EPDM ethylene-propylene diene terpolymer

PARAMETER	UNIT	VALUE	REFERENCES
GENERAL			
Common name	-	ethylene-propylene diene terpolymer	
CAS name	-	EPDM rubber	
Acronym	-	EPDM	
CAS number	-	25038-36-2; 308064-28-0	
HISTORY			
Person to discover	-	Ziegler, K; Natta, G	
Date	-	1951; 1962	
Details	-	discovery of catalyst essential for polymerization; commercial production	
SYNTHESIS			
Monomer(s) structure	-	CH_2=CH_2; CH_3CH=CH_2; diene (e.g., dicylopentadiene, ethylidene norbornene)	
Monomer(s) CAS number(s)	-	74-85-1; 115-07-1;	
Monomer(s) molecular weight(s)	dalton, g/mol, amu	28.05; 42.08;	
Monomer ratio (general)	-	ethylene – 50%, diene – 4%	
Ethylene content	wt%	42-85	
Ethylenenorbornene (vinylnorbonene) content	wt%	0.5-10.0	
Propylene content	wt%	10-53	
Method of synthesis	-	ENB is present in solution, catalyst is added and ethylene and propylene are bubbled through the solution	Bavarian, N; Baird, M C; Parent, J S, Macromol. Chem. Phys., 202, 3248-52, 2001.
Temperature of polymerization	°C	0	
Catalyst	-	Ziegler-Natta, metallocene	
Number average molecular weight, M_n	dalton, g/mol, amu	120,000-410,000	Kontos, E G, Antec, 2256-60, 1999; Young, H W; Brignac, S D; Kolbert, A C, Antec, 3429-4, 1997.
Mass average molecular weight, M_w	dalton, g/mol, amu	150,000-1,638,000	Kontos, E G, Antec, 2256-60, 1999; Young, H W; Brignac, S D; Kolbert, A C, Antec, 3429-4, 1997.
Polydispersity, M_w/M_n	-	1.6-6.3; 2-2.5 (typical)	Kontos, E G, Antec, 2256-60, 1999; Young, H W; Brignac, S D; Kolbert, A C, Antec, 3429-4, 1997; Snijders, E A; Boersma, A; van Baarle, B; Noordermeer, Polym. Deg. Stab., 89, 200-7, 2005.
Degree of branching	molecule^{-1}	27-28	Mitra, S; Jorgensen, M; Pedersen, W B; Almdal, K; Banerjee, J. Appl. Polym.Sci., 113, 2962-72, 2009.
Crystallinity	%	13-21 (high ethylene content); 0 (low ethylene content; e.g., Et<70%)	Parikh, D R; Edmondson, M S; Smith, B W; Winter, J M; Castille, M J; Magee, J M; Patel, R M; Karajala, T P, Antec, 3434-9, 1997; Mitra, S; Jorgensen, M; Pedersen, W B; Almdal, K; Banerjee, J. Appl. Polym.Sci., 113, 2962-72, 2009.
Cell type (lattice)	-	orthorhombic; pseudo-hexagonal	
Cell dimensions	nm	a:b:c=0.788:0.497:0.254 (86 mol% Et, similar to PE); a:b:c=0.866:0.50:0.254 (75 mol%, stretched; crystallinity disappears on heating)	Bassi, I W; Corradini, P; Fagherazzi, G; Valvassori, A, Eur. Polym. J., 6, 709-18, 1970.

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PARAMETER	UNIT	VALUE	REFERENCES
COMMERCIAL POLYMERS			
Some manufacturers	-	Crosspolimeri, Dow; ExxonMobil; Lanxess	
Trade names	-	Poligon; Nordel; Vistalon; Buna, Keltan	
PHYSICAL PROPERTIES			
Density at 20°C	g cm^{-3}	0.85-0.90	
Color	-	white to off-white	
Refractive index, 20°C	-	1.48 (vulcanized)	
Odor	-	none to mild	
Decomposition temperature	°C	>300	
Storage temperature	°C	<35	
Glass transition temperature	°C	-48 to -69	
Long term service temperature	°C	-54 to 100	
Hildebrand solubility parameter	$MPa^{0.5}$	16.0-16.5	
Surface tension	mN m^{-1}	34.5	Wu, S, Polym. Eng. Sci., 27, 335, 1987.
Dielectric constant at 100 Hz/1 MHz	-	2.35	Canaud, C; Visconte, L L Y; Sens, M A; Nunes, R C R, Polym. Deg. Stab., 70, 259-62, 2000.
Volume resistivity	ohm-m	1E13 to 1E16	
Surface resistivity	ohm	1.5E16	
Electric strength K20/P50, d=0.60.8 mm	kV mm^{-1}	27.4	
Coefficient of friction	-	1.5	Martinez, L; Nevshupa, R; Felhos, D; de Segovia, J L; Roman, E, Tribology Int., 2011 in press.
Diffusion coefficient of nitrogen	cm^2 s^{-1} $x10^7$	5.5	Rutherford, S W; Limmer, D T; Smith, M G; Honnell, K G, Polymer, 48, 6719-27, 2007.
Diffusion coefficient of oxygen	cm^2 s^{-1} $x10^7$	6.5	Rutherford, S W; Limmer, D T; Smith, M G; Honnell, K G, Polymer, 48, 6719-27, 2007.
Contact angle of water, 20°C	degree	91-110	Martinez, L; Nevshupa, R; Felhos, D; de Segovia, J L; Roman, E, Tribology Int., 2011 in press.
Surface free energy	mJ m^{-2}	32.5	
MECHANICAL & RHEOLOGICAL PROPERTIES			
Tensile strength	MPa	8.8-33.12	Wang, F; Zhang, Y; Zhang, B B; Hong, R Y; Kumar, M R; Xie, C R, Composites: Part B, 2015, in press.
Tensile stress at yield	MPa	5-12.5	
Tensile creep modulus, 1000 h, elongation 0.5 max	MPa	13.7-16.9	
Elongation	%	250-760	
Flexural strength	MPa	18-23	
Flexural modulus	MPa	580-770	
Tear strength	kN m^{-1}	114-142	
Izod impact strength, notched, 23°C	J m^{-1}	540-680 to NB; 16,270-17,330	Wang, F; Zhang, Y; Zhang, B B; Hong, R Y; Kumar, M R; Xie, C R, Composites: Part B, 2015, in press.
Izod impact strength, notched, -30°C	J m^{-1}	91-96	

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PARAMETER	UNIT	VALUE	REFERENCES
Compression set, 24h 70°C	%	50	
Shore A hardness	-	50-90	
Shrinkage	%	1.2-1.4	
Mooney viscosity	-	18-100	
Melt viscosity, shear rate=0 s^{-1}	MPa s	0.123-25	
Melt index, 190°C/2.16 kg	g/10 min	0.5-4.1	
CHEMICAL RESISTANCE			
Acid dilute/concentrated	-	fair-poor	
Alcohols	-	very good	
Alkalis	-	good	
Aliphatic hydrocarbons	-	poor	
Aromatic hydrocarbons	-	poor	
Esters	-	good	
Greases & oils	-	poor	
Halogenated hydrocarbons	-	poor	
Ketones	-	good	
FLAMMABILITY			
Limiting oxygen index	% O_2	16.9	Hirsch, D B; Beeson, H D, Improved methods to determine flammability of aerospace materials, Halon Options Technical Working Conference, 2001.
UL 94 rating	-	V-2; V-0 (flame retarded)	
WEATHER STABILITY			
Excitation wavelengths	nm	274	
Emission wavelengths	nm	365	
Products of degradation	-	hydroperoxides, unsaturations and products of their degradation, crosslinks, chain scission, caboxylic acids, alcohols, aldehydes, and radicals	
Stabilizers	-	UVA: 2-hydroxy-4-octyloxybenzophenone; 2-(2H-benzotriazol-2-yl)-p-cresol; Screener: carbon black, titanium dioxide; HAS: 1,3,5-triazine-2,4,6-triamine, N,N'''[1,2-ethanediyl-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 Phenolic antioxidant: 2,6,-di-tert-butyl-4-(4,6-bis(octylthio)-1,3,5,-triazine-2-ylamino) phenol; pentaerythritol tetrakis(3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate); 2-(1,1-dimethylethyl)-6-[[3-(1,1-dimethylethyl)-2-hydroxy-5-methylphenyl] methyl-4-methylphenyl acrylate; 1,3,5-tris(3,5-di-tert-butyl-4-hydroxybenzyl)-1,3,5-triazine-2,4,6(1H,3H,5H)-trione; 2,2'-ethylidenebis (4,6-di-tert-butylphenol); Other: hydrotalcite; 2,2'-thiodiethylene bis[3-(3,5-ditert-butyl-4-hydroxyphenyl)propionate]; 4,4'-thiobis(2-t-butyl-5-methyl-phenol); 2,2'-thiobis(6-tert-butyl-4-methylphenol); octylated diphenylamine, nickel dibutyldithiocarbamate	
BIODEGRADATION			
Colonized products		membranes	
Stabilizers	-	carbolic acid	

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TOXICITY			
NFPA: Health, Flammability, Reactivity rating	-	0-1/0-1/0; 1/1/0 (HMIS)	
Carcinogenic effect	-	not listed by ACGIH, NIOSH, NTP	
PROCESSING			
Typical processing methods	-	calendering, coating, extrusion, molding	
Processing temperature	°C	175-225; 160 (vulcanization)	
Additives used in final products	-	Fillers: aluminum hydroxide, antimony trioxide, calcinated clay, calcium borate, calcium carbonate, graphene, huntite, hydromagnesite, magnesium carbonate, magnesium hydroxide, MWCNF, nanoclay, silica, talc, titanium dioxide, zinc oxide; Plasticizers: polyisobutylene, paraffin oil, dibutyl phthalate, dioctyl phthalated, vulcanized vegetable oil; Anti-static: polyaniline; Antiblocking: silica; Release: magnesium stearate, PTFE, siloxane; Slip: erucamide, fatty acid amide, graphite; Antioxidant: tetrakis[methylene 3-(30,50-di-tert-butyl-40-hydroxyphenyl)-propionate]methane	Khan, M A; Kumar, S S; Raghu, T S; Kotresh, T M; Sailaja, R R N, Mater. Today. Commun., 4, 50-62, 2015; Wang, F; Zhang, Y; Zhang, B B; Hong, R Y; Kumar, M R; Xie, C R, Composites: Part B, 2015, in press.
Applications	-	automotive, cable jacketing, hoses, innertubes for automobile and bicycle tires, pond liners, profiles, roofing	
Outstanding properties	-	flexibility, ozone resistance, service life	
BLENDS			
Suitable polymers	-	ABS, NBR, LDPE, PA6, PA66, PA12, PBT, PE, PP, PPy, PS, SAN	
Compatibilizers	-	EPDM-g-MAH	Moustafa, H; Darwish, Int. J. Adh. Adh., 61, 15-22, 2015.
ANALYSIS			
FTIR (wavenumber-assignment)	cm^{-1}/-	carbonyl – 1713; CH_2 – 1642	Snijders, E A; Boersma, A; van Baarle, B; Noordermeer, Polym. Deg. Stab., 89, 200-7, 2005.
Raman (wavenumber-assignment)	cm^{-1}/-	C=C – 1603; C-H – 1365	Zhao, Q; Li, X; Gao, J, Polym. Deg. Stab., 94, 339-43, 2009.