EP epoxy resin

PARAMETER	UNIT	VALUE	REFERENCES
GENERAL			
Common name	-	epoxy resin	
CAS name	-	epoxy resin	
Acronym	-	EP	
CAS number	-	25036-25-3; 25068-38-6; 55818-57-0; 61788-97-4; 90598-46-2	
HISTORY			
Person to discover	-	Castan, P, licensed to Ciba	
Date	-	1936	
Details	-	bisphenol A based epoxy	
SYNTHESIS			
Monomer(s) structure	-	most frequently used epoxy monomer is a product of $C_{15}H_{16}O_2$ (bisphenol A); C_3H_5ClO (epichlorohydrin); oxirane groups can be generated from peroxidation of C=C bonds, most frequently oil or cycloaliphatic compounds are used	Pascault, J-P; Williams, R J J, Epoxy Polymers, Pascault, J-P; Williams, R J J, Eds., Wiley, 2010.
Monomer(s) CAS number(s)	-	80-05-7; 106-89-8	
Monomer(s) molecular weight(s)	dalton, g/mol, amu	228.29; 92.52	
Hardener(s)		polyamines (e.g., triethylenetetramine, $C_6H_{18}N_4$)	
CAS number(s)		112-24-3	
Molecular weight(s)	dalton, g/mol, amu	146.23	
Epoxide percentage	%	7.7-8.3	
Method of synthesis	-	final resin is obtained from combination of epoxy monomer and hardener; properties depend on monomers and their proportions; epoxy polymers are produced by step or chain polymerizations or their combinations, leading to linear or crosslinked polymers	Pascault, J-P; Williams, R J J, Epoxy Polymers, Pascault, J-P; Williams, R J J, Eds., Wiley, 2010; Jin, F-L; Li, X; Park, S-J, J. Ind. Eng. Chem., 29, 1-11, 2015.
Temperature of polymerization	°C	120-160 (baking); 5-150 (adhesives)	
Time of polymerization	min	15-25 (baking); 5 min to over 24 h (adhesives)	
Activation energy of polymerization	$kJ\ mol^{-1}$	46(foaming)	Mondy, L A; Rao, R R; Moffar, H; Adolf, D; Celina, M, Epoxy Polymers, Pascault, J-P; Williams, R J J, Eds., Wiley, 2010.
Activation energy of gelation	$kJ\ mol^{-1}$	54-92	Osbaldiston, J R; Smith, W; Farquharson, S; Shaw, M T, Antec, 939-44, 1998.
Heat of polymerization	$J\ g^{-1}$	250 (foaming)	Mondy, L A; Rao, R R; Moffar, H; Adolf, D; Celina, M, Epoxy Polymers, Pascault, J-P; Williams, R J J, Eds., Wiley, 2010.
STRUCTURE			
Crosssection surface area of chain	nm^2	0.39-0.44	Swarup, S; Nigam, A N, J. Appl. Polym. Sci., 39, 1727-31, 1990.
Number of carbon atoms per entanglement		500-533	Swarup, S; Nigam, A N, J. Appl. Polym. Sci., 39, 1727-31, 1990.
COMMERCIAL POLYMERS			
Some manufacturers	-	DOW	
Trade names	-	D.E.R. (solid and liquid epoxy resins); D.E.H (curing agents);	

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PHYSICAL PROPERTIES			
Density at 20°C	g cm^{-3}	1.15-1.3	
Refractive index, 20°C	-	1.51-1.58	
Melting temperature, DSC	°C	90-245	
Softening point	°C	80-90	
Thermal expansion coefficient, 23-80°C	$°C^{-1}$ x 10^{-6}	17-67	Meijerink, J I; Eguchi, S; Ogata, M; Ishii, T; Amagi, S; Numata, S; Sashima, H, Polymer, 35, 1, 179-86, 1994.
Thermal conductivity, melt	W m^{-1} K^{-1}	0.15-0.25	
Glass transition temperature	°C	37-127 (thermoplastic); 130-246 (adhesives); 54.5-62 (commercial)	White, J E, Epoxy Polymers, Pascault, J-P; Williams, R J J, Eds., Wiley, 2010; Abuin, S P, Epoxy Polymers, Pascault, J-P; Williams, R J J, Eds., Wiley, 2010; Jin, F-L; Li, X; Park, S-J, J. Ind. Eng. Chem., 29, 1-11, 2015; Michels, J; Widmann, R; Czaderski, C; Allahvirdizadeh, R; Motavalli, M, Composites: Part B, 77, 484-93, 2015.
Maximum service temperature	°C	-260 to 350 (Duralco, adhesive)	Bhowmik, S; Benedictus, R; Poulis, H, Polymers in Defence and Aerospace 2007, Rapra, 2007, paper 8.
Heat deflection temperature at 0.45 MPa	°C	53-194	
Heat deflection temperature at 1.8 MPa	°C	46-187	
Hansen solubility parameters, δ_D, δ_P, δ_H	$MPa^{0.5}$	19.2, 10.9, 9.6; 20.36, 12.03, 11.48; 18.1, 11.4, 9.0	
Interaction radius		11.1; 9.1	
Hildebrand solubility parameter	$MPa^{0.5}$	22.0-27.1	
Surface tension	mN m^{-1}	39.1-51.2	
Dielectric constant at 100 Hz/1 MHz	-	3.5-5.0/3.6	
Volume resistivity	ohm-m	1E14	
Surface resistivity	ohm		
Electric strength K20/P50, d=0.60.8 mm	kV mm^{-1}	15	
Coefficient of friction	-	0.5-0.6	Larsen, T O; Andersen, T L; Thorning, B; Horsewell, A; Vigild, Wear, 265, 203-13, 2008.
Contact angle of water, 20°C	degree	54.0-87.5	
Surface free energy	mJ m^{-2}	45.3	
Speed of sound	m s^{-1} x 10^{-3}	1.01-1.08	
MECHANICAL & RHEOLOGICAL PROPERTIES			
Tensile strength	MPa	27-200 (thermoplastic); 40-65 (adhesives)	White, J E, Epoxy Polymers, Pascault, J-P; Williams, R J J, Eds., Wiley, 2010; Abuin, S P, Epoxy Polymers, Pascault, J-P; Williams, R J J, Eds., Wiley, 2010.
Tensile modulus	MPa	850-4,800	Abuin, S P, Epoxy Polymers, Pascault, J-P; Williams, R J J, Eds., Wiley, 2010.

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Tensile stress at yield	MPa	36.6-117.7 (thermoplastic)	White J E, Epoxy Polymers, Pascault, J-P; Williams, R J J, Eds., Wiley, 2010.
Elongation	%	1.3-705 (thermoplastic); 3-5 (adhesives)	White J E, Epoxy Polymers, Pascault, J-P; Williams, R J J, Eds., Wiley, 2010; Abuin, S P, Epoxy Polymers, Pascault, J-P; Williams, R J J, Eds., Wiley, 2010.
Tensile yield strain	%	4	
Flexural strength	MPa	74-325	
Flexural modulus	MPa	2,550-15,500	
Elastic modulus	MPa	2,700-4,100	Ruggiero, A; Merola, M; Carlone, P; Archoduolaki, V-M, Composites: Part B, 79, 595-603, 2015; Jin, F-L; Li, X; Park, S-J, J. Ind. Eng. Chem., 29, 1-11, 2015.
Compressive strength	MPa	116-404	
Compressive modulus	MPa	3,100-4,500	Hergenrother, P M; Thompson, C M; Smith, J G; Connell, J W; Hinkley, J A; Lyon, R E; Moulton, R, Polymer, 46, 5012-24, 2005.
Young's modulus	MPa	3,600-4,300	
Izod impact strength, notched, 23°C	$J m^{-1}$	25-1246 (thermoplastic)	White J E, Epoxy Polymers, Pascault, J-P; Williams, R J J, Eds., Wiley, 2010.
Shear strength	MPa	12-24	Abuin, S P, Epoxy Polymers, Pascault, J-P; Williams, R J J, Eds., Wiley, 2010.
Fracture toughness	$MPa m^{1/2}$	3.53-4.48	Jin, F-L; Li, X; Park, S-J, J. Ind. Eng. Chem., 29, 1-11, 2015.
Poisson's ratio	-	0.42	
Shore D hardness	-	62-95	
Shrinkage	%	0.001-0.13	
Intrinsic viscosity, 25°C	$dl g^{-1}$	0.4-0.94 (thermoplastic)	
Water absorption, equilibrium in water at 23°C	%	0.04-4.0 (thermoplastic); 2-5 (adhesives)	Abuin, S P, Epoxy Polymers, Pascault, J-P; Williams, R J J, Eds., Wiley, 2010.
CHEMICAL RESISTANCE			
Acid dilute/concentrated	-	fair-excellent	
Alcohols	-	excellent-good	
Alkalis	-	excellent	
Aliphatic hydrocarbons	-	excellent-good	
Aromatic hydrocarbons	-	excellent	
Esters	-	good	
Greases & oils	-	good	
Halogenated hydrocarbons	-	excellent	
Ketones	-	poor	
FLAMMABILITY			
Ignition temperature	°C	>120 to 249; 32 (solvent based)	

PARAMETER	UNIT	VALUE	REFERENCES
Limiting oxygen index	% O_2	18.3-19; 23	Kumar, S A; Denchev, Z, Prog. Org. Coat., 66, 1-7, 2009; Szolnoki, B; Bocz, K; Soti, P L; Bodzay, B; Zimonyi, E; Toldy, A; Morlin, B; Bujnowicz, K; Wladyka-Przybylak, M; Marosi, G, Polym. Deg. Stab., 119, 68-76, 2015.
Heat release	kW m^{-2}	51-97	Hergenrother, P M; Thompson, C M; Smith, J G; Connell, J W; Hinkley, J A; Lyon, R E; Moulton, R, Polymer, 46, 5012-24, 2005.
Char at 500°C	%	3.9-15.9; 25-44 (flame retarded)	Lyon, R E; Walters, R N, J. Anal. Appl. Pyrolysis, 71, 27-46, 2004; Hergenrother, P M; Thompson, C M; Smith, J G; Connell, J W; Hinkley, J A; Lyon, R E; Moulton, R, Polymer, 46, 5012-24, 2005.
WEATHER STABILITY			
Spectral sensitivity	nm	300-330	
Important initiators and accelerators	-	alkaline products of corrosion, aromatic carbonyl groups, quinoic structures, hydroxide ions, double bonds	
Products of degradation	-	benzene, styrene, radicals, benzoic acid, benzaldehyde, benzophenone, water	
Stabilizers	-	UVA: 2,4-dihydroxybenzophenone; 2-(2H-benzotriazol-2-yl)-p-cresol; 2-benzotriazol-2-yl-4,6-di-tert-butylphenol; Screener: nano-ZnO; nano-silica-titania	
BIODEGRADATION			
Colonized products		coatings, marine coatings	
Typical biodegradants	-	fungi	Warscheid, T; Braams, J, Int. Biodet. Biodeg., 46, 343-68, 2000.
Stabilizers	-	silver-containing zeolite, coal tar, ferric benzoate, 4,5-dichloro-2-n-octyl-4-isothiazolin-3-one	
TOXICITY			
HMIS: Health, Flammability, Reactivity rating	-	2/1/0	
Carcinogenic effect	-	not listed by ACGIH, NIOSH, NTP	
Oral rat, LD_{50}	mg kg^{-1}	>2,000 to 5,800	
Skin rabbit, LD_{50}	mg kg^{-1}	>2,150	
ENVIRONMENTAL IMPACT			
Aquatic toxicity, *Daphnia magna*, LC_{50}, 48 h	mg l^{-1}	1.4-19.6; 2,000-114,000 (EC50)	Lithner, Ph D Thesis, Univrsity of Gothenburg, 2011.
Aquatic toxicity, *Rainbow trout*, LC_{50}, 48 h	mg l^{-1}	1.5-2.4	
PROCESSING			
Typical processing methods	-	casting, coatings, compounding, dipping, infusion molding, *in situ* polymerization, lamination, pultrusion, sheet molding; spraying, transfer molding	Constantino, S; Waldvogel, U, Epoxy Polymers, Pascault, J-P; Williams, R J J, Eds., Wiley, 2010.

PARAMETER	UNIT	VALUE	REFERENCES
Additives used in final products	-	Plasticizers/flexibilizers: epoxidized oils, low molecular polyamides, polysulfidesdibutyl phthalate, condensation products of adipic acid and glycols, isodecyl pelargonate, cyclohexyl pyrrolidone; Other: diluents (glycide ether), modifiers, rheological additives, flame retardants; Antistatics: alkyl dipolyoxyethylene ethyl ammonium ethyl sulfate, carbon black, carbon monofiber, graphite, quaternary ammonium compound, silver-coated basalt, tin oxide; Release: calcium carbonate, carnauba wax, ceramic microspheres, ethylene bis stearoformamide, montan wax, silicone oil; Slip: carbon fiber, PTFE, sorbitan tristearate	
Applications	-	adhesives, encapsulating compounds, biosensors, bonding and adhesives, coatings, composites (building/construction,encapsulation, marine, electrical/electronics, aircraft, communication satellites, automotive, pipes, consumer products), electrical/electronics (printed circuit panels, conductive adhesives), flooring, fuel cells, semiconductor packaging, surface protective coatings (protective and decorative - automotive, metal cans, industrial flooring, anticorrosive paints), tooling and casting, wear resistant tools	
BLENDS			
Suitable polymers	-	PA, PBT, PC, PCL, PEO, PMMA, PP, PSU, PVP	Jin, H; Yang, B; Jin, F-L; Park, S-J, J. Ind. Eng. Chem., 25, 9-11, 2015.