modulus	MPa	3,080-3,330; 9,860-10,820 (33% glass fiber); 14,110-16,440 (50% glass fiber)	Jia, N; Kagan, V A, Antec, 1706-12, 1998.
Compressive strength	MPa	55	
Young's modulus	GPa	235-337 (theoretical); 270-377 (experimental)	Peeters, A; van Alsenoy, C; Bartha, F; Bogar, F; Zhang, M-L; van Doren, V E, Int. J. Quantum Chem. 87, 303-10, 2002.
Charpy impact strength, unnotched, 23°C	kJ m ⁻²	no break to 50-250 (dry); no break (conditioned); 40-95 (12-50% glass fiber, dry); 100-105 (12-50% glass fiber, conditioned)	
Charpy impact strength, unnotched, -30°C	kJ m ⁻²	51-200 to no break (dry); 55-90 (12-50% glass fiber, dry)	
Charpy impact strength, notched, 23°C	kJ m ⁻²	3.5-82 (dry); 35-150 to no break (conditioned); 6.5-18 (12-50% glass fiber, dry); 25 (12-50% glass fiber, conditioned)	
Charpy impact strength, notched, -30°C	kJ m ⁻²	3-23 (dry); 4-22 (conditioned); 8 (12-50% glass fiber, dry)	
Izod impact strength, unnotched, 23°C	J m ⁻¹	1,700-2,000	Lin, H; Isayev, A I, Antec, 1518-22, 2003.
Crack growth velocity	x 10 ⁻⁶ m s ⁻¹	527	Rajesh, J J; Bijwe, J, Tribology lett., 18, 3, 331-40, 2005.
Fracture energy	x 10 ⁴ J m ⁻²	5.37	Rajesh, J J; Bijwe, J, Tribology lett., 18, 3, 331-40, 2005.
Ductility factor	mm	17.9	Rajesh, J J; Bijwe, J, Tribology lett., 18, 3, 331-40, 2005.
Stress necessary to cause spontaneous fracture	MPa	97.40	Rajesh, J J; Bijwe, J, Tribology lett., 18, 3, 331-40, 2005.
Tenacity (fiber) (standard atmosphere)	cN tex ⁻¹ (daN mm ⁻²)	40-90 (45-100)	Fourne, F, Synthetic Fibers. Machines and Equipment Manufacture, Properties. Carl Hanser Verlag, 1999.
Tenacity (wet fiber, as % of dry strength)	%	80-90	Fourne, F, Synthetic Fibers. Machines and Equipment Manufacture, Properties. Carl Hanser Verlag, 1999.
Fineness of fiber (titer)	dtex	1.4-300	Fourne, F, Synthetic Fibers. Machines and Equipment Manufacture, Properties. Carl Hanser Verlag, 1999.
Length (elemental fiber)	mm	38-300, filament	Fourne, F, Synthetic Fibers. Machines and Equipment Manufacture, Properties. Carl Hanser Verlag, 1999.
Poisson's ratio	-	calc.=0.440; exp.=0.33	
Shrinkage	%	0.87-1.4; 0.33-0.82 (12-50% glass fiber)	
Viscosity number	ml g ⁻¹	140-270; 130-170 (12-50% glass fiber, dry)	
Melt viscosity, shear rate=1000 s ⁻¹	Pa s	220-1,070	
Melt volume flow rate (ISO 1133, procedure B), 275°C/5 kg	cm ³ /10 min	40-185; 20-50 (15-50% glass fiber)	
Melt index, 190°C/2.16 kg	g/10 min	7.7-36.4	Faghihi, M; Shojaei, A; Bagheri, R, Composites: Part B, 78, 50-64, 2015.
Water absorption, equilibrium in water at 23°C	%	7.1-10; 4-8.1 (12-50% glass fiber, dry)	
Moisture absorption, equilibrium 20-90°C/saturation	%	2.0-3.3; 1.2-2.3 (12-50% glass fiber, dry)	

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PARAMETER	UNIT	VALUE	REFERENCES
CHEMICAL RESISTANCE			
Acid dilute/concentrated	-	good/poor	
Alcohols	-	good	
Alkalis	-	dilute - good, concentrated - poor	
Aliphatic hydrocarbons	-	resistant	
Aromatic hydrocarbons	-	resistant	
Greases & oils	-	resistant	
Ketones	-	resistant	
Good solvent	-	acetic acid, chlorophenol, m-cresol, ethylene carbonate, formic acid, phosphoric acid, sulfuric acid, trichloroacetic acid	
Non-solvent	-	alcohols, chloroform, DMF, esters, ethers, hydrocarbons, ketones	
FLAMMABILITY			
Flammability according to UL-94 standard; thickness 1.6/0.8 mm	class	V-2 or HB; HB (12-50% glass fiber, dry)	
Ignition temperature	°C	400	
Autoignition temperature	°C	424	
Limiting oxygen index	% O ₂	20-27; 22.5 (15-50% glass fiber)	
Char at 500°C	%	0	Lyon, R E; Walters, R N, J. Anal. Appl. Pyrolysis, 71, 27-46, 2004.
Heat of combustion	J g ⁻¹	31,400	
Volatile products of combustion	-	CO, HCN, caprolactam	
WEATHER STABILITY			
Spectral sensitivity	nm	290-310, 340-460	
Activation wavelengths	nm	300, 313, 334 (radical formation); 320 (yellowing)	
Excitation wavelengths	nm	282, 300, 310	
Emission wavelengths	nm	380, 420, 455, 460, 470	
Important initiators and accelerators	-	thermal degradation	
Products of degradation	-	CO, HCN, caprolactam, amines, carbon monoxide, hydrogen, hydrocarbons, crosslinks, carbon dioxide, acids, aldehydes, ketones, water, ammonia, hydroperoxides, pyrrole, ethylene	
BIODEGRADATION			
Typical biodegradants	-	bacterial hydrolases; filamentous fungus (<i>Phanerochaete Chrysosporium</i>)	Klun, U; Ffriedrich, J; Krzan, A, Polym. Deg. Stab., 79, 99-104, 2003.
TOXICITY			
HMIS: Health, Flammability, Reactivity rating	-	0-1/0-1/0	
Carcinogenic effect	-	not listed by ACGIH, IARC, or NTP	
PROCESSING			
Typical processing methods	-	extrusion, injection molding	
Preprocess drying: temperature/time/residual moisture	°C/h/%	80/4-10/0.15	

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PARAMETER	UNIT	VALUE	REFERENCES
Processing temperature	°C	250-280 (injection molding); 245-250 (film extrusion); 270-290 (profile extrusion)	
Processing pressure	MPa	3.5-12.5 (injection pressure)	
Applications	-	safety helmet parts, washers, gears, engine and motor parts, chutes; plugs, receptacles, covers, weed trimer components, clips, fasteners, flanges, key housing, flexible tubing, film, fans, hand-help power tools	
Outstanding properties	-	temperature resistance, chemical resistance to greases and oils	
BLENDS			
Suitable polymers	-	ABS, chitosan, HDPE, LDPE, NR, PA66, PBT, PC, PP, PPO, PS, PVDF	
ANALYSIS			
FTIR (wavenumber-assignment)	cm ⁻¹ /-	C=O – 1715; CH ₂ – 1463	Dong, W; Gijsman, P, Polym. Deg. Stab., 95, 1054-62, 2010.
Raman (wavenumber-assignment)	cm ⁻¹ /-	amide 1 – 1636; N-H – 1233; C-C – 1063/1076	Hendra, P J; Maddams, W F; Royaud, I A M; Willis, H A; Zichy, V, Spectrochim. Acta, 64A, 5, 747-56, 1990.
NMR (chemical shifts)	ppm	see ref.	Davis, R D; Jarrett, W L; Mathias, L J, Polymer, 42, 2621-26, 2001.