PA-6,10 polyamide-6,10

PARAMETER	UNIT	VALUE	REFERENCES
GENERAL			
Common name	-	polyamide-6,10, nylon-6,10; poly(iminohexamethyleneimino-sebacoyl), poly(hexamethylene sebacamide)	
CAS name	-	poly[imino-1,6-hexanediylimino(1,10-dioxo-1,10-decanediyl)]	
Acronym	-	PA-6,10	
CAS number	-	9008-66-6	
HISTORY			
Person to discover	-	Carothers, W H, 1937. Austin, P R	Carothers, W H, US Patent 2,071,250, DuPont, Feb. 16, 1937. Austin, P R, US Patent 2,244,183, DuPont, June 3, 1941.
Date	-	1937; 1941	
Details	-	Carothers patented polymerization; Austin patented plasticization	
SYNTHESIS			
Monomer(s) structure	-	$H_2N(CH_2)_6NH_2$ $HOC(=O)(CH_2)_8C(=O)OH$	
Monomer(s) CAS number(s)	-	124-09-4; 111-20-6	
Monomer(s) molecular weight(s)	dalton, g/mol, amu	116.21; 202.25	
Monomer ratio	-	0.575 (0.575:1)	
Number average molecular weight, M_n	dalton, g/mol, amu	18,900-22,140	
Polydispersity, M_w/M_n	-	2.0	
Molar volume at 298K	$cm^3 mol^{-1}$	calc.=238 (crystalline); 271.5 (amorphous)	
Van der Waals volume	$cm^3 mol^{-1}$	calc.=169.2 (crystalline); 169.2 (amorphous)	
Chain-end groups	meq g^{-1}	NH_2 – 0.021, COOH – 0.085; NH_2 – 0.21, COOH – 0.42	Koning, C; Teuwen, L; de Jong, R; Janssen, G; Coussens, B, High Perform. Polym., 11, 387-94, 1999; Davis, R D; Jarrett, W L; Mathias, L J, Polymer, 42, 2621-26, 2001.
STRUCTURE			
Crystallinity	%	26.5-45; 34 (dry); 31 (wet)	Extrand, C W, J. Colloid Interface Sci., 248, 136-42, 2002.
Cell type (lattice)	-	triclinic	Jones, N A; Atkins, E D T; Hill, M J; Cooper, S J; Franco, L, Polymer, 38, 11, 2689-99, 1997.
Cell dimensions	nm	a:b:c=0.49:0.53:2.23 (α); 0.49:0.799:2.23 (β); a:b:c=0.495:0.54:2.24	Jones, N A; Atkins, E D T; Hill, M J; Cooper, S J; Franco, L, Polymer, 38, 11, 2689-99, 1997; Ruehle, D A; Perbix, C; Castaneda, M; Dorgan, J R; Mittal, V; Halley, P; Martin, D, Polymer, 54, 6961-70, 2013.
Unit cell angles	degree	α:β:γ=49:77:64 (α); 90:77:66 (β); α:β:γ=49:76.5:63.5	Jones, N A; Atkins, E D T; Hill, M J; Cooper, S J; Franco, L, Polymer, 38, 11, 2689-99, 1997; Ruehle, D A; Perbix, C; Castaneda, M; Dorgan, J R; Mittal, V; Halley, P; Martin, D, Polymer, 54, 6961-70, 2013.

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PARAMETER	UNIT	VALUE	REFERENCES
Number of chains per unit cell	-	1/2	Jones, N A; Atkins, E D T; Hill, M J; Cooper, S J; Franco, L, Polymer, 38, 11, 2689-99, 1997.
Polymorphs	-	α, β	Jones, N A; Atkins, E D T; Hill, M J; Cooper, S J; Franco, L, Polymer, 38, 11, 2689-99, 1997.
Cis content	%	1.1	Davis, R D; Jarrett, W L; Mathias, L J, Polymer, 42, 2621-26, 2001.
Lamellae thickness	nm	18	Elzein, T; Brogly, M; Castelein, G; Schultz, J, J. Polym. Sci. B, 40, 1464-76, 2002.
Rapid crystallization temperature	°C	179	
Avrami constants, k/n	-	n=2.5-3.1	
COMMERCIAL POLYMERS			
Some manufacturers	-	BASF; EMS	
Trade names	-	Ultramid; Grilamid	
PHYSICAL PROPERTIES			
Density at 20°C	g cm^{-3}	1.03-1.10	
Bulk density at 20°C	g cm^{-3}	0.62-0.65	
Refractive index, 20°C	-	1.52-1.57	
Melting temperature, DSC	°C	215-230	
Decomposition temperature	°C	350	
Thermal expansion coefficient, 23-80°C	10^{-4} °C^{-1}	1.1-2 (dry, parallel); 1.1-1.5 (dry, normal)	
Thermal conductivity, melt	W m^{-1} K^{-1}	0.23; 0.35 (moist)	
Glass transition temperature	°C	65-70 (dry); 40 (50% RH); 10 (100% RH)	
Heat of fusion	kJ kg^{-1}	201-215	
Maximum service temperature	°C	110-130	
Long term service temperature	°C	160	
Heat deflection temperature at 0.45 MPa	°C	115-150 (dry)	
Heat deflection temperature at 1.8 MPa	°C	50-65 (dry)	
Surface tension	mN m^{-1}	37	
Dielectric constant at 100 Hz/1 MHz	-	3.9/3.3 (dry), 6.5/3.5 (at 65% RH)	
Relative permittivity at 100 Hz	-	0.04	
Relative permittivity at 1 MHz	-	0.03	
Volume resistivity	ohm-m	1E13 (dry); 2E10 (saturated at 50% RH, 20°C); 3E8 (saturated at 100% RH, 20°C)	
Surface resistivity	ohm	>1E15 (conditioned)	
Electric strength K20/P50, d=0.60.8 mm	kV mm^{-1}	36-38 (dry); 34-44 (conditioned)	
Comparative tracking index	-	600 (conditioned)	
Power factor	-	0.02	
Contact angle of water, 20°C	degree	71; 73.8/49.1 (asc/rec)	
Surface free energy	mJ m^{-2}	40.5	

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PARAMETER	UNIT	VALUE	REFERENCES
MECHANICAL & RHEOLOGICAL PROPERTIES			
Tensile strength	MPa	40-66 (dry); 40-60 (conditioned)	
Tensile modulus	MPa	750-3,160 (dry); 450-1,500 (conditioned)	
Tensile stress at yield	MPa	60-66 (dry); 45-52 (conditioned)	
Elongation	%	37 (dry); 140 (conditioned)	
Tensile yield strain	%	4.5-5 (dry); 18-20 (conditioned)	
Charpy impact strength, unnotched, 23°C	kJ m^{-2}	NB (dry); NB (conditioned)	
Charpy impact strength, unnotched, -30°C	kJ m^{-2}	NB to 300 (dry); NB (conditioned)	
Charpy impact strength, notched, 23°C	kJ m^{-2}	NB to 5-8 (dry; NB to 10-18 (conditioned)	
Charpy impact strength, notched, -30°C	kJ m^{-2}	3-15 (dry); 8-15 (conditioned)	
Poisson's ratio	-	0.3-0.4	
Ball indention hardness at 358 N/30 S (ISO 2039-1)	MPa	50-120 (dry); 35-70 (conditioned)	
Shrinkage	%	0.9-2.3	
Brittleness temperature (ASTM D746)	°C	-90 (dry); -62 (50% RH)	
Viscosity number	ml g^{-1}	148-150	
Intrinsic viscosity, 25°C	dl g^{-1}	1.147	
Melt viscosity, shear rate=1000 s^{-1}	Pa s	27	
Melt volume flow rate (ISO 1133, procedure B), 275°C/5 kg	cm^3/10 min	120	
Water absorption, equilibrium in water at 23°C	%	3-3.3	
Moisture absorption, equilibrium 23°C/50% RH	%	0.5-1.7	
CHEMICAL RESISTANCE			
Acid dilute/concentrated	-	fair-poor	
Alcohols	-	fair	
Alkalis	-	good-fair	
Aliphatic hydrocarbons	-	good	
Aromatic hydrocarbons	-	good	
Esters	-	good-fair	
Greases & oils	-	good	
Halogenated hydrocarbons	-	good-poor	
Ketones	-	fair	
Good solvent	-	m-cresol, phenol, sulfolane (hot), trichloroethanol	
FLAMMABILITY			
Ignition temperature	°C	>350	
Autoignition temperature	°C	415	
Limiting oxygen index	% O_2	21-24	Levchik, S V; Costa, L; Camino, G, Polym. Deg. Stab., 43, 43-54, 1994.

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PARAMETER	UNIT	VALUE	REFERENCES
Volatile products of combustion	-	CO_2, NH_3, CO, hydrocarbons	Levchik, S V; Costa, L; Camino, G, Polym. Deg. Stab., 43, 43-54, 1994.
UL 94 rating	-	HB	
PROCESSING			
Typical processing methods	-	injection molding	
Preprocess drying: temperature/ time/residual moisture	°C/h/%	80/4/0.15	
Processing temperature	°C	250-270 (injection molding)	
Processing pressure	MPa	0.17-0.35 (back)	
Applications	-	automotive (air intake systems, compressed air systems, hydraulic systems, fuel systems, powertrain and chassis), electrical & electronics (electrical appliances, electrical equipment, cables & tubes, connectors), industry & consumer goods (housewares, hydraulics and pneumatics, mechanical engineering, sports & leisure, tools & accessories)	
Outstanding properties	-	low water absorption, low melting temperature, bio-based	
BLENDS			
Suitable polymers	-	ABS, PA11, PP, SMA	Ruehle, D A; Perbix, C; Castaneda, M; Dorgan, J R; Mittal, V; Halley, P; Martin, D, Polymer, 54, 6961-70, 2013.
ANALYSIS			
FTIR (wavenumber-assignment)	cm^{-1}/-		Yoshioka, Y; Tashiro, K; Ramesh, C, J. Polym. Sci. B, 41, 1294-1307, 2003.
NMR (chemical shifts)	ppm		Davis, R D; Jarrett, W L; Mathias, L J, Polymer, 42, 2621-26, 2001.