

Handbook OF POLYMERS



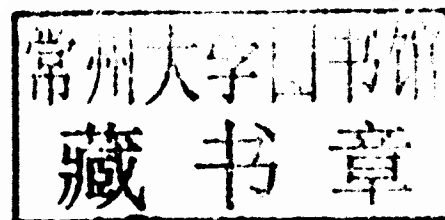
George Wypych



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Handbok of Polymers

George Wypych



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Introduction

Polymers selected for this edition of the Handbook of Polymers include all major polymeric materials used by the plastics and other branches of the chemical industry as well as specialty polymers used in the electronics, pharmaceutical, medical, and space fields. Extensive information is provided on biopolymers.

The data included in the Handbook of Polymers come from open literature (published articles, conference papers, and books), literature available from manufacturers of various grades of polymers, plastics, and finished products, and patent literature. The above sources were searched, including the most recent literature. It can be seen from the references that a large portion of the data comes from information published in 2011. This underscores one of the major goals of this undertaking, which is to provide readers with the most up-to-date information.

Frequently, data from different sources vary in a broad range and they have to be reconciled. In such cases, values closest to their average and values based on testing of the most current grades of materials are selected to provide readers with information which is characteristic of currently available products, focusing on the potential use of data in solving practical problems. In this process of verification many older data were rejected unless they have been confirmed by recently conducted studies.

Presentation of data for all polymers is based on a consistent pattern of data arrangement, although, depending on data availability, only data fields which contain actual values are included for each individual polymer. The entire scope of the data is divided into sections to make data comparison and search easy.

The following sections of data are included:

- General
- History
- Synthesis
- Structure
- Commercial polymers
- Physical properties
- Mechanical properties
- Chemical resistance
- Flammability
- Thermal stability
- Weather stability
- Biodegradation
- Toxicity
- Environmental impact
- Processing
- Blends
- Analysis

It can be anticipated from the above breakdown of information that the Handbook of Polymers contains information on all essential data used in practical applications, research, and legislation, providing such data are available for a particular material. In total, over 230 different types of data were searched for each individual polymer. The last number does not include special fields that might be added to characterize the performance of specialty polymers in their applications.

In most cases, the information provided is self-explanatory, considering that each data field is composed of parameter (or measured property), unit, value, and reference. In some cases, different values or a range of values are given. This is to indicate the fact that there is a disagreement in the published data which cannot be reconciled, or that the data falls into a broader range because various grades differ in properties. Utmost care is taken that the specified range contains all grades known from published data. If there are specific grades differing in properties, a set of separate ranges is given in some cases.

After some data, information is given in parenthesis to indicate additional characteristics of tested samples. The usual convention is that the first value given is for pure or typical material, followed by its different modifications (e.g., reinforcements with different fibers or different levels of crystallinity, structure, or different conditions of sample as to its temperature, state, etc.).

The range of molecular weights and related data (e.g., polymerization degree) requires additional explanation. In some cases, the number average molecular weight data do not correspond to mass average molecular data (as could be expected from a given range of polydispersities). This is because these data are given based on values found in literature without any attempts to reconcile them by means of calculation, which seems to be the correct approach because the data strictly reflect values found in the literature, not the results of any approximations which will artificially compare sets of data for materials coming from different experimental or production conditions. This is in agreement with one essential goal of this collection – authenticity of the data selected.

We hope that the results of our thorough search will be useful and that the data will be skillfully applied by users of this book for the benefit of their research and applications.

ABS poly(acrylonitrile-co-butadiene-co-styrene)

PARAMETER	UNIT	VALUE	REFERENCES
GENERAL			
Common name	-	poly(acrylonitrile-co-butadiene-co-styrene)	
IUPAC name	-	buta-1,3-diene; prop-2-enenitrile; styrene	
CAS name	-	2-propenenitrile, polymer with 1,3-butadiene and ethenylbenzene	
Acronym	-	ABS	
CAS number	-	9003-56-9	
RETECS number	-	AT6970000	
Linear formula	-	$[\text{CH}_2\text{CH}(\text{CN})]_x(\text{CH}_2\text{CH}=\text{CHCH}_2)_y[\text{CH}_2\text{CH}(\text{C}_6\text{H}_5)]_z$	
HISTORY			
Details	-	ABS was patented in 1948 and introduced to commercial markets by the Borg-Warner Corporation in 1954	
SYNTHESIS			
Monomer(s) structure	-	$\text{H}_2\text{C}=\text{CHC}\equiv\text{N}$ $\text{H}_2\text{C}=\text{CHCH}=\text{CH}_2$ 	
Monomer(s) CAS number(s)	-	107-13-1 (acrylonitrile); 106-99-0 (butadiene); 100-42-5 (styrene)	
Monomer(s) molecular weight(s)	dalton, g/mol, amu	53.06; 54.09; 104.15	
Monomer(s) expected purity(ies)	%	variable	
Monomer ratio	-	acrylonitrile: 15-50%; butadiene: 5-30%; styrene: 40-60%	
SAN/BP	-	90-40/10-60	
Formulation example	-	H ₂ O (solvent) 17,070, emulsifier 3558, polybutadiene latex 6384, tertdodecyl mercaptan 70, FeSO ₄ 1610, styrene 8565, acrylonitrile 4236, cumene hydroperoxide 53	Hu, K-H; Kao, C-S; Duh, Y-S, J. Hazardous Mater., 159, 25-34, 2008.
Method of synthesis	-	the most frequently used are emulsion, mass, and suspension polymerizations; styrene and acrylonitrile are being grafted onto rubber by chemical grafting, chemical grafting blending, or physical mixing; chemical grafting blending is the most frequently used method and specifically emulsion grafting-bulk SAN blending is a method of choice	Huang, P; Tan, D; Luo, Y, J. Env. Sci., Technol., 3, 3, 148-58, 2010.
Temperature of polymerization	°C	62-75	
Heat of polymerization	J g ⁻¹	styrene: 647; acrylonitrile: 2290; ABS: 890	
Number average molecular weight, M_n	dalton, g/mol, amu	30,000-200,000	
Mass average molecular weight, M_w	dalton, g/mol, amu	81,000-308,000	
Polydispersity, M_w/M_n	-	2.72-2.88	
Domain size of rubber	nm	<1,000 (emulsion polymerization); 500-5,000 (mass polymerization)	Lucarini, M; Pedullii, G F; Motyakin, M V; Schlick, S, Prog. Polym. Sci., 28, 331-340, 2003.
Cis content	%	32.3-97.0 (polybutadiene); 1.5-51.6 (<i>trans</i> in polybutadiene)	Yu, Z; Li, Y; Zhao, Z; Wang, C; Yang, J; Zhang, C; Li, Z; Wang, Y, Polym. Eng. Sci., 49, 2249-56, 2009.

ABS poly(acrylonitrile-co-butadiene-co-styrene)

PARAMETER	UNIT	VALUE	REFERENCES
COMMERCIAL POLYMERS			
Some manufacturers	-	BASF; Daicel; Denka; Formosa; Sabic	
Trade names	-	Lustran, Terluran; Cevian; Novodur; Tairilac; Cicolac	
PHYSICAL PROPERTIES			
Density at 20°C	g cm ⁻³	1.03-1.09; 0.93 (melt)	Terluran, BASF; Cevian, Daicel
Bulk density at 20°C	g cm ⁻³	0.6	
Color	-		
Refractive index, 20°C	-	1.540	
Transmittance	%	80-90	Cevian, Daicel
Haze	%	0.4-5	
Gloss, 60°, Gardner (ASTM D523)	%	85-95 (glossy); 1.8-6.6 (matt)	Arino, I; Kleist, U; Rigdahl, M, Polym. Eng. Sci., 45, 733-44, 2005.
Melting temperature, DSC	°C	220-260	Terluran, BASF; Karahaliou, E K; Tarantili, P A, Polym. Eng. Sci., 49, 2269-75, 2009.
Softening point	°C	>90	Terluran, BASF
Onset temperature of thermal degradation	°C	385-407	Li, Y; Zheng, Y; Liu, J; Shang, H, J. Appl. Polym. Sci., 115, 957-62, 2010.
Thermal expansion coefficient, 23-80°C	°C ⁻¹	0.6-1.1E-4	Terluran, BASF; Cevian, Daicel
Thermal conductivity, melt	W m ⁻¹ K ⁻¹	0.16	Terluran, BASF
Glass transition temperature	°C	102-107 (acrylonitrile-styrene mesophase) and -58 (butadiene component); 103 (DSC) and 121 (DMA)	Terluran, BASF; Xue, M-L; Yu, Y-L; Rhee, J M; Kim, N H; Lee, J H, Eur. Polym. J., 43, 9, 3826-37, 2007; Santos, R M; Botelho, G L; Machado, A V, J. Appl. Polym. Sci., 2005-14, 2010; Karahaliou, E K; Tarantili, P A, Polym. Eng. Sci., 49, 2269-75, 2009.
Specific heat capacity	J K ⁻¹ kg ⁻¹	1,780-2,030 (88°C); 2,300-2,400 (melt)	Terluran, BASF
Calorific value	kJ kg ⁻¹		
Maximum service temperature	°C	80	Terluran, BASF
Heat deflection temperature at 0.45 MPa	°C	89-113	Terluran, BASF
Heat deflection temperature at 1.8 MPa	°C	67-109	Terluran, BASF; Cevian, Daicel
Vicat temperature VST/A/50	°C	90-112	Terluran, BASF
Vicat temperature VST/B/50	°C	95-100	Terluran, BASF
Start of thermal degradation	°C		
Melting enthalpy peak	J g ⁻¹	9.6	Karahaliou, E K; Tarantili, P A, Polym. Eng. Sci., 49, 2269-75, 2009.
Hansen solubility parameters, δ_D , δ_P , δ_H	MPa ^{0.5}	17.0, 5.7, 6.8	
Interaction radius		9.4	
Hildebrand solubility parameter	MPa ^{0.5}	19.2	
Dielectric constant at 100 Hz/1 MHz	-	1.5-4.1	
Relative permittivity at 100 Hz	-	2.9	Terluran, BASF
Relative permittivity at 1 MHz	-	2.8	Terluran, BASF

ABS poly(acrylonitrile-co-butadiene-co-styrene)

PARAMETER	UNIT	VALUE	REFERENCES
Dissipation factor at 100 Hz	E-4	48-160	Terluran, BASF
Dissipation factor at 1 MHz	E-4	79-140	Terluran, BASF
Volume resistivity	ohm-m	1E+13; 1E+1 (with 0.18 vol fraction of Ni coated mica)	Terluran, BASF; Kandasubramanian, B; Gilbert, M, Macromol. Symp., 211, 185-95, 2005.
Surface resistivity	ohm	1E+13 to 1E+15	Terluran, BASF
Electric strength K20/P50, d=0.60.8 mm	kV mm ⁻¹	37-41	Terluran, BASF
Comparative tracking index, CTI, test liquid A	(-)	600	Terluran, BASF
Comparative tracking index, CTIM, test liquid B	(-)	225	Terluran, BASF
Arc resistance	MV/m	91-102	
Power factor	-		
Shielding effectiveness	dB	16-16.5	Kandasubramanian, B; Gilbert, M, Macromol. Symp., 211, 185-95, 2005.
Coefficient of friction	ASTM D1894	0.21-0.28 (chrome steel); 0.40 (aluminum)	Maldonado, J E, Antec, 3431-35, 1998.
Contact angle of water, 20°C	degree	80.9; 89.7	Accu Dyne Test, Diversified Enterprizes; K. Fukuzawa, in Adhesion Science and Technology, H. Mizumachi, ed., International Adhesion Symposium, Yokohama, Japan, 1994.
Surface free energy	mJ m ⁻²	35-42	D.A. Markgraf, in Film Extrusion Manual, 2nd Ed., T.I. Butler, ed., TAPPI Press, Norcross, GA, 2005, p. 299.
Speed of sound	m s ⁻¹	36.2-37.5	Alan R. Selfridge, IEEE Trans. Sonics Ultrasonics, SU-32, 3, 381-394, 1985.
Acoustic impedance		2.31-2.36	Alan R. Selfridge, IEEE Trans. Sonics Ultrasonics, SU-32, 3, 381-394, 1985.
Attenuation	dB cm ⁻¹ , 5 MHz	10.9-11.3	Alan R. Selfridge, IEEE Trans. Sonics Ultrasonics, SU-32, 3, 381-394, 1985.
MECHANICAL & RHEOLOGICAL PROPERTIES			
Tensile strength	MPa	25-65	Li, J; Cai, C L, Current Appl. Phys., 11, 50, 2011; Lee, J-W; Lee, J-C; Pandey, J; Ahn, S-H; Kang, Y J, J. Compos. Mater., 44, 1701-16, 2010.
Tensile modulus	MPa	1900-2700	Terluran, BASF
Tensile stress at yield	MPa	35-58	Terluran, BASF
Tensile creep modulus, 1000 h, elongation 0.5 max	MPa	1250	Terluran, BASF
Elongation	%	8-20	Terluran, BASF; Karahaliou, E K; Tarantili, P A, Polym. Eng. Sci., 49, 2269-75, 2009.
Tensile yield strain	%	2.4-4	Terluran, BASF
Flexural strength	MPa	55-125	Jin, F-L; Lu, S-L, Song, Z-B; Pang, J-X; Zhang, L; Sun, J-D; Cai, X-P, Mater. Sci. Eng., A527, 3438-41, 2010; Terluran, BASF; Cevian, Daicel
Flexural modulus	MPa	2150-2300	Vitands, E, Antec, 2986-2991, 1996.

ABS poly(acrylonitrile-co-butadiene-co-styrene)

PARAMETER	UNIT	VALUE	REFERENCES
Elastic modulus	MPa	1208-1939	Lee, J-W; Lee, J-C; Pandey, J; Ahn, S-H; Kang, Y J, J. Compos. Mater., 44, 1701-16, 2010; Karahaliou, E K; Tarantili, P A, Polym. Eng. Sci., 49, 2269-75, 2009.
Compressive strength	MPa	65-86; 120 (30% glass fiber)	
Young's modulus	MPa	2,300	
Tear strength	N m ⁻¹		
Charpy impact strength, unnotched, 23°C	kJ m ⁻²	120-190 to NB	Terluran, BASF; Cevian, Daicel
Charpy impact strength, unnotched, -30°C	kJ m ⁻²	80-140	Terluran, BASF; Cevian, Daicel
Charpy impact strength, notched, 23°C	kJ m ⁻²	5-40	Terluran, BASF; Cevian, Daicel
Charpy impact strength, notched, -30°C	kJ m ⁻²	2-25	Terluran, BASF; Cevian, Daicel
Izod impact strength, notched, 23°C	J m ⁻¹	30-450	Jin, F-L; Lu, S-L, Song, Z-B; Pang, J-X; Zhang, L; Sun, J-D; Cai, X-P, Mater. Sci. Eng., A527, 3438-41, 2010; Terluran, BASF; Cevian, Daicel
Izod impact strength, notched, -40°C	J m ⁻¹	8-280	Terluran, BASF; Cevian, Daicel
Shear modulus	MPa	700-1,50	
Rockwell hardness	-	101; 102-124	(-); Jin, F-L; Lu, S-L, Song, Z-B; Pang, J-X; Zhang, L; Sun, J-D; Cai, X-P, Mater. Sci. Eng., A527, 3438-41, 2010.
Ball indentation hardness at 358 N/30 S (ISO 2039-1)	MPa	97	
Shrinkage	%	0.4-0.7; 0.72 (across the flow), 1.11 (along the flow)	Terluran, BASF; Chang, T; Faison, E, Polym. Eng. Sci., 41, 5, 703-10, 2001.
Melt viscosity, shear rate=1000 s ⁻¹	Pa s	140-250	Xue, M-L; Yu, Y-L; Rhee, J M; Kim, N H; Lee, J H, Eur. Polym. J., 43, 9, 3826-37, 2007.
Melt volume flow rate (ISO 1133, procedure B), 220°C/10 kg	cm ³ /10 min	2-34	Terluran, BASF
Pressure coefficient of melt viscosity, b	G Pa ⁻¹	33.7	Aho, J; Syrjala, S, J. Appl. Polym. Sci., 117, 1076-84, 2010.
Melt index, 230°C/3.8 kg	g/10 min	1.5; 2.5-7.0; 18-34	Karahaliou, E K; Tarantili, P A, Polym. Eng. Sci., 49, 2269-75, 2009; (-); Jin, F-L; Lu, S-L, Song, Z-B; Pang, J-X; Zhang, L; Sun, J-D; Cai, X-P, Mater. Sci. Eng., A527, 3438-41, 2010,
Water absorption, equilibrium in water at 23°C	%	0.7-1.03	Terluran, BASF
Moisture absorption, equilibrium 23°C/50% RH	%	0.21-0.35	Terluran, BASF
CHEMICAL RESISTANCE			
Acid dilute/concentrated	-	no resistance to concentrated; good resistance to dilute	Terluran, BASF
Alcohols	-	limited resistance; insoluble	Terluran, BASF
Alkalis	-	good resistance to dilute	Terluran, BASF
Aliphatic hydrocarbons	-	limited resistance; insoluble	Terluran, BASF

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PARAMETER	UNIT	VALUE	REFERENCES
Aromatic hydrocarbons	-	no resistance	Terluran, BASF
Esters	-	no resistance	Terluran, BASF
Greases & oils	-	limited resistance; insoluble: mineral oil	Terluran, BASF
Halogenated hydrocarbons	-	no resistance; soluble: dichloromethane	Terluran, BASF
Ketones	-	no resistance; soluble: acetone, methyl-ethyl ketone	Terluran, BASF
Other	-	resistant: water, salt solutions; soluble: dimethylformamide, tetrahydrofuran, toluene	Terluran, BASF
Good solvent	-	acetophenone, aniline, benzene, chlorobenzene, chloroform, dimethylformamide, dioxane, ethyl benzene	
Non-solvent	-	cyclohexane, diethanolamine, diethylene glycol, dipropylene glycol, petroleum ether	
Chemicals causing environmental stress cracking	-	nonionic surfactants	Kawaguchi, T; Nishimura, H; Kasahara, K; Kuriyama, T; Narisawa, I, Polym. Eng. Sci., 43, 2, 419-30, 2003.
Effect of EtOH sterilization (tensile strength retention)	%	105-110 (high gloss); 82-95 (low gloss)	Navarrete, L; Hermanson, N, Antec, 2807-18, 1996.
FLAMMABILITY			
Ignition temperature	°C	405	
Autoignition temperature	°C	>400	Terluran, BASF, MSDS
Limiting oxygen index	% O ₂	18.1; 23-35 (with flame retardants)	Yan, I; Zheng, Y; Liu, J; Shang, H, J. Appl. Polym. Sci., 115, 957-62, 2010; Hourston, D J, Shreir's Corrosion, Elsevier, 2010, Chapter 3.31, 2369-2386; Li, Y; Zheng, Y; Liu, J; Shang, H, J. Appl. Polym. Sci., 115, 957-62, 2010.
Heat release	kW m ⁻²	1037; 602-796 (with organoclays); 243-268 (with flame retardant)	Du, X; Yu, H; Wang, Z; Tang, T, Polym. Deg. Stab., 95, 587-92, 2010; Yu, B; Liu, M; Lu, L; Dong, X; Gao, W; Tang, K, Fire Mater., 34, 251-61, 2010.
NBS smoke chamber	Ds	800	Padey, D; Walling, J; Wood A, Polymers in Defence and Aerospace 2007, Rapra, 2007, paper 15.
Char, 554°C	%	0-0.6; 9.4; 0.43-2.89	Yang, S; Castilleja, J R; Barrera, E V; Lozano, K, Polym. Deg. Stab., 83, 3, 383-88, 2004; Du, X; Yu, H; Wang, Z; Tang, T, Polym. Deg. Stab., 95, 587-92, 2010; Karahaliou, E K; Tarantili, P A, Polym. Eng. Sci., 49, 2269-75, 2009; Lyon, R E; Walters, R N, J. Anal. Appl. Pyrolysis, 71, 27-46, 2004.
Heat of combustion	J g ⁻¹	39,840	Walters, R N; Hacket, S M; Lyon, R E, Fire Mater., 24, 5, 245-52, 2000.
CO yield	%	13	
UL rating	-	HB	
THERMAL STABILITY			
Activation energy under nitrogen	kJ mol ⁻¹	134.5-242.4	Yang, S; Castilleja, J R; Barrera, E V; Lozano, K, Polym. Deg. Stab., 83, 3, 383-88, 2004; Polli, H; Pontes, L A M; Araujo, A S; Barros, J M F; Fernandes, V J, J. Therm. Anal. Calorimetry, 95, 1, 131-34, 2009.
Activation energy under air	kJ mol ⁻¹	156.3	Yang, S; Castilleja, J R; Barrera, E V; Lozano, K, Polym. Deg. Stab., 83, 3, 383-88, 2004.

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PARAMETER	UNIT	VALUE	REFERENCES
Temperature of maximum degradation (air)	°C	428-445 (1st step); 554 (2nd step)	Yang, S; Castilleja, J R; Barrera, E V; Lozano, K, Polym. Deg. Stab., 83, 3, 383-88, 2004; Karahaliou, E K; Tarantili, P A, Polym. Eng. Sci., 49, 2269-75, 2009.
Weight loss	%	85.6 (1st step); 13.8 (2nd step)	Yang, S; Castilleja, J R; Barrera, E V; Lozano, K, Polym. Deg. Stab., 83, 3, 383-88, 2004.
Onset temperature of oxidation	°C	80 (isothermal test); 120 (dynamic scanning)	Duh, Y-S; Ho, T-C; Chen, J-R; Kao, C-S, Polymer, 51, 2, 171-84, 2010.
Heat of oxidation	J g ⁻¹	2,800; 4,720 (polybutadiene)	
WEATHER STABILITY			
Activation wavelengths	nm	320, 385	
Depth of UV penetration	µm	110-150	Jouan, X; Gardette, J L, J. Polym. Sci., Polym. Chem., 29, 685, 1991; Bokria, J G; Schlick, S, Polymer, 43, 3239-46, 2002.
Products of degradation	-	hydroperoxides, carboxylic acids, anhydrides, gamma lactones, chain scission	Santos, R M; Botelho, G L; Machado, A V, J. Appl. Polym. Sci., 2005-14, 2010.
Stabilizers	-	UVA: 2-hydroxy-4-octyloxybenzophenone; 2-hydroxy-4-methoxybenzophenone; 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; 2,4-di-tert-butyl-6-(5-chloro-2H-benzotriazole-2-yl)-phenol; 2-[4,6-bis(2,4-dimethylphenyl)-1,3,5-triazin-2-yl]-5-(octyloxy)phenol; ethyl-2-cyano-3,3-diphenylacrylate; HAS: 1,3,5-triazine-2,4,6-triamine, N,N''[1,2-ethane-diyl-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; 2,2,6,6-tetramethyl-4-piperidinyl stearate; N,N'-bisformyl-N,N'-bis-(2,2,6,6-tetramethyl-4-piperidinyl)-hexamethylenediamine; alkenes, C20-24-.alpha.-, polymers with maleic anhydride, reaction products with 2,2,6,6-tetramethyl-4-piperidinamine; 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 antioxidants: ethylene-bis(oxyethylene)-bis(3-(5-tert-butyl-4-hydroxy-m-tolyl)-propionate); 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; isotridecyl-3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate; 2,2'-ethylidenebis(4,6-di-tert-butylphenol); 2,2'-methylenebis(4-ethyl-6-tertbutylphenol); 3,5-bis(1,1-dimethylethyl)-4-hydroxy-benzenepropanoic acid, C13-15 alkyl esters; phenol, 4-methyl-, reaction products with dicyclopentadiene and isobutene; Phosphite: trinonylphenol phosphite; isodecyl diphenyl phosphite	
BIODEGRADATION			
Colonized products	-	bathroom fixtures, health care products, pipes	
Stabilizers	-	Microban, nanosilver	

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PARAMETER	UNIT	VALUE	REFERENCES
TOXICITY			
NFPA: Health, Flammability, Reactivity rating	-	1/1/0	
Carcinogenic effect	-	not listed by ACGIH, NIOSH, NTP	
MAK/TRK	mg m ⁻³	styrene: 86; acrylonitrile: 7; 1,3-butadiene: 11	
Oral rat, LD ₅₀	mg kg ⁻¹	>5,000	
ENVIRONMENTAL IMPACT			
Cradle to grave non-renewable energy use	MJ/kg	92-95	
PROCESSING			
Typical processing methods	-	calendering, casting, electroplating, extrusion, film lamination, injection molding, rotational molding, thermoforming, vacuum forming, vacuum metallization	Sarkar, K; Gomez, C; Zambrano, S; Ramirez, M; de Hoyos, E; Vasquez, H; Lozano, K, Mater. Today, 13, 11, 12-14, 2010.
Preprocess drying: temperature/time/residual moisture	°C/h/%	80-95/2-4/0.01	
Processing temperature	°C	190-275; 220-260 (injection molding)	
Processing pressure	MPa	5 (backpressure); 53 (holding pressure)	Ingnell, S; Kelist, U; Rigdahl, M, Polym. Eng. Sci., 50, 2114-21, 2010.
Additives used in final products	-	Fillers: antimony oxide, carbon black, glass beads, magnesium hydroxide, nickel or copper coated carbon fibers, talc; Plasticizers: hydrocarbon processing oil, phosphate esters (e.g., triphenyl phosphate, resorcinol bis(diphenyl phosphate), or oligomeric phosphate), long chain fatty acid esters, and aromatic sulfonamide; Antistatics: ethanol, 2,2'-iminobis-, N-coco alkyl derivatives, glycerol monostearate, polyaniline, polyesteramide, sodium alkyl sulfonate; Antiblocking: talc; Release: cetyl palmitate, fluorocarbon, methyl behenate, paraffin wax; Slip: bis-stearamide wax	
Applications	-	appliance (refrigerator liners, kitchen appliance housings, vacuum cleaners, power tools), automotive (instrument panels, consoles, door parts, knobs, trim, wheel covers, mirror and headlight housing, front radiator grilles), business machines (computers, discs, phones), furniture, hot tubs, lawn and garden equipment, luggage, lunch and tool boxes, medical applications, military, packaging, pipes and fittings, recreation (snowmobiles, boats, vehicles), toys	
Outstanding properties	-	combination of 3 monomers gives specific advantages: styrene gives rigidity, electrical properties, easy processability and surface gloss, butadiene improves low temperature toughness, and acrylonitrile improves ABS' chemical, weathering and heat resistance and increases tensile strength	Huang, P; Tan, D; Luo, Y, J. Env. Sic., Technol., 3, 3, 148-58, 2010.
BLENDS			
Suitable polymer	-	chitosan, ground rubber, PA6, PANI-EB, PC, PLA, PTT, PVC, SAN	
Compatibilizers	-	SBM	

ABS poly(acrylonitrile-co-butadiene-co-styrene)

PARAMETER	UNIT	VALUE	REFERENCES
ANALYSIS			
FTIR (wavenumber-assignment)	cm ⁻¹ /-	hydroxy – 3460; carbonyl – 1646, 1718, 1722, 1730, 1785; C=N – 2237; C-O – 1450, 950; styrene – 700, 765, 1028, 1449, 1456-1495, 1582-1601; poly-1,2-butadiene – 910-911; poly-trans-1,4-butadiene – 966-967; C=C of 1,2 structures – 1640	Jouan, X; Gardette, J-L, J. Polym. Sci., Polym. Chem., 29, 685, 1991; Motyakin, M V; Schlick, S, Poly. Deg. Stab., 91, 7, 1462-70, 2006; Santos, R M; Botelho, G L; Machado, A V, J. Appl. Polym. Sci., 2005-14, 2010.