


# POM polyoxymethylene

PARAMETER	UNIT	VALUE	REFERENCES
<b>GENERAL</b>			
Common name	-	polyoxymethylene, polyacetal	
IUPAC name	-	poly(oxymethylene)	
CAS name	-	poly(oxymethylene) (9002-81-7); poly(oxymethylene), $\alpha$ -acetyl- $\omega$ -(acetyloxy)- (25231-38-3)	
Acronym	-	POM	
CAS number	-	9002-81-7, 25231-38-3	
Formula		$\left[ \text{CH}_2\text{O} \right]_n$	
<b>HISTORY</b>			
Person to discover	-	Hermann Staudinger	
Date	-	1920, 1956 (commercial application by DuPont)	
<b>SYNTHESIS</b>			
Monomer(s) structure	-		
Monomer(s) CAS number(s)	-	110-88-3	
Monomer(s) molecular weight(s)	dalton, g/mol, amu	90.08	
Monomer ratio	%	at least 95 monomer units	
Comonomer	-	ethylene oxide (thermal stabilization by Celanese method); formaldehyde+cyclic ethers (decelerator of thermal degradation)	Yang, F; Li, H; Cai, L; Lan, F; Xiang, M, Polym.-Plast. Technol. Eng., 48, 530-34, 2009; Ramirez, N V; Sanchez-Soto, M; Illescas, S; Gordillo, A, Polym.-Plast. Techn. Eng., 48, 470-77, 2009.
Method of synthesis	-	anhydrous formaldehyde is polymerized in the presence of anionic catalysis and the resulting polymer stabilized by reaction with acetic anhydride	
Temperature of polymerization	°C	80	
Catalyst	-	$\text{BF}_3 \cdot \text{OEt}_2$	
Heat of polymerization	J g <sup>-1</sup>	-706	
Number average molecular weight, $M_n$	dalton, g/mol, amu	20,000-110,000	
Mass average molecular weight, $M_w$	dalton, g/mol, amu	21,000-1,000,000	
Polydispersity, $M_w/M_n$	-	1.84-14.7	Sukhanova, T; Bershtein, V; Keating, M; Matveeva, G; Vylegzhanina, M; Egorov, V; Peschanskaya, N; Yakushev, P; Flexman, E; Greulich, S; Sauer, B; Schodr, K, Maacromol. Symp., 214, 135-145, 2004.
Molar volume at 298K	cm <sup>3</sup> mol <sup>-1</sup>	19.3 (crystalline)	
Van der Waals volume	cm <sup>3</sup> mol <sup>-1</sup>	13.9 (crystalline)	
Radius of gyration	nm	2.8-3.3	Sukhanova, T; Bershtein, V; Keating, M; Matveeva, G; Vylegzhanina, M; Egorov, V; Peschanskaya, N; Yakushev, P; Flexman, E; Greulich, S; Sauer, B; Schodr, K, Maacromol. Symp., 214, 135-145, 2004.

# POM polyoxymethylene

PARAMETER	UNIT	VALUE	REFERENCES
Chain-end groups	-	acetyl, acetyloxy (improve thermal stability by DuPont method)	Yang, F; Li, H; Cai, L; Lan, F; Xiang, M, Polym.-Plast. Technol. Eng., 48, 530-34, 2009.
<b>STRUCTURE</b>			
Crystallinity	%	48-85; 72-92 (highly oriented)	Zhao, X; Ye, L; Mater. Sci. Eng., A528, 4585-91, 2011.
Orientation factor	-	0.84-0.99 (draw ratio up to 1000%)	Zhao, X; Ye, L; Mater. Sci. Eng., A528, 4585-91, 2011.
Cell type (lattice)	-	hexagonal	Zhao, X; Ye, L; Mater. Sci. Eng., A528, 4585-91, 2011.
Cell dimensions	nm	a:b:c=0.443-0.447:0.443-0.447:1.725-1.739	Zhao, X; Ye, L; Mater. Sci. Eng., A528, 4585-91, 2011.
Unit cell angles	degree	1	
Crystallite size	nm	10-15.6	
Chain conformation	-	helix 9/5	
Entanglement molecular weight	dalton, g/mol, amu	calc.=2540	
Lamellae thickness	nm	200-5,400	Sukhanova, T; Bershtein, V; Keating, M; Matveeva, G; Vylegzhanina, M; Egorov, V; Peschanskaya, N; Yakushev, P; Flexman, E; Greulich, S; Sauer, B; Schodr, K, Maacromol. Symp., 214, 135-145, 2004.
Avrami constant, k/n	-	n=1.5-3.9; n=1.3-1.5 (non-isothermal crystallization)	Shu, Y; Ye, L; Zhao, X, Polym.-Plast. Technol. Eng., 45, 963-70, 2006; Zhao, X; Ye, L, Composites, B42, 926, 33, 2011; Li, Y; Zhou, T; Chen, Z; Hui, J; Li, L; Zhang, A, Polymer, 52, 2059-69, 2011.
<b>COMMERCIAL POLYMERS</b>			
Some manufacturers	-	BASF; DuPont; Mitsubishi Chemical	
Trade names	-	Ultraform; Delrin; Lupital	
<b>PHYSICAL PROPERTIES</b>			
Density at 20°C	g cm <sup>-3</sup>	1.35-1.44; 1.49-1.53 (crystalline); 1.49-1.60 (10-25% glass fiber); 1.14-1.16 (melt); 1.33 (melt, 20% glass fiber)	
Bulk density at 20°C	g cm <sup>-3</sup>	0.85	
Refractive index, 20°C	-	1.545-1.553; 1.47	
Odor	-	odorless	
Melting temperature, DSC	°C	166-185; 168-178 (10-25% glass fiber)	
Decomposition temperature	°C	230-250 (air); 277-326 (nitrogen)	Yang, F; Li, H; Cai, L; Lan, F; Xiang, M, Polym.-Plast. Technol. Eng., 48, 530-34, 2009; Archodoulaki, V-M; Lueftl, S; Seidler, S, Polym. Deg. Stab., 86, 75-83, 2004.
Freezing temperature	°C	140	
Thermal expansion coefficient, -40 to 100°C	°C <sup>-1</sup>	1-1.2E-4; 0.14-1.0E-4 (10-25% glass fiber)	
Thermal conductivity, melt	W m <sup>-1</sup> K <sup>-1</sup>	0.294-0.312; 0.13-0.15 (melt); 0.2 (melt, 20% glass fiber); 0.78 (11.6 vol% carbon nanotubes)	Zhao, X; Ye, L, Composites, B42, 926, 33, 2011.
Glass transition temperature	°C	calc.= -50; exp.= -60 to -90	
Specific heat capacity	J K <sup>-1</sup> kg <sup>-1</sup>	2,200-3,100 (melt)	
Heat of fusion	kJ kg <sup>-1</sup>	80-140	

# POM polyoxymethylene

PARAMETER	UNIT	VALUE	REFERENCES
Maximum service temperature	°C	140	
Long term service temperature	°C	90	
Heat deflection temperature at 0.45 MPa	°C	150-160; 174-176 (10-25% glass fiber)	
Heat deflection temperature at 1.8 MPa	°C	85-116; 161-172 (10-25% glass fiber)	
Vicat temperature VST/A/50	°C	150-160; 160-163 (20-25% glass fiber)	
Vicat temperature VST/B/50	°C	170-190	
Surface tension	mN m <sup>-1</sup>	calc.=44.6	
Dielectric constant at 100 Hz/1 MHz	-	3.0-3.7	
Dielectric loss factor at 1 kHz	-	0.001	
Relative permittivity at 100 Hz	-	3.7-3.9; 3.7-4.0 (10-25% glass fiber)	
Relative permittivity at 1 MHz	-	3.7-3.9; 3.9-4.1 (10-25% glass fiber)	
Dissipation factor at 100 Hz	E-4	10-200; 40 (10-25% glass fiber)	
Dissipation factor at 1 MHz	E-4	40-70; 70 (10-25% glass fiber)	
Volume resistivity	ohm-m	1E12-1E13; 1E11 to 1E12 (10-25% glass fiber)	
Surface resistivity	ohm	1E12-1E16; 1E14 (25% glass fiber)	
Electric strength K20/P50, d=0.60.8 mm	kV mm <sup>-1</sup>	21-40; 28-29 (10-25% glass fiber)	
Comparative tracking index	-	600; 600 (10-25% glass fiber)	
Arc resistance	s	120-200	
Power factor	-		
Coefficient of friction	-	0.10-0.38 (against itself); 0.18-0.41 (against steel); 0.11 (dynamic)	De Baets, P; Ost, W; Samyn, P; Schoukens, G; Van Parys, F, J. Synthetic Lubrication, 19, 2, 109-18,2002; Hu, K H; Wang, J; Schraube, Y F; Xu, Y F; Hu, X G; Stengler, R, Wear, 266, 1198-1207, 2009.
Permeability to water vapor, 25°C	cm <sup>3</sup> cm cm <sup>-2</sup> s <sup>-1</sup> Pa <sup>-1</sup> x 10 <sup>12</sup>	68.3	
Diffusion coefficient of water vapor	cm <sup>2</sup> s <sup>-1</sup> x10 <sup>6</sup>	0.027	
Contact angle of water, 20°C	degree	74.5-79.0	
Surface free energy	mJ m <sup>-2</sup>	38.6	
<b>MECHANICAL &amp; RHEOLOGICAL PROPERTIES</b>			
Tensile strength	MPa	52-60; 95-145 (10-25% glass fiber); 900-2,000 (highly oriented)	Zhao, X; Ye, L; Mater. Sci. Eng., A528, 4585-91, 2011.
Tensile modulus	MPa	2,400-3,200; 5,500-9,400 (10-25% glass fiber); 12,000-25,000 (highly oriented)	Zhao, X; Ye, L; Mater. Sci. Eng., A528, 4585-91, 2011.
Tensile stress at yield	MPa	43-74	
Tensile creep modulus, 1000 h, elongation 0.5 max	MPa	1,300-1,700; 4,500-5,800 (20-25% glass fiber)	
Elongation	%	20-120; 3 (20-25% glass fiber)	
Tensile yield strain	%	7.5-30; 4.3 (10-25% glass fiber)	
Flexural strength	MPa	88-98	
Flexural modulus	MPa	2,500-3,000; 4,800-8,500 (10-25% glass fiber)	

# POM polyoxymethylene

PARAMETER	UNIT	VALUE	REFERENCES
Elastic modulus	MPa	3,000	
Compressive strength	MPa	85; 100 (30% glass fiber)	
Charpy impact strength, unnotched, 23°C	kJ m <sup>-2</sup>	70-280; 50-55 (10-25% glass fiber)	
Charpy impact strength, unnotched, -30°C	kJ m <sup>-2</sup>	22-230; 50-60 (10-25% glass fiber)	
Charpy impact strength, notched, 23°C	kJ m <sup>-2</sup>	5.3-8; 5-9 (10-25% glass fiber)	
Charpy impact strength, notched, -30°C	kJ m <sup>-2</sup>	2.5-5.5; 5.0-8.5 (10-25% glass fiber)	
Shear modulus	MPa	3,100	
Poisson's ratio	-	0.27	Benabdallah, H S; Wei, J J. J. Tribology, 127, 766-75, 2005.
Rockwell hardness	-	M79-92; R117-120	
Shrinkage	%	1.9-2.1; 0.4-1.6 (10-25% glass fiber)	
Intrinsic viscosity, 25°C	ml g <sup>-1</sup>	63.2-96.8	Oner, M; White, D H, Polym. Deg. Stab., 40, 297-303, 1993.
Melt viscosity, shear rate=1000 s <sup>-1</sup>	Pa s	100-500	
Melt volume flow rate (ISO 1133, procedure B), 190°C/2.16 kg	cm <sup>3</sup> /10 min	2.2-45; 4-4.3 (20% glass fiber)	
Melt index, 190°C/3.8 kg	g/10 min	1.9-52	
Water absorption, equilibrium in water at 23°C	%	0.8-1.65; 0.9-1.1 (10-25% glass fiber)	
Moisture absorption, equilibrium 23°C/50% RH	%	0.2-0.4; 0.15-0.17 (10-25% glass fiber)	
<b>CHEMICAL RESISTANCE</b>			
Acid dilute/concentrated	-	good-poor	
Alcohols	-	good	
Alkalis	-	good-poor	
Aliphatic hydrocarbons	-	very good	
Aromatic hydrocarbons	-	good	
Esters	-	good	
Greases & oils	-	good	
Halogenated hydrocarbons	-	good	
Ketones	-	good	
Good solvent	-	aniline, benzyl alcohol, bromobenzene, $\gamma$ -butyrolactone, chlorophenols, diphenyl ether, DMF, formamide, phenol (all at elevated temperatures)	
Non-solvent	-	lower alcohols, diethyl ether, lower esters, hydrocarbons	
<b>FLAMMABILITY</b>			
Flammability according to UL-94 standard; thickness 1.6/0.8 mm	class	HB	
Ignition temperature	°C	320-340	
Autoignition temperature	°C	375	
Limiting oxygen index	% O <sub>2</sub>	15-16; 21 (10-25% glass fiber); 31-46 (with flame retardant)	Wang, Z-Y; Liu, Y; Wang, Q, Polym. Deg. Stab., 95, 945-54, 2010.

# POM polyoxymethylene

PARAMETER	UNIT	VALUE	REFERENCES
Heat release	kW m <sup>-2</sup>	268.8	Wang, Z-Y; Liu, Y; Wang, Q, Polym. Deg. Stab., 95, 945-54, 2010.
Burning rate (Flame spread rate)	mm min <sup>-1</sup>	50	
Char at 500°C	%	0	Lyon, R E; Walters, R N, J. Anal. Appl. Pyrolysis, 71, 27-46, 2004.
Heat of combustion	J g <sup>-1</sup>	17,390	Walters, R N; Hacket, S M; Lyon, R E, Fire Mater., 24, 5, 245-52, 2000.
Volatile products of combustion	-	formaldehyde, CO, CO <sub>2</sub> , and more	Pan, G; Li, H; Cao, Y, J. Appl. Polym. Sci., 93, 577-83, 2004.
UL 94 rating	-	HB, V-1 (with flame retardant)	Wang, Z-Y; Liu, Y; Wang, Q, Polym. Deg. Stab., 95, 945-54, 2010.
<b>WEATHER STABILITY</b>			
Excitation wavelengths	nm	290	
Emission wavelengths	nm	312, 435, 450	
Important initiators and accelerators	-	CuCl <sub>2</sub> , water, acids	
Products of degradation	-	hydroperoxides, carbonyls, chain scission, hydrogen, carbon oxides, methane, ethane, formaldehyde	
Stabilizers	-	UVA: 2-(2H-benzotriazol-2-yl)-p-cresol; 2-(2H-benzotriazole-2-yl)-4,6-di-tert-pentylphenol; 2-(2H-benzotriazole-2-yl)-4-(1,1,3,3-tetraethylbutyl)phenol; 2,2'-methylenebis(6-(2H-benzotriazol-2-yl)-4-1,1,3,3-tetramethylbutyl)phenol; 2-(2H-benzotriazol-2-yl)-4,6-bis(1-methyl-1-phenylethyl)phenol; 2-(3-sec-butyl-5-tert-butyl-2-hydroxyphenyl)benzotriazole; HAS: 1,3,5-triazine-2,4,6-triamine, N,N''[1,2-ethanediy-bis[[[4,6-bis[butyl (1,2,6,6-pentamethyl-4-piperidinyl) amino]-1,3,5-triazine-2-yl]imino]-3,1-propanediyl] bis[N',N''-dibutyl-N',N''-bis(1,2,2,6,6-pentamethyl-4-piperidinyl)-; bis(2,2,6,6-tetramethyl-4-piperidyl) sebacate; poly[[[6-[1,1,3,3-tetramethylbutyl)amino]-1,3,5-triazine-2,4-diy]]2,2,6,6-tetramethyl-4-piperidinyl]imino]-1,6-hexanediy][2,2,6,6-tetramethyl-4-piperidinyl]imino]; butanedioic acid, dimethylester, polymer with 4-hydroxy-2,2,6,6-tetramethyl-1-piperidine ethanol; 1,6-hexanediamine, N, N'-bis(2,2,6,6-tetramethyl-4-piperidinyl)-, polymers with 2,4-dichloro-6-(4-morpholinyl)-1,3,5-triazine; 1,6-hexanediamine, N,N'-bis(2,2,6,6-tetramethyl-4-piperidinyl)-, polymers with morpholine-2,4,6-trichloro-1,3,5-triazine reaction products, methylated; Phenolic antioxidant: ethylene-bis(oxyethylene)-bis(3-(5-tert-butyl-4-hydroxym-tolyl)-propionate); pentaerythritol tetrakis(3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate); N,N'-hexane-1,6-diy]bis(3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionamide)); 1,3,5-tris(4-tert-butyl-3-hydroxy-2,6-dimethyl benzyl)-1,3,5-triazine-2,4,6-(1H,3H,5H)-trione; 2,2'-methylenebis(4-methyl-6-tertbutylphenol); Optical brightener: Fluorescent Brightener 378 (Clariant)	
Results of exposure, tensile strength retention	SAE J-1885, 1000 h; %	about 50; 98 (UV stabilized)	
Low earth orbit erosion yield	cm <sup>3</sup> atom <sup>-1</sup> x 10 <sup>-24</sup>	9.14	Waters, D L; Banks, B A; De Groh, K K; Miller, S K R; Thorson, S D, High Performance Polym., 20, 512-22, 2008.

# POM polyoxymethylene

PARAMETER	UNIT	VALUE	REFERENCES
$\gamma$ -radiation	Mrad	5 (dose sufficient to make compacts brittle)	Kassem, M E; Bassiouni, M E; El-Muraikhi, J. Mater. Sci., Mater. Electronics, 13, 717-19, 2002.
<b>BIODEGRADATION</b>			
Typical biodegradants	-	not biodegradable	
Stabilizers	-	POM releases its own product of degradation which is formaldehyde acting as biocide	
<b>TOXICITY</b>			
NFPA: Health, Flammability, Reactivity rating	-	0-1/1/0	
Carcinogenic effect	-	not listed by ACGIH, NIOSH, NTP (decomposition produces formaldehyde, which is Group 1 carcinogen according to IARC)	
<b>PROCESSING</b>			
Typical processing methods	-	blow molding, compression molding, extrusion, foam molding, injection molding, machining, rotational molding, stamping, transfer molding	
Preprocess drying: temperature/time/residual moisture	°C/h/%	80-100/2-4/0.1-0.2	
Processing temperature	°C	180-230, 205-215 (recommended) (injection molding); 175-180 (film and profile extrusion)	
Processing pressure	MPa	80-100 (hold pressure); 50-100 (injection)	
Process time	s	42 (cycle), 4 (injection)	Ramirez, N V; Sanchez-Soto, M; Illiescas, S; Gordillo, A, Polym.-Plast. Techn. Eng., 48, 470-77, 2009.
Additives used in final products	-	Fillers: aramid fiber, calcium carbonate, carbon black, carbon fiber, carbon nanotubes, glass beads, glass fiber, iron powder, metal flakes, nano-CaCO <sub>3</sub> (nucleating agent), PTFE fiber, talc, zinc whisker; Antistatics: polyetheresteramide, quaternary ammonium compound, superconductive carbon black; Release: fluoropolymer, N,N'-ethylene bisstearamide, paintable silicone; Slip: PTFE; Thermal stabilizer: triethanolamine	
Special grades	-	toughened, UV resistant, low-friction and low wear	
Applications	-	appliances, automotive parts (door handles, window winders, tank filler necks and caps, carburetor, screw caps for cooling system expansion tanks, fuel pumps), bearings, cams, clips, containers, home electronics and hardware, parts of textile machines, phones (dialing units and slider guideways), pneumatic components, pump impellers, rollers, shower parts, springs, and many other applications	
Outstanding properties	-	fatigue endurance, high resistance to repeated impacts, dimensional stability, electrical insulating capabilities	
<b>BLENDS</b>			
Suitable polymers	-	HDPE, MBS, PA, PAH, PE, PTFE (nucleation), PUR	
<b>ANALYSIS</b>			
FTIR (wavenumber-assignment)	cm <sup>-1</sup> /-	C=O – 1733; CH <sub>2</sub> – 1470, 1430	Ramirez, N V; Sanchez-Soto, M; Illiescas, S; Gordillo, A, Polym.-Plast. Techn. Eng., 48, 470-77, 2009.
Raman (wavenumber-assignment)	cm <sup>-1</sup> /-	C-O-C – 936, 545; CH <sub>2</sub> – 1491, 1324;	Zhao, X; Ye, L; Mater. Sci. Eng., A528, 4585-91, 2011.

# POM polyoxymethylene

PARAMETER	UNIT	VALUE	REFERENCES
<b>NMR (chemical shifts)</b>	ppm	CH <sub>2</sub> -O – 5.20, 4.63, 4.5; CH <sub>2</sub> -CH <sub>2</sub> -O – 3.73	Pan, G; Li, H; Cao, Y, J. Appl. Polym. Sci., 93, 577-83, 2004.
<b>x-ray diffraction peaks</b>	degree	22.9, 34.6, 48.4	Zhao, X; Ye, L; Mater. Sci. Eng., A528, 4585-91, 2011.