# Handbook OF POLYMERS

George Wypych

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# Handbok of Polymers

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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.

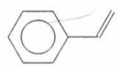
In most cases, the information provided is self-explanatory, considering that each data field is composed of parameter (or measured property), unit, value, and reference. In some cases, different values or a range of values are given. This is to indicate the fact that there is a disagreement in the published 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** | | $[CH_2CH(CN)]_x(CH_2CH{=}CHCH_2)_y[CH_2CH(C_6H_5)]_z$ | |
| **HISTORY** | | | |
| **Details** | - | ABS was patented in 1948 and introduced to commercial markets by the Borg-Warner Corporation in 1954 | |
| **SYNTHESIS** | | | |
| **Monomer(s) structure** | - | $H_2C{=}CHC{\equiv}N$ $H_2C{=}CHCH{=}CH_2$  | |
| **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** | - | $H_2O$ (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; Pedulli, 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 (*trans* 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; Cycolac | |
| **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, $\delta_D$, $\delta_P$, $\delta_H$** | $MPa^{0.5}$ | 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 indention 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. |

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

| 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, andydrides, 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)-hexamethylendiamine; 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-dimethyethyl)-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 | |

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

| 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 sufonate; 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. |