APPENDIX B:
GENERAL PROPERTIES AND DATA ON ELASTOMERS AND PLASTICS

Table B.1 Properties of Important Plastics and Elastomers

	Molecular mass (g/mol)	Enthalpy of melting (kJ/mol)	Glass transition Temperature °C	Glass transition Temperature °F	Melt temperature °C	Melt temperature °F	Density (g/cm³) Amorphous	Density (g/cm³) Crystalline
Polyolefins								
Polyethylene	28.1	8.0	−78	−108.4	141	285.8	0.85	1.00
Polypropylene	42.1	1.9/10.9	−35, 26	−31, 78.8	112, 208	233.6, 406.4	0.85	0.95
1,2-Poly(1,3-butadiene) (iso)	54.1	—	−75, −30	−103, −22	2, 44	35.6, 111.2	—	0.96
1,2-Poly(1,3-butadiene) (syndio)	54.1	—	—	—	155	311	0.92	0.96
Poly(1-butene)	56.1	4.1/13.9	−45, −24	−49, −11.2	106, 142	222.8, 287.6	0.85	0.95
Polyisobutylene	56.1	12.0	−75, −30	−103, −22	2, 44	35.6, 111.2	0.84	0.94
Poly(3-methyl-1-butane)	70.1	17.3	50	122	300, 310	572, 590	0.90	0.93
Poly(1-pentane)	70.1	4/6.3	−50, 14	−58, 57.2	111, 130	231.8, 266	0.85	0.92
Poly(4-methyl-1-pentene)	84.2	11.9/19.7	22, 42	71.6, 107.6	228, 250	442.4, 482	0.84	—
Poly(1-hexene)	84.2	—	−50	−58	48	118.4	0.86	0.91
Poly(5-methyl-1-hexene)	98.2	—	−14	6.8	110, 120	230, 248	—	0.84
Poly(1-octadecane)	252.5	—	55	131	68, 80	154.4, 176	0.86	0.95
Polyoxides								
Poly(methylene oxide)	30	3.7/10	−88, −79	−126.4, −110	60, 198	140, 388.4	1.25	1.54
Poly(ethylene oxide)	44.1	7.3/12	−67, −27	−88.6, −16.6	62, 72	143.6, 161.6	1.13	1.33
Polyacetylaldehyde	44.1	—	−30	−22	165	329	1.07	1.14
Poly(tetramethylene oxide)	72.1	12.4/14.4	−88, −79	−126.4, −110	60, 198	140, 388.4	0.98	1.18
Poly(*trans*-2-butene oxide)	72.1	—	4	39.2	114	237.2	1.01	1.10
Poly(ethylene formal)	74.1	16.7	−65	−83.2	55, 74	131, 165.2	—	1.32/1.414
Poly(3-methoxypropylene oxide)	88.1	—	−62	−79.6	57	134.6	1.10	—
Poly(3-chloropropylene oxide)	92.5	—	—	—	117, 135	242.6, 275	1.37	1.46
Poly(hexene oxide)	100.2	—	−69	−92.2	72	161.6	0.92	0.97
Poly(tetramethylene formal)	102.1	14/14.7	−84	−119.2	23	73.4	—	1.23
Poly(octane oxide)	128.1	—	−70	−94	87	188.6	0.94	0.97

Table B.1 *(continued)*

	Molecular mass (g/mol)	Enthalpy of melting (kJ/mol)	Glass transition Temperature		Melt temperature		Density (g/cm³)	
			°C	°F	°C	°F	Amorphous	Crystalline
Polystyrene								
Polystyrene	104.1	8.4/10.1	90, 100	176, 212	225, 250	437, 482	1.05	1.13
Poly(2-methylstyrene)	118.2	—	136	276.8	360	680	1.027	1.07
Poly(4-methylstyrene)	118.2	—	93, 106	199.4, 222.8	—	—	1.04	—
Poly(3-phenyl-1-propene)	118.2	—	60	140	230, 240	446, 464	1.046	1.05
Poly(4-methoxystyrene)	134.2	—	89	192.2	238	460.4	—	1.12
Poly(2-chlorostyrene)	138.6	—	119	246/2	—	—	1.25	—
Poly(4-chlorostyrene)	138.6	—	110, 126	230, 258.8	—	—	—	—
Polyacrylates								
Poly(acrylic acid)	72.1	—	106	222.8	—	—	—	—
Poly(methyl acrylate)	86.1	—	8	46.4	—	—	1.22	—
Poly(ethyl acrylate)	100.1	—	−22	−7.6	—	—	1.22	—
Poly(propyl acrylate)	114.1	—	−44	−47.2	115, 162	239, 323.6	1.08	1.18
Poly(isopropyl acrylate)	114.1	5.9	−11, 11	12.2, 51.8	116, 180	240.8, 356	—	1.08/1.18
Poly(butyl acrylate)	128.2	—	−52	−61.6	47	116.6	1.00/1.09	—
Polyacrylics								
Polyacrylonitrile	53.1	4.9/.2	80, 105	176, 221	318	604.4	1.184	1.27/1.54
Polymethacrylonitrile	67.1	—	121	249.8	250	482	1.1	1.134
Polyacrylamide	71.1	—	165	329	—	—	1.302	—
Poly(methyl chloroacrylate)	120.5	—	143	289.4	—	—	1.45/1.49	—

Polyhalo-olefins								
Poly(vinyl fluoride)	46	7.5	−20, 40	−4, 104	200	392	1.37	1.44
Poly(vinyl chloride)	62.5	2.8/11.3	−26, 83	−14.8, 181.4	212, 83	413.6, 181.4	1.385	1.52
Poly(vinylidene fluoride)	64	8.9	−40, 13	−40, 55.4	137, 238	278.6, 460.4	1.74	2
Poly(vinylidene chloride)	97	1.4	−18, 15	−0.4, 59	190, 210	374, 410	1.66	1.95
Poly(tetrafluoroethylene)	100	5.7	−113, 127	−171.4, 260.6	19, 299	66.2, 750.2	2	2.35
Poly(vinyl bromide)	107	—	—	—	100	212	—	—
Polyvinyls								
Poly(vinyl alcohol)	44.1	6.97/7	70, 99	158, 210.2	232, 265	449.6, 509	1.26	1.35
Poly(vinyl methyl ether)	58.1	—	−31, −13	−23.8, 8.6	144, 150	291.2, 302	1.03	1.175
Poly(vinyl methyl ketone)	70.1	—	—	—	170	338	1.12	1.216
Poly(vinyl ether ether)	72.1	—	−42, −19	−43.6, −2.2	86	186.8	0.94	0.97
Poly(vinyl formate)	72.1	—	31, 37	87.8, 98.6	—	—	1.35	1.49
Poly(methyl isopropenyl ketone)	84.1	—	80, 114	176, 237.2	200, 240	392, 464	1.12/1.15	1.15/1.17
Poly(vinyl propyl ether)	86.1	—	—	—	76	168.8	0.94	—
Poly(vinyl isopropyl ether)	86.1	—	−3	26.6	191	375.8	0.924	0.93
Poly(vinyl acetate)	86.1	—	28	82.4	—	—	1.19	1.2
Poly(vinyl cyclopentane)	96.2	—	75	167	292	557/6	0.965	0.986
Poly(vinyl butyl ether)	100.2	—	−53	−63.4	64	147.2	0.927	0.944
Poly(vinyl isobutyl ether)	100.2	—	−27, −18	−16.6, −0.4	170	338	0.93	0.94
Poly(vinyl *sec*-butyl ether)	100.2	—	−20	−4	170	338	0.92	0.956
Poly(vinyl propionate)	100.2	—	10	50	—	—	1.02	—
Poly(vinyl hexyl ether)	128.2	—	−77, −50	−106.6, −58	—	—	0.925	—
Poly(vinyl propionate)	100.2	—	10	50	—	—	1.02	—

Polyesters								
acid)	58	12	38, 95	100.4, 203	223, 260	433.4, 500	1.6	1.7
ydrobenzoate)	120.1	—	147	296.6	317, 497	602.6, 926.6	1.44	1.48
succinate)	144.1	320/338	—	—	−70, −40	−94, −40	1.175	1.36
oxybenzoate)	164.2	10.5	82	179.6	202, 227	395.6, 440.6	1.34	—
adipate)	172.2	—	−70, −40	−94, −40	47, 65	116.6, 149	1.18/1.22	1.25/1.45
thylene te)	220.2	—	—	—	153	307.4	1.27	1.31
azelate)	214.3	—	−45	−49	46	114.8	—	1.17/1.22
e-1,5-naphthalene)	242.2	—	71	159.8	230	446	1.33	1.35
e-2,6-naphthalene)	242.2	—	113, 180	235.4, 356	260, 268	500, 514.4	1.3	1.37
thylene te)	303.3	43.5/48.6	−5, 25	23, 77	123, 138	253.4, 280.4	—	1.022
thalene sebacate) 1.13	340.5	30.2/56.5	—	—	—	71, 85	159.8, 185	—
Polyamides								
hexanoic acid)	113.1	17.6/23	50, 75	122, 167	214, 233	417.2, 451.4	1.08	1.23
heptanoic acid)	127.2	—	52, −38	125.6, −36.4	217, 233	422.6, 451.4	1.095	1.21
nonanoic acid)	155.2	—	51	123.8	194, 209	381.2, 408.2	1.052	1.066
oundecanoic acid)	183.3	41.4	46	114.8	182, 220	359.6, 428	1.01	1.12/1.23
thylene adipamide)	226.2	36.8/46.9	45, 57	113, 134.6	250, 272	482, 521.6	1.07	1.24
thylene e)	282.4	30.6/58.6	30, 50	86, 122	215, 233	419, 451.4	1.04	1.19
thylene azelamide)	324.5	36.3/68.2	—	—	214	417.2	1.04	—
thylene e)	338.5	32.7/51.1	46, 60	114.8, 140	196, 216	384.8, 420.8	1.03	1.06

Table B.4 Synthesis and Features of Hydrogenated Aromatic-Diene Copolymers

Types of starting polymers[a]	Unhydrogenated precursor		Hydrogenated polymer		Features
	Block 1	Block 2	Block 1	Block 2	
S-B_{mv}S	Polystyrene	1,2-Polybutadiene (medium vinyl)	Polystyrene[b]	Poly(ethylene-co-butylene)	Thermally and oxidatively stable
SBS (linear or star)	Polystyrene	Polybutadiene	Polystyrene[b]	Polyethylene	Thermoplastic elastomer
S-$B_{1,2}$S	Polystyrene	1,2-polybutadiene	Polystyrene[b]	Polybutylene	Enhanced compression set
S-(α-MeS)$B_{1,4}$	Polystyrene poly(α-methylstyrene)	High 1,4-polybutadiene 1,2-polybutadiene	Polystyrene (poly-(α-methylpoly-styrene)[b]	Polyethylene	
S-$B_{1,2}$	Polystyrene	1,2-Polybutadiene	Polystyrene[b]	Polybutylene	Improved tensile strength and elongation
S-$B_{1,4}$	Polystyrene	1,4-Polybutadiene	Poly(vinyl cyclo-hexane)	Polyethylene	Hydrogenation of both blocks
S-I-S	Polystyrene	Polyisoprene	Polystyrene[b]	Poly(ethylene-co-propylene)	
S-(α-MeS)-I	Polystyrene poly(α-methylstyrene)	Polyisoprene	Polystyrene poly(α-methylstyrene)[b]	Poly(ethylene-co-propylene)	
Random SBR	Polystyrene	1,4-Polybutadiene (~20% 1,2)	Polystyrene[b]	Poly(ethylene-co-butylene)	

[a]B_{mv}, medium vinyl (35–60% 1,2-polybutadiene block); B = $B_{1,4}$, high 1,4-polybutadiene block; B_{12}, high 1,2-polybutadiene block; αMeS, α-methylstyrene block; SBS, poly(styrene-*b*-butadiene-*b*-styrene); SBR, poly(styrene-co-1,4-butadiene-*b*-styrene).
[b]Selective hydrogenation; this block not hydrogenated.

Table B.5 Hydrogenation of Functional Diene Polymers

Functionality	Backbone[a]	Method	Features
$-OH$	Polybutadiene	Homogeneous hydrogenation [e.g., Ni or Co/triethyl aluminum (or Ru, Rh catalysis)]; heterogeneous catalysis (Raney Ni)	Hydrogenated mixed 1,4- and 1,2-polybutadienes as heat-resistant polyurethane prepolymers
$-COOH$	SBR, NBR	Rh catalysis	
$-COOCH_3$	Poly(butadiene-alt-methyl methacrylate	Pt black	
$-CN$	SBR, NBR, IR	Rh catalysis	
	PP	[NH=NH]	
$-SO_3Na$	PP	[NH=NH]	
$-PO(OCH_3)_2$	PP	[NH=NH]	
$-NO_2$	NR, PIP, 1,4-BR	Raney Ni, Zn−AcOH	Partial reduction of NO_2 groups; complete hydrogenation of double bonds
	Poly(butadiene-*b*-vinyl pyridine) or poly(isoprene-*b*-vinyl pyridine)	Ni/Et_3Al catalysis	BF_3 and Cl_2AlEt used to complex vinyl pyridine to increase rate of hydrogenation; BF_3 released by NH_4OH

[a]BR, polybutadiene; SBR, poly(styrene-co-1,4-butadiene; NBR, poly(acrylonitrile-co-1,4-butadiene); PP, polypentenamer; IR, polyisoprene.

Table B.6 Properties of Liquid Polysulfide Polymers

	LP-31	LP-2	LP-32	LP-12	LP-3	LP-33
Viscosity (poise) (25°C)	950–1550	410–525	410–525	410–525	9.4–14.4	15–20
Mercaptan content (%)	1.0–1.5	1.5–2.0	1.5–2.0	1.5–2.0	5.9–7.7	5.0–6.5
Average molecular weight	8000	4000	4000	4000	1000	1000
Pour point (°C)	10	7	7	7	−26	−23
Cross-linking agent (%)	0.5	2.0	0.5	0.2	2.0	0.5
Specific gravity (25°C)	1.31	1.29	1.29	1.29	1.27	1.27
Average viscosity (poise) (4°C)	7400	3800	3800	3800	90	165
Stress–strain properties						
Tensile strength (MPa)	2.59	2.82	2.07	2.07	2.07	2.59
300% Modulus (MPa)	2.07	2.41	1.45	1.38	1.03	1.38
Elongation (%)	600	510	930	900	275	700
Hardness, Shore A	48	50	50	48	45	34

Recipe: LP-31, LP-32, LP-2, LP-12

Base compound:	
Liquid polymer	100
M774 black	30
Curing paste:	
PbO_2[a]	*7.8*
HP-40 (plasticizer)	*0.2*
Alumina (Al_2O_3)	*0.2*

Cure: 2 hr at 70°C in closed mold, postcure 20 hr at 23°C, 50% RH after demolding

Recipe: LP-33 and LP-3

Base compound:	
Liquid polymer	100
N990 black	20
p-Quinonedioxime (GMF)	*6.67*
Diphenylguanidine (DPG)	*0.67*
Magnesium oxide	*0.50*

Cure: 20 hr at 77°C in mold, postcure minimum 2 hr at 23°C and 50% RH after demolding

Source: Courtesy of Morton Thiokol Inc.
[a]With LP-31, 5.0 parts of PbO_2 was used.

Table B.7 Properties of Arco Poly bd R-45 HT Urethane Composition

	Formulations							
Poly bd R-45 HT (g)	100	100	100	100	100	100	100	100
Isonol 100 (g)[a]	—	2.22	4.45	8.89	11.85	17.78	26.67	35.56
Catalyst T-12 (drops)[b]	4	4	4	4	4	4	4	4
CAO-14 (g)[c]	12.76	15.45	19.14	25.53	29.78	38.29	51.05	63.81
Equivalent ratio: Poly bd/Isonol 100	—	4/1	2/1	1/1	3/4	1/2	1/3	1/4
Vulcanizate properties (press cure 30 min at 80°C; postcure 64 hr at 49°C.)								
Tensile strength (MPa)	1.2	1.7	2.6	6.2	8.2	13.9	18.6	24.0
200% modulus (MPa)	—	—	1.3	2.6	5.3	10.3	14.7	19.4
Harness								
Shore A	53	56	62	75	82	—	—	—
Shore D	—	—	—	—	—	43	51	53

Source: Courtesy of ARCO Chemical Co.
[a]*N,N*-bis(2-Hydroxypropyl)aniline (Upjohn Co.).
[b]Dibutyltin dilaurate.
[c]Antioxidant (Sherex Chemical Co.).
[d]Polyfunctional liquid isocyanate (Upjohn Co.)

Table B.8 Properties of CTBN–Expoxy Resin Compositions

	Formulations				
DGEBA[a]	100	100	100	100	100
Hycar CTBN 1300X8[b]	—	5	10	15	20
Piperidine	5	5	5	5	5
Physical properties (cure 16 hr at 120°C)					
Tensile strength (MPa)	65.8	62.8	58.4	51.4	47.2
Tensile modulus (GPa)	2.8	2.5	2.3	2.1	2.2
Elongation (%)	4.8	4.6	6.2	8.9	12.0
Fracture surface energy (kJ/m^2)	0.18	2.63	3.33	4.73	3.33
Gardner impact (J)	6	8	8	8	25
Heat-distortion temperature (°C)	80	76	74	71	69

Source: Courtesy of the B.F. Goodrich Co.
[a]Diglycidyl ether of bisphenol A.
[b]ACN content 18 wt%, functionality 1.8, $\bar{M}_n$ 3600.

Table B.9 Properties of Unfilled Thermoplastic Compositions

Composition number	Resin type/parts per 100 parts of rubber (phr)[a]	Sulfur (phr) Y	Method of preparation	Cross-link density, $r/2$ (moles $\times 10^5$ per ml of rubber)	Rubber particle size (μm) d_n	Rubber particle size (μm) d_w	Shore D hardness	Young's modulus (MPa)	Stress at 100% strain (MPa)	Tens. str. (MPa)	Ult. elong. (%)	Tens. set (%)
1	Polypropylene/66.7	2.0	S	16.4	72	750	43	97	8.2	8.6	165	—
2	Polypropylene/66.7	2.0	S	16.4	39	200	41	102	8.4	9.8	215	22
3	Polypropylene/66.7	2.0	S	16.4	17	96	41	105	8.4	13.9	380	22
4	Polypropylene/66.7	2.0	S	16.4	5.4	30	42	103	8.4	19.1	380	22
5	Polypropylene/66.7	2.0	D	16.4	About 1 to 2		42	58	8.0	24.3	530	16
6	Polypropylene/66.7	1.0	D	12.3	—		40	60	7.2	18.2	490	17
7	Polypropylene/66.7	0.05	D	7.8	—		39	61	6.3	15.0	500	19
8	Polypropylene/66.7	0.25	D	5.4	—		40	56	6.7	15.8	510	19
9	Polypropylene/66.7	0.125	D	1.0	—		35	57	6.0	9.1	407	27
10	Polypropylene/66.7	0.00	—	0.0	—		22	72	4.8	4.9	190	66
11	Polypropylene/33.3	1.00	D	12.3	—		29	13	3.9	12.8	490	7
12	Polypropylene/42.9	2.00	D	16.4	—		34	22	5.6	17.9	470	9
13	Polypropylene/53.8	2.00	D	16.4	—		36	32	7.6	25.1	460	12
14	Polypropylene/81.8	2.00	D	16.4	—		43	82	8.5	24.6	550	19
15	Polypropylene/122	2.00	D	16.4	—		48	162	11.3	27.5	560	31
16	Polypropylene/233	5.00	D	14.5	—		59	435	13.6	28.8	580	46
17	None[c]/0.00	2.00	S	16.4	—		11	2.3	1.5	2.0	150	1
18	Polypropylene[c]/∞	0	—	—	—		71	854	10.2	28.5	530	—
19	Polyethylene/66.7	2.00	D	12.3	—		35	51	7.2	14.8	440	18
20	Polyethylene/66.7	0.0	—	0.0	—		21	46	4.1	3.5	240	24

[a]Polypropylene is Profax 6723 and polyethylene is Marlex EHM 6006.
[b]S, static; D, dynamic. [c]Compositions 17 and 18 control compositions purely of cured rubber or polypropylene.

Table B.10 True Stress at Break of Selected Melt-Mixed Rubber-Plastic Blends[a]

Rubber	Plastic	True stress at break (MPa)
IIR	Polypropylene	26
EPDM	Polypropylene	26
NR	Polypropylene	16
NBR	Polypropylene	23
EPDM	Polyethylene	27
NBR	Polyethylene	13
NBR	Poly(tetramethylene terephthalate)	27
IIR	Polystyrene	2.3
EPDM	Polystyrene	3.7
BR	Polystyrene	4.1
IIR	SAN	5.0
NBR	SAN	10.5
IIR	PMMA	3.6

[a]The compositions were 60:40 and 50:50 rubber-plastic weight ratio. The stress at the break is the product of the ultimate extension ratio.

Table B.11 Properties of Various Types of Elastomer Compositions

	Partially vulcanized EPDM/Polypropylene blend[a]	Completely vulcanized EPDM/Polypropylene blend[b]	Neoprene vulcanizate	Ester-ether copolymer thermoplastic elastomer[c]
Shore A hardness	77	80	80	92
Tensile strength (MPa)	6.6	9.7	9.7	25.5
Ultimate elongation (%)	200	400	400	450
Volume swell in ASTM No. 3 Oil (74 hr at 100°C) (%)	Disintegrated	50	35	30
Compression set (method B: 22 hr at 100°C) (%)	70	39	35	33
Use temperature (°C)	100	125	110	125
Type of processing[d]	TP	TP	CV	TP

[a]TPR-1700 (Uniroyal).
[b]Santoprene (Monsanto).
[c]Hytrel (DuPont).
[d]TP, thermoplastic; CV, conventional vulcanizate.

Table B.12 Nonextended Polymers with Unsaturated Center Block

	Solprene or Finaprene					Kraton		
Polymer[a]	406	414	411	416	418	1101	1102	1107
Diolefin/styrene ratio	60:40	60:40	70:30	70:30	85:15[b]	70:30	72:28	86:14[b]
Molecular weight	High	Low	High	Low	—	—	—	—
Type structure	Radial	Radial	Radial	Radial	Radial	Linear	Linear	Linear
Specific gravity	0.95	0.95	0.94	0.94	0.92	0.94	0.94	0.92
Melt flow (200°C/5 kg)[c]	0	4	0	3	3	<1	6	9
300% modulus (MPa)	4.1	4.1	2.1	2.9	1.0	2.8	2.8	0.7
Tensile (MPa)	26.9	27.6	19.3[d]	20.0	16.5	31.7	31.7	21.4
Elongation (%)	700	750	700	720	1050	880	880	1300
Shore A hardness	93	90	78	68	34	71	62	37

[a]Partial listing only.
[b]Isoprene-styrene; others are butadiene-styrene.
[c]ASTM D1238.
[d]Resin additives result in higher tensile strength—retains tensile better than polymers of lower molecular weight on extension.

Table B.13 Some Commercial Macroglycols That Have Been Used to Make TPU Elastomers

Abbreviation	Common chemical name	Structure
PTAd	Poly(tetramethylene adipate) glycol[a]	$HO-[(CH_2)_4-OCO(CH_2)_4-COO]-(CH_2-)_4-OH$
PCL	Poly(ε-captrolactone)glycol[b]	$H-[O-(CH_2)_5CO_x-ORO-[CO(CH_2)_5-O]_y-H$
PHC	Poly(hexamethylenecarbonate)glycol[c]	$HO-[(CH_2)_6-OCOO]_n-(CH_2)_6-OH$
PTMO	Poly(oxytetramethylene)glycol[d]	$HO-[(CH_2)_4-O]_n-H$
PPG	Poly(1,2-oxypropylene)glycol[d]	$HO-[CH-CH_3-CH_2-O]_n-CH_2-CHCH_3-OH$

[a]Polyester(carboxylate).
[b]Polyester(lactone).
[c]Polyester(carbonate).
[d]Polyether.

Table B.14 TPU Product Comparison Chart

Property	ASTM method	Units	BFG Estane				Dow (Upjohn) Pellethane				Mobay Texin	
			Polyester		Polyether		Polyester		Polyether		Polyester	
			58206	58137	58300	58810	2102-85A	2355-65D	2103-80A	2103-90A	480A	902E
Shore hardness	D2240	degrees	85A	70D	80A	90A/42D	87A±5	63D±4	80A±5	90A/47D	86A	75D
Specific gravity	D792	g/cm^3	1.20	1.23	1.13	1.15	1.18	1.22	1.13	1.14	1.20	1.21
Ultimate tensile strength	D412	Mpa	45	40	32	44	43	41	41	43	40	41–48
		psi	6500	5800	4600	6400	6300	5900	6000	6250	5800	6–7000
Tensile stress	D412	MPa	8.5	22	4.8	9	8	22	6	11	5	37
At 100% elongation		psi	800	3200	700	1300	1100	3200	800	1530	700	5400
		Mpa	10	33	6.9	17	15	31	12	24	11	—
At 300% elongation		psi	1500	4800	1000	2400	2100	4500	1675	3430	1600	—
Ultimate elongation	D412	%	550	440	700	590	600	450	550	475	520	150–175
Compression set[a] (22 hr at 70°C)	D395	%	64	80	78	64	30	50	25–40	25–40	55	—
Flex modulus	D790	Mpa	—	331	—	—	—	269	—	—	55	1068
at 23°C		psi	—	48,000	—	—	—	39,000	—	—	8000	155,000
Vicat softness	D1525	°C	85	149	76	111	—	—	—	—	91	182
temperature (method B)		°F	185	300	169	232	—	—	—	—	196	360

Taber abrasion	D1044	mg/1000 cycles										
CS17 wheel, 1-kg load			3	12	—	—	—	—	—	—	2.7	—
H18 wheel, 1-kg load			36	119	36	70	—	—	—	—	—	—
H22 wheel, 1-kg load			—	—	—	—	50	15	20	10	—	—
Tear resistance, die C	D624	kN/m	88	228	70	88	88	245	83	95	94	—
		pli	500	1300	400	500	500	1400	475	540	535	—
Mold shrinkage[b]	—	in./in.	0.012	0.005	0.016	0.614	[c]	[c]	—	—	0.008[d]	—
Price (list)		$/lb (T/L qty)	2.13	2.11	2.70	2.75	2.42	2.04	2.53	2.50	2.19	2.19

Source: Estane thermoplastic polyurethane product comparison data (1985).
[a]BFG samples unannealed, Dow (Upjohn) and Mobay samples annealed 16 hr at 240°F.
[b]Mold shrinkage determined on 0.125 × 3 × 6 in molded plaques; actual shrinkage will vary with part size and design.
[c]Mold shrinkage values for pellethane:

Part thickness (in.)	80A	55D
0.125	0.011–0.015	0.008–0.011
0.250	0.015–0.020	0.010–0.015
>0.250	0.020–0.030	0.015–0.020

[d]0.120-in. wall thickness.

Table B15 Physical Properties of 1,2-Polybutadiene

Properties	Testing methods	Measured values		
		JSR RB810	JSR RB820	JSR RB830
Density (kg/m^3)	Density-gradient tube method	901	906	909
Crystallinity (%)	Density-gradient tube method	~15	~25	~29
Microstructure 1,2-unit content (%)	Infrafred ray spectrum (Morero method)	90	92	93
Refractive index, n_{25}^{d}	ASTM D542	1.513	1.515	1.517
Melt flow index (g/10 min) 150°C, 2160 g	ASTM D1238	3	3	3
Thermal properties				
Vicat softening point (°C)	ASTM D1525 (DSC method)	39	52	66
Melting point (°C)[a]		75	80	90
Brittle point (°C)	JIS K 6301	−40	−37	−35
Tensile properties				
300% Modulus (MPa)	JIS K6301	4.0	6.0	8.0
Tensile strength (MPa)		6.5	10.5	13.5
Elongation (%)		750	700	670
Hardness				
Shore D (degrees)	ASTM D1706	32	40	47
JIS A (degrees)	JIS K6301	79	91	95
Izod impact (kg · m/m)	ASTM D256	Not broken	Not broken	Not broken
Light transmittance (%)	JIS K6714	91	89	82
Haze (%)[b]	JIS K6714	2.6	3.4	8.0

Source: Reprinted with permission from Japan Synthetic Rubber Co. Ltd.

[a]Endothermic peak temperature according to the differential scanning calorimeter method. (Speed of temperature rise: 20°C/min.)

[b]The figures apply to 2-mm-thick sheet injection molded with cylinder temperature of 150°C and mold temperature 20°C.

Table B.16 Applications and features of 1,2-Polybutadiene

Application	Features
Application as a thermoplastic resin	
Films: stretch film, laminated film, shrinkable film	Safe for food packages, transparency, self-tack, pliability, shrinkability at low temperature, puncture strength resistance, heat sealability at low temperature, gas permeability
Various footwear soles: unit soles, inner soles, and outer soles by injection molding	Light weight, hardness, rubbery feeling, no deformation snappiness, reprodicibility of mold pattern, coating performance, adhesive properties, crack resistance
Tubes and hoses: liquid food transfer tubes, tubes for medical practice	Safe for food transfer, safe for medical practice, transparency, flexibility
Other: blow moldings, injection moldings, resin modifier	Flexibility, safe for food packages
Application as a rubber	
Various sponges: microcellular sponge, hard sponge, semihard sponge, soft sponge, crepe-tone sponge	One-step vulcanization, wide range of curing conditions, high loading elasticity, snappiness, no deformation, weatherability, ozone resistance, heat resistance, tear resistance, coating performance, adhesive properties, skid resistance, abrasion resistance
Various high-hardness rubber goods: footwear, solid tires, industrial goods, dock fenders, sporting goods, sundries	Elongation, tensile strength, hardness, snappiness, good flowability, easy vulcanization, weatherability, ozone resistance, heat resistance, skid resistance, abrasion resistance
Injection cured goods: footwear, solid tires, industrial goods, rubber gloves	Flowability, injection molding processability easy vulcanization, weatherability, ozone resistance, heat resistance, skid resistance, abrasion resistance, snappiness
Rubber modifier: various rubber goods	Green strength, flowability, extrudability injection molding processability, weatherability, ozone resistance, heat resistance snappiness

Table B.16

Application	Features
Application as a rubber	
Other: transparent cured rubber goods	Transparency, safe for food application, weatherability, heat resistance
Other applications	
Adhesive (hot melt type): adhesive for various woven or unwoven cloth, paper, leather, and wooden board	Low melting point, flowability
Reaction accelerator: cross-linking accelerator for polyolefins	Easy cross-linking, reduction in use of cross-linking agents
Photo-sensitive polymer: printing plates, photo-sensitive paint, etching-resistant material	Photo sensitivity (photo curing), flowability, low solution viscosity
Thermo-setting resin: electrical insulation material	Chemical resistance, heat resistance, electric properties
Others: fibers, modifiers for composite resins, photo-degradable polymer	

Source: Reprinted with permission from Japan Synthetic Rubber Co. Ltd.

Table B17 Chemical and Oil Resistance of Silicone Rubber

Chemical or medium	Percent volume change	
	Fluorosilicone rubber (FVMQ)	Silicone rubber (VMQ)
Acid (7 days, 24°C)		
10% Hydrochloric	+1	+2
Hydrochloride	+8	+15
10% Sulfuric	Nil	+5
10% Nitric	+1	+8
Alkali (7 days, 24°C)		
10% Sodium hydroxide	Nil	Nil
50% Sodium hydroxide	+1	+9
Solvent (24 hr, 24°C)		
Acetone	+180	+15
Ethyl alcohol	+5	+9
Xylene	+20	Over 150
JP4 fuel	+10	Over 150
Butyl acetate	Over 150	Over 150
Oils		
ASTM No. 3 (7 days, 149°C)	+6	+20 +50
Turbo oil 15 (Mil L07808) (1 day, 177°C)	+8	30
Dimethyl siloxane, 500 cS (14 days, 205°C)	Nil	Swells, deteriorates

Table B.18 Summary of Solid EP and EPDM Worldwide Products[a]

Manufacturer	Trade name	Type elastomer	Grade designation	Oil content (phr)	Mooney viscosity (1′ + 8′) at 127°C	Ethylene content	Diene type	Diene content	Molecular weight distribution classification
Exxon Chemical	Vistalon	Copolymers	V-504	—	25	Low	—	—	Medium
			V-404	—	33	Very low	—	—	Very broad
			MD-78-5	—	26	Very low	—	—	Narrow
			MD-80-6	—	29	High	—	—	Narrow
			V-808	—	40	Very high	—	—	Narrow
			V-606	—	57	Low	—	—	Medium
			MD805-1	—	33	Very high	—	—	Narrow
		Terpolymers	MD-7504-1	—	30	Low	ENB	Medium	Narrow
			V-2504	—	24	Low	ENB	Medium	Very broad
			V-2200	—	30	Low	ENB	Low	Broad
			V-4507	—	45	Low	ENB	Medium	Medium
			V-7507	—	50	Low	ENB	Medium	Narrow
			V-2555	—	50	Medium	ENB	Low	Broad
			V-3708	—	50	High	ENB	Medium	Broad
			V-7000	—	55	High	ENB	Medium	Narrow
			V-4608	—	60	Low	ENB	Medium	Broad
			V-7509	—	68	Low	ENB	Medium	Narrow
			V-5600	—	70	Medium	ENB	Medium	Broad
			V-5630	30	35	Medium	ENB	Medium	Broad
			V-3666	75	52	Medium	ENB	Medium	Medium
			V-3777	75	45	High	ENB	Medium	Medium
			V-6505	—	46	Low	ENB	High	Narrow
			V-6630	30	33	Medium	ENB	High	Broad

Huels	Buna AP	Copolymers	AP201	—	22	Low	—	—	Broad
			AP 407	—	51	High	—	—	NA
			AP 301	—	45	Low	—	—	NA
		Terpolymers	AP 321	—	40	Medium	DCPD	High	NA
			AP 421	—	60	Medium	DCPD	High	NA
			AP 324	50	40	Medium	DCPD	High	NA
			AP 521	—	70	Medium	DCPD	High	NA
			AP 147	—	22	High	ENB	Medium	Narrow
			AP 241	—	25	Low	ENB	Medium	Narrow
			AP 331	—	41	Low	ENB	Low	Narrow
			AP 341	—	41	Low	ENB	Medium	Narrow
			AP 437	—	52	High	ENB	Low	Narrow
			AP 447	—	52	High	ENB	Medium	Narrow
			AP 238	30	30	High	ENB	Low	Narrow
			AP 248	30	30	Medium	ENB	Medium	Narrow
			AP 541	—	70	Low	ENB	Medium	Narrow
			AP 344	50	43	Low	ENB	Medium	Narrow
			AP 244	50	33	Low	ENB	Medium	Narrow
			AP 251	—	26	Low	ENB	High	Narrow
			AP 451	—	56	Low	ENB	High	Narrow
			AP 258	30	31	High	ENB	High	Narrow
			AP 338	25	50	High	ENB	High	Broad
			AP 451 H	—	51	Low	ENB	Very high	Narrow
			AP 454	50	50	Low	ENB	Very high	NA
Montedison	Dutral	Copolymers	CO 034	—	23	Medium	—	—	Narrow
			CO 054	—	29	Low	—	—	Broad
			CO 038	—	56	High	—	—	Narrow
			CO 059	—	60	Low	—	—	Narrow
			CO 554	100	24	Very low	—	—	Narrow
			CS 15/84	—	60	Low	—	—	Narrow

Table B.18 Summary of Solid EP and EPDM Worldwide Products[a]

Manufacturer	Trade name	Type elastomer	Grade designation	Oil content (phr)	Mooney viscosity (1′ + 8′) at 127°C	Ethylene content	Diene type	Diene content	Molecular weight distribution classification
			CS 16/84	—	23	Low	—	—	Narrow
		Terpolymers	044 E	—	25	Low	ENB	Low	Narrow
			054 E	—	27	Low	ENB	Medium	Narrow
			045 E	—	32	Low	ENB	Medium	Narrow
			048 E	—	60	Low	ENB	Medium	Narrow
			058 E	—	58	Low	ENB	Medium	Narrow
			038 E	—	57	High	ENB	Medium	Narrow
			334 E	40	23	High	ENB	Medium	Narrow
			535 E	100	20	Medium	ENB	Medium	Narrow
			436 X	65	50	High	ENB	High	Narrow
			346	45	32	Medium	ENB	High	Narrow
			TS 03/84	—	45	High	ENB	Medium	NA
			TS 12/84	—	55	High	ENB	Medium	NA
			TS 04/84	—	56	Low	ENB	Medium	NA
			TS 09/84	—	20	High	ENB	Medium	NA
			TS 11/84	—	70	High	ENB	Medium	NA
			0436	24	36	Low	ENB	Medium	Narrow
			TS 2084	—	30	Low	ENB	Medium	Medium
			TS 10/84	—	17	High	ENB	Medium	NA
			046 E3	—	40	Medium	ENB	Very high	Narrow
			235 E2	30	30	Medium	ENB	High	Narrow
			537 E2	100	46	Medium	ENB	High	NA
			TS 13/84	—	30	Medium	ENB	High	NA
			TS 14/84	—	75	Medium	ENB	High	NA

DSM	Keltan	Terpolymers	520	—	45	Medium	DCPD	Medium	Broad
			720	—	57	Medium	DCPD	Medium	Broad
			520 x 58	50	40	Medium	DCPD	Medium	Broad
			480 x 100	100	34	High	DCPD	Medium	Broad
			540	—	40	Medium	ENB	Medium	Broad
		Tetrapolymers	312	—	31	Low	ENB/DCPD	High	Broad
			512	—	37	Low	ENB/DCPD	High	Broad
			578	—	46	High	ENB/DCPD	High	Broad
			712	—	50	Medium	ENB/DCPD	Medium	Broad
			778	—	58	High	ENB/DCPD	High	Broad
		Terpolymers	740	—	60	Medium	DCPD	Low	Narrow
		Tetrapolymers	812	—	67	Low	ENB/DCPD	High	Broad
		Terpolymers	4802	—	73	Low	ENB	Medium	Narrow
			802	—	64	Low	ENB	Medium	Broad
		Tetrapolymers	512 x 50	50	33	Low	ENB/DCPD	High	Broad
		Terpolymers	700 x 15	15	60	High	ENB	Medium	Narrow
			808	—	81	High	ENB	Medium	Medium
		Tetrapolymers	738	—	32	High	ENB/DCPD	High	Narrow
			514	—	40	Medium	ENB/DCPD	Very high	Broad
			714	—	58	Medium	ENB/DCPD	Very high	Broad
			DR 90	—	36	Medium	ENB/DCPD	Very high	Broad
		Terpolymers	4703	—	56	Low	ENB	High	Narrow
			509 x 100	100	40	High	ENB	High	Broad
Polysar	Polysar EP	Copolymers	306	—	20	Medium	—	—	Narrow
			405	—	22	Low	—	—	Narrow
			807	—	52	High	—	—	Narrow
		Terpolymers	P 227	—	12	High	ENB	Low	Narrow
			345	—	20	Medium	ENB	Medium	Narrow
			346	—	18	Medium	ENB	Medium	Narrow
			545	—	27	Low	ENB	Medium	Narrow

Table B.18 Summary of Solid EP and EPDM Worldwide Products[a]

Manufacturer	Trade name	Type elastomer	Grade designation	Oil content (phr)	Mooney viscosity (1′ + 8′) at 127°C	Ethylene content	Diene type	Diene content	Molecular weight distribution classification
			965	—	90	Low	ENB	High	Narrow
			6463	50	50	Medium	ENB	Medium	Narrow
			5465	100	55	Medium	ENB	Medium	Narrow
			585	—	32	Medium	ENB	Very high	Narrow
			5875	100	44	High	ENB	Very high	Narrow
DuPont	Nordel	Terpolymers	1320	—	18	Low	1,4-HD	Low	Narrow
			2522	—	21	Medium	1,4-HD	Medium	Narrow
			2722	—	21	Very high	1,4-HD	Medium	Narrow
			1040	—	35	Low	1,4-HD	Low	Very broad
			1440	—	33	Low	1,4-HD	Medium	Very broad
			1145	—	38	Medium	1,4-HD	Low	Narrow
			2744	—	40	High	1,4-HD	Medium	Very broad
			1660	—	52	Medium	1,4-HD	Medium	Narrow
			1070	—	62	Low	1,4-HD	Low	Very broad
			1070E	50	26	Low	1,4-HD	Low	Very broad
			1470	—	62	Low	1,4-HD	Medium	Very broad
			2670	—	54	High	1,4-HD	Medium	Narrow
Copolymer	Epsyn	Copolymers	4006	—	40	Medium	—	—	Narrow
		Tetrapolymers	3007	—	35	Medium	ENB/VNB	Very low	NA
			2308	—	23	High	ENB/VNB	Low	Narrow
			2506	—	25	Medium	ENB/VNB	Medium	Medium
			P 337	30	35	High	ENB/VNB	Medium	Narrow
			P 558	50	25	High	ENB/VNB	Medium	Medium

		Terpolymers	5009	—	50	High	VNB	Very low	Narrow
			4506	—	35	Low	VNB	Low	Medium
			40A	—	38	Low	ENB	Low	Medium
			5508	—	55	High	ENB	Medium	Narrow
			5509	—	50	Very high	ENB	Medium	Narrow
			5206	—	50	Medium	ENB	Low	Medium
			7506	—	62	Low	ENB	Medium	Broad
			70 A	—	66	Low	ENB	Low	Narrow
			N 597 (P597)	100	50	50	Medium	ENB	Medium
Narrow				N 557 (P557)	50	Medium	ENB	Medium	Narrow
			4986	—	45	Medium	ENB	High	Narrow
			55	—	50	Low	ENB	High	Narrow
			N 997	100	50	Medium	ENB	High	Narrow
Uniroyal	Royalene	Terpolymers	301T	—	31	Medium	DCPD	Medium	Medium
			375	—	48	High	DCPD	Medium	Medium
			359	—	53	Low	DCPD	Medium	Medium
			400	100	36	Medium	DCPD	High	High
			X2753	—	40	Low	ENB	Low	Broad
			X2794	—	25	Low	ENB	Medium	Broad
			521	—	25	Low	ENB	Medium	Medium
			501	—	30	Low	ENB	Medium	Narrow
			580HT	—	33	Low	ENB	Low	Medium
			512	—	52	Medium	ENB	Medium	Medium
			X2817	—	50	Low	ENB	Low	Broad
			502	—	53	Low	ENB	Medium	Narrow
			552	—	50	High	ENB	Medium	Narrow
			X2859	—	53	Low	ENB	Medium	Broad
			539	—	68	High	ENB	Medium	Broad
			611	40	24	High	ENB	High	Medium
			622	40	37	High	ENB	Medium	Narrow

Table B.18 Summary of Solid EP and EPDM Worldwide Products[a]

Manufacturer	Trade name	Type elastomer	Grade designation	Oil content (phr)	Mooney viscosity (1′ + 8′) at 127°C	Ethylene content	Diene type	Diene content	Molecular weight distribution classification
			X2899	75	37	High	ENB	Medium	NA
			X2935	25	43	Medium	ENB	Low	Broad
			505	—	42	Low	ENB	High	Broad
			509	—	57	High	ENB	High	Broad
			525	—	60	Low	ENB	High	Medium
			X2914	75	60	High	ENB	High	Medium
Japan Synthetic Rubber Co.	JSR	Copolymers	EP 01P	—	10	High	—	—	Very narrow
			EP 02P	—	12	High	—	—	Narrow
			EP 07P	—	32	High	—	—	Narrow
			EP 11	—	21	Low	—	—	Very broad
			911P	—	10	Very high	—	—	Very narrow
			912P	—	6	High	—	—	Very narrow
		Terpolymers	EP 75F	—	50	Medium	DCPD	High	Medium
			EP 86	—	25	Medium	DCPD	Medium	Broad
			EP 87	—	31	Medium	DCPD	Low	Broad
			7001DE	100	40	Medium	DCPD	Low	Very broad
			EP 21	—	20	Medium	ENB	High	Medium
			EP 22	—	22	Low	ENB	Medium	Broad
			EP 24	—	35	Low	ENB	Medium	Broad
			EP 27	—	65	Low	ENB	Medium	Medium
			EP 43	—	26	Low	ENB	Low	Broad
			EP 51	—	19	High	ENB	Medium	Broad
			EP 57C	—	58	High	ENB	Medium	Medium
			EP 93	—	28	Low	ENB	Low	Narrow
			EP 96	50	58	High	ENB	High	Medium
			EP 25	—	49	Medium	ENB	Medium	Broad
			EP 98	75	63	High	ENB	Medium	Narrow

			EP 103	—	80	Low	ENB	Medium	Narrow
			EP 33	—	22	Low	ENB	High	Broad
			EP 35	—	56	Low	ENB	High	NA
			EP 37C	—	55	Low	ENB	High	Broad
			EP 65	—	34	Low	ENB	High	Medium
Sumitomo Chemical Co.	Esprene	Terpolymer	301	—	30	High	DCPD	NA	Broad
			305	—	35	High	DCPD	NA	Broad
			400	100	39	High	DCPD	NA	Broad
			501A	—	24	Low	ENB	Medium	Broad
			507	—	35	Low	ENB	Low	Broad
			522	—	50	Low	ENB	Medium	Broad
			502	—	50	Low	ENB	Medium	Narrow
			512F	—	52	High	ENB	Medium	Narrow
			532	—	65	Low	ENB	Medium	Medium
			601F	70	52	Medium	ENB	Medium	Narrow
			600F	100	34	High	ENB	Medium	Narrow
			505A	—	26	Medium	ENB	Very high	Broad
			505	—	40	Medium	ENB	Very high	Broad
			606	40	47	High	ENB	High	Medium
Mitsui Chemical Co.	Mitsui	Copolymer Terpolymers	0045	—	17	Low	—	—	Broad
			1035	—	21	Medium	DCPD	NA	Broad
			1045	—	21	Medium	DCPD	NA	Broad
			1070	—	35	Medium	DCPD	NA	Broad
			1071	—	45	Medium	DCPD	Medium	Broad
			3045	—	19	Medium	ENB	Medium	Broad
			3070	—	38	Medium	ENB	Medium	Narrow
			3091	—	50	Medium	ENB	Medium	Broad
			3075E	40	47	High	ENB	Medium	Narrow
			X-3092P	—	50	High	ENB	Medium	Narrow
			4021	—	11	Medium	ENB	High	Broad
			4045	—	21	Medium	ENB	High	Broad
			4070	—	36	Medium	ENB	High	Broad

[a]These data for typical properties of EP polymers are either as measured or as advertised by respective manufacturers. This table is not intended to be definitive either in terms of the total grade slate or the specific data reported for each producer. Note that the molecular weight distribution data are based on a qualitative comparison of GPC curves. Mooney viscosities are reported for final product form (i.e., in the case of oil-extended rubbers, the viscosity is that of the EP plus oil.