

PA-4,6 polyamide-4,6

PARAMETER	UNIT	VALUE	REFERENCES
GENERAL			
Common name	-	polyamide-4,6; poly(iminotetramethyleneiminoadipoyl)	
CAS name	-	poly[imino-1,4-butanediylimino(1,6-dioxo-1,6-hexanediyl)]	
Acronym	-	PA-4,6	
CAS number	-	50327-22-5	
HISTORY			
Person to discover	-	Wallace Hume Carothers	Carothers, W H, US Patent 2,130,948, DuPont, Sept. 20, 1938.
Date	-	1938	
Details	-	first patent (first application filed in 1931)	
SYNTHESIS			
Monomer(s) structure	-	$\text{H}_2\text{N}(\text{CH}_2)_4\text{NH}_2 \quad \begin{array}{c} \text{O} \quad \text{O} \\ \parallel \quad \parallel \\ \text{HO}(\text{CH}_2)_4\text{COH} \end{array}$	
Monomer(s) CAS number(s)	-	110-60-1; 124-04-9	
Monomer(s) molecular weight(s)	dalton, g/mol, amu	88.15; 146.14	
CH ₂ /CONH ratio		4	
Method of synthesis	-	polyamide-4,6 is a product of polycondensation of tetramethylene-diamine and adipic acid. Due to the very high melting temperature the production of polyamide-4,6 was very difficult. As late as 1985 a process was invented to produce polyamide-4,6 on a commercially attractive scale in two step process including precondensation and solid-state post-condensation	
Number average molecular weight, M _n	dalton, g/mol, amu	6,100-24,400	
Mass average molecular weight, M _w	dalton, g/mol, amu	14,000-55,000	
Polydispersity, M _w /M _n	-	1.95-2.3	
STRUCTURE			
Crystallinity	%	25-70; 49 (dry); 44 (wet)	Zhang, Q; Zhang, Z; Zhang, H; Mo, Z, J. Polym. Sci. B, 40, 1784-93, 2002; Extrand, C W, J. Colloid Interface Sci., 248, 136-42, 2002; Adriaensens, P; Pollaris, A; Carlleer, R; Vanderzande, D; Gelan, J; Litvinov, V M; Tijssen, J, Polymer, 42, 7943-52, 2001.
Cell type (lattice)	-	monoclinic	
Cell dimensions	nm	a:b:c=0.96:1.48:0.806	Franco, L; Puiggali, Polymer, 40, 3255-59.
Unit cell angles	degree	β=67	Franco, L; Puiggali, Polymer, 40, 3255-59.
Polymorphs	-	α (the most stable), γ	
Rapid crystallization temperature	°C	260-265	
Avrami constants, k/n	-	n=4.1-4.2	
COMMERCIAL POLYMERS			
Some manufacturers	-	Cool Polymers; DSM; ERJKS	
Trade names	-	CoolPoly; Stanyl; Ertalon	

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PHYSICAL PROPERTIES			
Density at 20°C	g cm ⁻³	1.17-1.18; 0.978 (melt); 1.29-1.52 (15-60% glass fiber); 1.1-1.55 (15-60% glass fiber; melt)	
Melting temperature, DSC	°C	290-295; 295 (15-60% glass fiber)	
Thermal decomposition	°C	>350	
Thermal expansion coefficient, 23-80°C	10 ⁻⁴ °C ⁻¹	0.7-1.1; 0.2-0.6 (15-60% glass fiber)	
Thermal conductivity, melt	W m ⁻¹ K ⁻¹	0.252 (melt); 0.267- 0.43 (15-60% glass fiber, melt); 1.2 (special conductive polymer)	
Glass transition temperature	°C	43-80; 75 (15-60% glass fiber)	
Specific heat capacity	J K ⁻¹ kg ⁻¹	2,800 (melt); 1,450-2,540 (15-60% glass fiber, melt)	
Heat of fusion	kJ mol ⁻¹	15.1	
Maximum service temperature	°C	100	
Temperature index (50% tensile strength loss after 20,000 h/5000 h)	°C	130/152; 153/177 (15-60% glass fiber)	
Heat deflection temperature at 0.45 MPa	°C	220-285; 290 (15-60% glass fiber)	
Heat deflection temperature at 1.8 MPa	°C	160-190; 275-290 (15-60% glass fiber)	
Vicat temperature VST/A/50	°C	290; 290 (15-60% glass fiber)	
Dielectric constant at 100 Hz/1 MHz	-	3.83/	
Relative permittivity at 100 Hz	-	3.9; 22 (conditioned)	
Relative permittivity at 1 MHz	-	3.6; 4.5 (conditioned)	
Dissipation factor at 100 Hz	E-4	70; 8,700 (conditioned)	
Dissipation factor at 1 MHz	E-4	260; 1,200 (conditioned)	
Volume resistivity	ohm-m	5E12; 1E7 (conditioned)	
Surface resistivity	ohm	8E15; 1E13 (conditioned)	
Electric strength K20/P50, d=0.60.8 mm	kV mm ⁻¹	25; 15 (conditioned); 30 (15-60% glass fiber)	
Comparative tracking index, CTI, test liquid A	-	400; 175 (15-60% glass fiber)	
Coefficient of friction	-	0.08-0.38	Gordon, D H; Kukureka, S N, Wear, 267, 669-78, 2009.
Contact angle of water, 20°C	degree	57.6/32.8 (ascending/receding)	
MECHANICAL & RHEOLOGICAL PROPERTIES			
Tensile strength	MPa	55-100; 140-255 (15-60% glass fiber)	
Tensile modulus	MPa	3,300-3,900; 6,100-20,000 (15-60% glass fiber)	
Tensile stress at yield	MPa	40-100	
Tensile creep modulus, 1000 h, elongation 0.5 max	MPa	550; 10,500 (15-60% glass fiber)	
Elongation	%	7; 2-4 (15-60% glass fiber)	
Tensile yield strain	%	10	
Flexural strength	MPa	140-150; 225 (15-60% glass fiber)	
Flexural modulus	MPa	3,000-3,800; 7,500-17,000 (15-60% glass fiber)	
Young's modulus	MPa	932	
Charpy impact strength, unnotched, 23°C	kJ m ⁻²	6.5-10; 40-90 (15-60% glass fiber)	

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Charpy impact strength, unnotched, -30°C	kJ m ⁻²	4; 40-65 (15-60% glass fiber)	
Charpy impact strength, notched, 23°C	kJ m ⁻²	6-18 (15-60% glass fiber)	
Charpy impact strength, notched, -30°C	kJ m ⁻²	6-18 (15-60% glass fiber)	
Izod impact strength, notched, 23°C	J m ⁻¹	10; 6-18 (15-60% glass fiber)	
Izod impact strength, notched, -30°C	J m ⁻¹	4; 6-18 (15-60% glass fiber)	
Crack growth velocity	x 10 ⁻⁶ m s ⁻¹	800	Rajesh, J J; Bijwe, J, Tribology lett., 18, 3, 331-40, 2005.
Fracture energy	x 10 ⁴ J m ⁻²	9.29	Rajesh, J J; Bijwe, J, Tribology lett., 18, 3, 331-40, 2005.
Ductility factor	mm	10.81	Rajesh, J J; Bijwe, J, Tribology lett., 18, 3, 331-40, 2005.
Stress necessary to cause spontaneous fracture	MPa	197.13	Rajesh, J J; Bijwe, J, Tribology lett., 18, 3, 331-40, 2005.
Poisson's ratio	-	0.37	
Shrinkage	%	0.3-2; 0.4-1.5 (15-60% glass fiber)	
Viscosity number	ml g ⁻¹	175; 75-150 (15-60% glass fiber)	
Water absorption, equilibrium in water at 23°C	%	9.5-13.5; 5.4-11.5 (15-60% glass fiber)	Adriaensens, P; Pollaris, A; Rulkens, R; Litvinov, V M; Gelan, J, Polymer, 45, 2465-73, 2004; Adriaensens, P; Pollaris, A; Carleer, R; Vanderzande, D; Gelan, J; Litvinov, V M; Tijssen, J, Polymer, 42, 7943-52, 2001.
Moisture absorption, equilibrium 23°C/50% RH	%	2.6-3.7; 1.4-3.15 (15-60% glass fiber)	
CHEMICAL RESISTANCE			
Acid dilute/concentrated	-	poor	
Alcohols	-	good	
Alkalis	-	fair-poor	
Aliphatic hydrocarbons	-	good	
Aromatic hydrocarbons	-	good	
Esters	-	good	
Greases & oils	-	good	
Halogenated hydrocarbons	-	fair-poor	
Ketones	-	good	
Good solvent	-	formic acid, hexafluoroisopropanol, sulfuric acid	
FLAMMABILITY			
Autoignition temperature	°C	420	
Limiting oxygen index	% O ₂	22-27	
Volatile products of combustion	-	CO ₂ , H ₂ O, CO, NH ₃ , NO _x , HNC, cyclopentanone	
UL 94 rating	-	V-2; HB to V-0 (15-60% glass fiber)	

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TOXICITY			
Carcinogenic effect	-	not listed by ACGIH, NIOSH, NTP	
TLV, ACGIH	mg m ⁻³	3 (respiratory), 10 (total)	
OSHA	mg m ⁻³	5 (respiratory), 15 (total)	
PROCESSING			
Typical processing methods	-	extrusion, injection molding	
Preprocess drying: temperature/ time/residual moisture	°C/h/%	80-95/2-24/0.05	
Processing temperature	°C	315-320; 305-315 (15-60% glass fiber)	
Processing pressure	MPa	5.2-10.4 (injection), 1.7-5.2 (hold), 0.35 (back)	
Additives used in final products	-	flame retardants; fillers (glass fiber); heat stabilizers; impact modifiers, lubricants; release agents	
Applications	-	automotive (ABS controllers, alternator parts, chain tensioners, clutch components, inlet manifolds, oil filters, radiator end caps, sensors and switches, etc.)	