SECTION V

PHYSICAL CONSTANTS OF SOME IMPORTANT POLYMERS

Physical Constants of Rubbery Polymers

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A. INTRODUCTION

Where a range is given, there are available several observations which differ. In most cases the differences are thought to be real, arising from differences in the rubber rather than from errors of observation. Where a single value is given, it is either because no other observations are available or because there seems to be no significant disagreement among values within the errors of observation. Where values are not given, data have not been found. Where dashes are shown, either the physical measurement is impossible or the constant in question is not adequately defined under the given conditions. The values shown refer to specific vulcanizates cited in the corresponding references. Other vulcanizates may yield a broader range of values.

The values are expressed in the International System of Units (SI), the modern metric system, described in National Bureau of Standards Special Publication 330, 1981 edition, and in American Society for Testing and Materials Metric Practice Guide E380–85.

Values are given for constants at a temperature of 25°C (273.15 K) and a pressure of 1 normal atmosphere = 101.325 kPa.

B. TABLES

TABLE 1. 1,4-*cis*(96–98%)POLY(BUTADIENE)

Property	Units	Unvulcanized	Refs.	Pure-gum vulcanizate	Refs.
Density	kg/m^3			1.01	1
Coefficient of expansion	K^{-1} ($\times 10^6$)	669	2		
Glass transition temperature	°C			−110 to −95	3
Specific heat	J/kg/K ($\times 10^3$)	1.96	4	1.960–1.970	1
Thermal conductivity	W/m/K ($\times 10^{-3}$)			200	5
Thermal diffusivity	m^2/s ($\times 10^{-9}$)				
Solubility parameter	$MPa^{1/2}$	17.0	6		
Polymer–solvent interaction parameter (25–30°C)					
	Solvent				
	n-Heptane	0.51	7		
	n-Hexane	0.53	7		
	Cyclohexane	0.45	8		
	Benzene	0.44	7		
	Toluene	0.36	7		

TABLE 1. *cont'd*

Property	Units	Unvulcanized	Refs.	Pure-gum vulcanizate	Refs.
Equilibrium melting temperature	K (°C)	1.0	10		
		0	11		
Temperature of most rapid crystallization	K (°C)	− 52 to − 57	3		
Heat of fusion of crystal	J/kg ($\times 10^3$)	47	11		
		169	10		
Refractive index	N_D	1.526	12		
Molar polarizability	cm^3 ($\times 10^{-25}$)	71.4	12		
Dielectric constant (50 Hz)		2.3	3		
Dielectric loss factor (50 Hz)		0.8	3		
Compressibility	Pa^{-1} ($\times 10^{-12}$)	500	2		
Young's modulus	Pa ($\times 10^6$)			1.3	9
Shear modulus	Pa ($\times 10^6$)			0.96	9
Storage modulus (1 Hz)	log Pa			5.98	9
Loss modulus	log Pa			4.79	9
Loss tangent				0.065	9

TABLE 2. POLY(BUTADIENE-*co*-ACRYLONITRILE)

Property	Units	Unvulcanized	Refs.	Pure-gum vulcanizate	Refs.
Density	kg/m^3			0.95[a] (20%)	3
				1.02 (45%)	3
Glass transition temperature	°C			− 85 + A(20–40%) (A = AN%)	3
Specific heat	J/kg/K ($\times 10^3$)			1.970(40%)	3
Thermal conductivity	W/m/K ($\times 10^{-3}$)			250 (18–35%)	3
Thermal diffusivity	m^2s ($\times 10^{-9}$)				
Solubility parameter	$MPa^{1/2}$	18.5–21.0 (18–39%)	6		
Polymer–solvent interaction parameter (25–30°C)					

Solvent	AN% 18	AN% 30	AN% 39	Refs.
n-Heptane	0.96	1.88	3.6	9
n-Hexane	0.99		2.8	9
Dichloromethane	0.39	0.31	0.32	9
Cyclohexane	0.70	1.42	2.6	9
Benzene	0.39	0.31	0.32	9
Toluene	0.43	0.8	0.6	8

Property	Units	Unvulcanized	Refs.	Pure-gum vulcanizate	Refs.
Refractive index	N_D			1.519 (20%)	3
				1.521 (45%)	3
Dielectric constant (10^6 Hz)				5.5 (27%)	3
				4.8 (40%)	3
Dielectric loss factor (10^6 Hz)				35 (27%)	3
				42 (40%)	3

[a] Bound acrylonitrile content (= AN%)).

TABLE 3. POLY(BUTADIENE-*co*-STYRENE) (23.5–25% BOUND STYRENE CONTENT)

Property	Units	Unvulcanized	Refs.	Pure-gum vulcanizate	Refs.
Density	kg/m^3	933	43	980	17
		(932.5–933.5)	43	940–1000	17
Coefficient of expansion	K^{-1} ($\times 10^6$)	660	43	660	17,18,44
Glass transition temperature	°C	−64 to −59	43	−52	21
Specific heat	J/kg/K ($\times 10^3$)	1.89	45	1.83	24
Thermal conductivity	W/m/K ($\times 10^{-3}$)			190–250	46,47
Thermal diffusivity	m^2/s ($\times 10^{-9}$)			90	48
Solubility parameter	$MPa^{1/2}$	17.0	6		
Polymer–solvent interaction parameter (25–30°C)					
	Solvent				
	n-Heptane	0.59	9		
	n-Hexane	0.66	9		
	Dichloromethane	0.47	9		
	Cyclohexane	0.48	9		
	Benzene	0.40	9		
	Toluene	0.31	13		
Heat of combustion	J/kg ($\times 10^6$)	56.5	43		
Refractive index	N_D	1.5345	43		
		(1.534–1.535)	43		
Molar polarizability	cm^3 ($\times 10^{-25}$)				
Dielectric constant (1 kHz)		2.5	33	2.66	33
Dielectric loss factor		0.0009	33	0.0009	33
Electric conductivity	Sm^{-1} ($\times 10^{-15}$)				
Compressibility	Pa^{-1} ($\times 10^{-12}$)	530	49	510	50
Bulk modulus (isothermal)	Pa ($\times 10^6$)	1890	49	1960	49
Young's modulus	Pa ($\times 10^6$)			1.6	21,35
				1.0–2.0	35
Shear modulus	Pa ($\times 10^6$)			0.53	21
				0.3–0.7	35
Shear compliance	Pa^{-1} ($\times 10^{-6}$)			7	21,35
				3–10	21,35
Storage modulus	log Pa	5.82	40	5.88	64
		(5.82–5.85)	40	5.64–6.20	64
Loss modulus	log Pa	4.94	40	4.92	64
		(4.56–4.94)	40	4.73–5.04	64
Loss tangent		0.13	40	0.11	64
		(0.05–0.13)	40		
Tensile strength	MPa			1.4-3.0	19,42
Ultimate elongation	%			400–600	19,42

TABLE 4. POLY(CHLOROPRENE) (CR NEOPRENE)

Property	Units	Unvulcanized	Refs.	Pure-gum vulcanizate	Refs.
Density	kg/m^3	1230	43,51,58	1320	17
Coefficient of expansion	K^{-1} ($\times 10^6$)	600	46,58	610–720	17,58,59
Glass transition temperature	°C	−45	60	−45	21,59,60,61
Specific heat	J/kg/K ($\times 10^3$)	2.2– 2.2	46	2.1– 2.2	46
Thermal conductivity	W/m/K ($\times 10^{-3}$)	192	58	192	58
Thermal diffusivity	m^2/s	10^{-9}			
Solubility parameter	$MPa^{1/2}$	18.5	6		

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TABLE 4. *cont'd*

Property	Units	Unvulcanized	Refs.	Pure-gum vulcanizate	Refs.
Polymer–solvent interaction parameter (25–30°C)	**Solvent**				
	n-Heptane	0.85	9		
	n-Hexane	0.89	9		
	Dicyclomethane	0.53	9		
	Cyclohexane	0.69	9		
	Benzene	0.26	9		
	Toluene	0.70	13		
Equilibrium melting temperature	K (°C)	328–351 (55–78)	62,63		
Temperature of most rapid crystallization	K (°C)	268 (− 5)	65	261 (− 12)	65,66
Heat of fusion of crystal	J/kg ($\times 10^3$)	95	63		
Refractive index	N_D	1.558	20		
Dielectric constant				6.5–8.1	33
Dielectric loss factor				0.03/0.86	33
Electric conductivity	Sm^{-1} ($\times 10^{-15}$)			3–1400	33
Compressibility	Pa^{-1} ($\times 10^{-12}$)	480	49,50	440	49,50
Bulk modulus (isothermal)	Pa ($\times 10^6$)	2080	50	2270	50
Young's modulus	Pa ($\times 10^6$)			1.6	21,35
Shear modulus	Pa ($\times 10^6$)			0.52	21
Shear compliance	Pa^{-1} ($\times 10^{-6}$)			2.0	19,21,35
Poisson's ratio				0.49974	38
Storage modulus	log Pa			5.81	57,59
Loss modulus	log Pa			5.04	57,59
Loss tangent				0.17	57,59
Tensile strength	MPa			25–38	19,42
Ultimate elongation	%			800–1000	19,42

TABLE 5. POLY(ISOBUTENE-*co*-ISOPRENE) BUTYL RUBBER (IIR)

Property	Units	Unvulcanized	Refs.	Pure-gum vulcanizate	Refs.
Density	kg/m^{-3}	917	51	933	52
				930–970	17
Coefficient of expansion	K^{-1} ($\times 10^6$)	750	53	560	52,54
Glass transition temperature	°C	− 71	53	− 63	21
Specific heat	J/kg/K ($\times 10^3$)	1.95	23,24,29	1.85	24
Thermal conductivity	W/m/K ($\times 10^{-3}$)			130	47
Thermal diffusivity	m^2/s ($\times 10^{-9}$)			70	55
Solubility parameter	$MPa^{1/2}$	16.0	6		
Polymer–solvent interaction parameter	**Solvent**				
	n-Heptane	0.48	14		
	n-Hexane	0.52	14		
	Dicyclomethane	0.58	14		
	Cyclohexane	0.44	14		
	Benzene	0.66	14		
	Toluene	0.56	14		
Equilibrium melting temperature	K (°C)	275 (1.5)	53		
Temperature of most rapid crystallization	K (°C)	239 (− 34)	53		
Refractive index	N_D	1.5081	43		
Dielectric constant (1 kHz)		2.38	33	2.42	33
Dielectric loss factor		0.003	33	0.0054	33

TABLE 5. *cont'd*

Property	Units	Unvulcanized	Refs.	Pure-gum vulcanizate	Refs.
Compressibility	Pa^{-1} ($\times 10^{12}$)			508	54
Bulk modulus (isothermal)	Pa ($\times 10^6$)			1970	54
Young's modulus	Pa ($\times 10^6$)			1.0	21,35
Shear modulus	Pa ($\times 10^6$)			0.33	21,35
				0.2–0.5	19,21,35
Shear compliance	Pa^{-1} ($\times 10^{-6}$)			3.1	21
Strage modulus	log Pa	6.50	56	5.64	57
Loss modulus	log Pa	5.98	56	5.48	57
Loss tangent		0.3	56	0.7	57
Tensile strength	MPa			18–21	19,42
Ultimate elongation	%			750–950	19,42

TABLE 6. POLYISOPRENE, NATURAL RUBBER

Property	Units	Unvulcanized	Refs.	Pure-gum vulcanizate	Refs.
Density	kg/m^3	913	16	970	17,18
		906–916	16	(920–1000)	19
Coefficient of expansion	K^{-1} ($\times 10^6$)	670	16	660	16
Glass transition temperature	°C	− 72	20	− 63	21
		(− 74 to − 69)	20	(− 72 to − 61)	21
Specific heat	J/kg/K ($\times 10^3$)	1.905	22,23	1.828	24
Thermal conductivity	W/m/K ($\times 10^{-3}$)	134	16	153	25,26
Thermal diffusivity	m^2/s ($\times 10$)			70	27
Solubility parameter	$MPa^{1/2}$	1.7	6		
Polymer–Solvent interaction parameter (25–30°C)	**Solvent**				
	n-Heptane	0.43	9		
	n-Hexane	0.47	9		
	Dichloromethane	0.40	9		
	Cyclohexane	0.53	9		
	Benzene	0.44	9		
	Toluene	0.39	9		
Equilibrium melting temperature	K (°C)	308.6 (35.5)	28	313(40)	29
Temperature of most rapid crystallization	K (°C)	248 (− 25)	30		
Heat of fusion of crystal	J/kg ($\times 10^3$)	67.3	31		
Heat of combustion	J/kg ($\times 10^6$)	45.2	16	44.4	16
Refractive index	$N_D K^{-1}$	1.5191(25°C)	32	1.5264	16
Molar polarizability	cm^3 ($\times 10^{-25}$)				
Dielectric constant (1 kHz)		2.37–2.45	16,33	2.68	33
Dielectric loss factor (1 kHz)		0.001–0.003	33	0.002–0.04	33
Electric conductivity	Sm^{-1} ($\times 10^{-15}$)	2.57	16,33	2–100	16,33
Compressibility	Pa^{-1} ($\times 10^{-12}$)	515	34	514	34
Bulk modulus (isothermal)	Pa ($\times 10^6$)	1940	34	1950	34
Young's modulus	Pa ($\times 10^6$)			1.3	35,36
				(1.0–2.0)	19,35
Shear modulus	Pa ($\times 10^6$)			0.43	21,36
				0.3–0.7	21,37
Shear compliance	Pa^{-1} ($\times 10^{-6}$)			2.3	21,36
				(1.5–3.5)	21,37
Poisson's ratio				0.49989	34,38,39
Storage modulus	log Pa	5.61	40	5.61	41
		5.53–5.75		5.49–5.78	
Loss modulus	log Pa	4.46	40	3.80	41
		(4.43–4.65)		3.72–4.48	

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TABLE 6. *cont'd*

Property	Units	Unvulcanized	Refs.	Pure-gum vulcanizate	Refs.
Loss tangent		0.09	40	0.016	41
		0.07–0.13		0.01–0.05	
Tensile strength	MPa			17–25	19,42
Ultimate elongation	%			750–850	19,42

TABLE 7. ETHYLENE–PROPYLENE–DIENE–TERPOLYMER (EPDM)

Property	Units	Unvulcanized	Refs.	Pure-gum vulcanizate	Refs.
Density	kg/m^3			0.85	3
Glass transition temperature	°C			– 60 to – 69	1
Specific heat	J/kg/K ($\times 10^3$)			2340	3
Thermal conductivity	W/m/K ($\times 10^{-3}$)				
Thermal diffusivity	m^2/s ($\times 10^{-9}$)				
Solubility parameter	$MPa^{1/2}$	16.0–16.5	6		
Polymer–Solvent interaction parameter (25–30°C)					
	Solvent				
	n-Heptane	0.44	15		
	n-Hexane	0.49	16		
	Dichloromethane	0.32	16		
	Cyclohexane	0.35	15		
	Benzene	0.58	15		
	Toluene	0.49	15		
Refractive index	N_D			1.48	3
Young's modulus	Pa ($\times 10^6$)			2.0	13
Shear modulus	Pa ($\times 10^6$)			1.59	13
Storage modulus (1 Hz)	MPa			1.59	13
Loss modulus (1 Hz)	MPa			0.12	13
Loss tangent (1 Hz)				0.077	13

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