11

Nonmetallic Materials

TYPICAL PROPERTY RANGES FOR PLASTICS

Thermosets[a]	Specific Gravity	Tensile Strength		Modulus of Elast., Tension		Impact Strength Izod[c]		Max use no Load		HDT at 254 psi[d]		Chemical Resistance(e)					
		ksi	MPa	10^2 ksi	10^2 MPa	ft-lb	J	°F	°C	°F	°C	Weather res	Weak acid	Strong acid	Weak alkali	Strong alkali	Solvents
Alkyds																	
Glass filled	2.12–2.15	4–9.5	(28–66)	20–28	(138–193)	0.6–10	(0.8–14)	450	(230)	400–500	(200–260)	R	A	A	A	A	A
Mineral filled	1.60–2.30	3–9	(21–62)	5–30	(34–207)	0.3–0.5	(0.4–0.7)	300–450	(150–230)	350–500	(180–260)	R	R	A	A	A	D
Asbestos filled	1.65	4.5–7	(31–48)	–	–	0.4–0.5	(0.6–0.7)	450	(230)	315	(160)	R	R	S	R	R	S
Syn. fiber filled	1.24–2.10	4.5–7	(31–48)	20	(138)	0.5–4.5	(0.7–6.1)	300–430	(150–220)	245–430	(120–220)	R	R	S	R	A	S
Alkyl diglycol carbonate	1.30–1.40	5–6	(34–41)	3.0	(21)	0.2–0.4	(0.3–0.5)	212	(100)	140–190	(60–90)	R	R	A[k]	R	R-S	R
Diallyl pythalates																	
Glass filled	1.61–1.78	6–11	(41–76)	14–22	(97–152)	0.4–15	(0.5–20)	300–400	(150–200)	330–540	(165–280)	R	R	S	R-S	S	R
Mineral filled	1.65–1.68	5–9	(34–62)	12–22	(83–152)	0.3–0.5	(0.4–1)	300–400	(150–200)	320–540	(160–280)	R	R	S	R-S	S	R
Asbestos filled	1.55–1.65	7–8	(48–55)	12–22	(83–152)	0.4–0.5	(0.5–0.7)	300–400	(150–200)	320–540	(160–280)	R	R	S	R-S	S	R
Epoxies (bis A)																	
No filler	1.06–1.40	4–13	(28–90)	2.15–5.2	(15–36)	0.2–1.0	(0.3–1.4)	250–500	(120–260)	115–500	(45–260)		R	A	R	S	R-S
Graphite fiber	1.37–1.38	185-200	(1280–1380)	118–120	(814–827)	–	–	–	–	–	–		R	R	R	R	R-S
Mineral filled	1.6–2.0	5–15	(34–103)	–	–	0.3–0.4	(0.4–0.5)	300–500	(150–260)	250–500	(120–260)	S	R	R	R	R	R-S
Glass filled	1.7–2.0	10–30	(69–207)	30	(207)	10–30	(14–41)	300–500	(150–260)	250–500	(120–260)	S	R	R-S	R	R	R-S
No filler	1.12–1.24	5–11	(34–76)	2.15–5.2	(15–36)	0.3–0.7	(0.4–0.9)	400–500	(200–260)	450–500	(230–260)	R	R	R	R	R	R

Thermosets[a]	Specific Gravity	Tensile Strength		Modulus of Elast., Tension		Impact Strength Izod[c]		Max use (no Load)		HDT at 254 psi[d]		Chemical Resistance(e)					
		ksi	MPa	10^2 ksi	10^2 MPa	ft-lb	J	˚F	˚C	˚F	˚C	Weather res	Weak acid	Strong acid	Weak alkali	Strong alkali	Solvents
Epoxies (novolac)																	
No filter	1.12–1.24	5-11	(34–76)	2.15–5.2	(15–36)	0.3–0.7	(0.4–0.9)	400–500	(200–260)	450–500	(230–260)	R	R	R	R	R	R
Epoxies (cycloaliphatic)																	
No filler	1.12–1.18	10-17.5	(69–121)	5–7	(34–48)	–	–	480–550	(250–290)	500–550	(260–290)	R	R	R-A	R	R-A	R
Melamines																	
Cellulose filled	1.45–1.52	5–9	(34–62)	11	(76)	0.2–0.4	(0.3–0.5)	250	(120)	270	(130)	S	R-S	D	R	D	R
Flock filled	1.50–1.55	7–9	(48-62)	–	–	0.4–0.5	(0.5–0.7)	250	(120)	270	(130)	S	R-S	D	R	D	R-S
Asbestos filled	1.70–2.0	5–7	(34–48)	20	(138)	0.3–0.4	(0.4–0.5)	250–400	(120-200)	265	(130)	S	R-S	D	S	S	R
Fabric filled	1.5	8–11	(55–76)	14–16	(97–110)	0.6–1.0	(0.8–1.4)	250	(120)	310	(150)	S	R	D	R	A	R-S
Glass filled	1.8–2.0	5–10	(34–69)	24	(165)	0.6–18	(0.8–24)	300–400	(150-200)	400	(200)	S	R	D	R	R-S	R
Phenolics																	
Woodflour filled	1.34–1.45	5–9	(34-62)	8–17	(55–117)	0.2–0.6	(0.3–0.8)	300–350	(150–180)	300–370	(150–190)	S	R-S	S-D	S-D	A	R-S
Asbestos filled	1.45–2.00	4.5–7.5	(31–52)	10–30	(69–207)	0.2–0.4	(0.3–0.5)	350–500	(180–260)	300–500	(150–260)	S	R-S	S-D	S-D	A	R-S
Mica filled	1.65–1.92	5.5–7	(38–48)	25–50	(172–345)	0.3–0.4	(0.4–0.5)	250-300	(120–150)	300-350	(150–180)	S	R-S	S-D	S-D	A	R-S
Glass filled	1.69–1.95	5–18	(34–124)	19-33	(131–228)	0.3–18	(0.4–24)	350–550	(180–290)	300–600	(150–320)	S	R-S	S-D	S-D	A	R-S
Fabric filled	1.36–1.43	3–9	(21–62)	9–14	(62–97)	0.8–8	(1.1–11)	220–250	(100–120)	250–330	(120–170)	S	R-S	S-D	S-D	A	R-S
Polybutadienes Very high vinyl																	
(no filler)	1.00	8	(55)	2	(14)	1.1	(1.5)	500	(260)	–	–	S	R	R	R	R	R

Thermosets[a]	Specific Gravity	Tensile Strength ksi	Tensile Strength MPa	Modulus of Elast., Tension 10^2 ksi	Modulus of Elast., Tension 10^2 MPa	Impact Strength Izod[c] ft-lb	Impact Strength Izod[c] J	Max use no Load °F	Max use no Load °C	HDT at 254 psi[d] °F	HDT at 254 psi[d] °C	Weather res	Chemical Resistance(e) Weak acid	Strong acid	Weak alkali	Strong alkali	Solvents
Polyesters																	
Glass filled BMC	1.7–2.3	4–10	(28–69)	16–25	(110–172)	1.5–16	(2.0–22)	300–350	(150–180)	400–450	(200-230)	R-E	R-A	S-A	S-A	S-D	A-D
Glass filled SMC	1.7–2.1	8–20	(55–138)	16–25	(110–172)	8–22	(11–30)	300–350	(150–180)	400–450	(200-230)	R-E	R-A	S-A	S-A	S-D	A-D
Glass cloth reinf.	1.3–2.1	25–50	(172-345)	19–45	(131–310)	5–30	(7–41)	300–350	(150–180)	400–450	(200-230)	R-E	R-A	S-A	S-A	S-D	A-D
Glass filled	1.7–2.0	4–6.5	(28–45)	10–15	(69–103)	3–15	(4–20)	600	(320)	600	(320)	R-S	R-S	R-S	S	S-A	R-A
Mineral filled	1.8–2.8	4–6	(28–41)	13–18	(90–124)	0.3–0.4	(0.4–0.5)	600	(320)	600	(320)	R-S	R-S	R-S	S	S-A	R-A
Ureas																	
Cellulose filled	1.47–1.52	5.5–13	(38–90)	10–15	(69–103)	0.2–0.4	(0.3–0.5)	170	(80)	260–290	(130–140)	S	R-S	A-D	S-A	D	R-S
Urethanes																	
No filler	1.1–1.5	0.2–10	(1–69)	1–10	(7–69)	5-NB	(7)	190–250	(90–120)	–	–	R-S	S	A	S	S-A	R-S

Thermoplastics		Specific Gravity	Tensile Strength		Modulus of Elast., Tension		Impact Strength Izod[c]		Max use Temp. (no Load)		Max use no Load		HDT at 254 psi[d]		Weather res	Chemical Resistance(e)				
			ksi	MPa	10^2 ksi	10^2 MPa	ft-lb	J	°F	°C	°F	°C	°F	°C		Weak acid	Strong acid	Weak alkali	Strong alkali	Solvents
ABS	GP	1.05–1.07	5.9	(41)	3.1	(21)	6	(8)	160–200	(70–90)	210–225	(100–110)	190–206	(90–95)	R-E	R	A[k]	R	R	A[m] R
	Hi. imp.	1.01–1.06	4.8	(33)	2.4	(17)	7.5	(10)	140–210	(60–100)	210–225	(100–110)	188–211	(85– 100)	R-E	R	A[k]	R	R	A[m] R
	Ht. res.	1.06–1.08	7.4	(51)	3.9	(27)	2.2	(30)	190–230	(90–110)	225–252	(110–120)	226–240	(110–115)	R-E	R	A[k]	R	R	A[m] R
	Trans.	1.07	5.6	(39)	2.9	(20)	5.3	(7.1)	130	(55)	180	(80)	165	(75)	R-E	R	A[k]	R	R	A[m] R
		1.20	6.0	(41)	3.2	(22)	2.5	(3.4)	130–180	(55–80)	210–220	(100–105)	195	(90)	R-E	R	A[k]	R	R	A[m] R
Acetals	Homo	1.42	10	(69)	5.2	(36)	1.4	(1.9)	195	(90)	338	(170)	255	(125)	R(j)	R	A	R	A-D	R
	Copol	1.41	8.8	(61)	4.1	(28)	1.2–1.6	(1.6–2.2)	212	(100)	316	(160)	230	(110)	R(j)	R	A	R	R	R
Acrylics	GP	1.11–1.19	5.6– 11.0	(39– 76)	2.25 4.65	(16– 32)	0.3–2.3	(0.4–3.1)	130–230	(55–110)	175–225	(80–110)	165–210	(75– 100)	R	R	A[k]	R	A	A[m] R
	Hi. imp.	1.12–1.16	5.8– 8.0	(40– 55)	2.3– 3.3	(16– 23)	0.8–2.3	(1.1–3.1)	140–195	(60–90)	180–205	(80–95)	165–190	(75– 90)	R	R	A[k]	R	R	A[m] R
		1.21–1.28	8.0– 12.5	(55– 86)	3.5– 4.8	(24– 33)	0.3–0.4	(0.4–0.5)	125–200	(50–90)	170–200	(75–95)	155–205	(70– 95)	R	R	A[k]	R	A	A[m] R
	Cast	1.18–1.28	9.0– 12.5	(62– 86)	3.7– 5.0	(26– 34)	0.4–1.5	(0.5–2.0)	140–200	(60–90)	165–235	(75–115)	160–215	(70– 100)	R	R	A[k]	R	A	A[m] R
	Multi polymer	1.09–1.14	6–8	(41–55)	3.1–4.3	(21–30)	1–3	(1–4)	165–175	(75–80)	–	–	185–195	(85–90)	E	R	A[k]	R	S	A[m]

Thermoplastics		Specific Gravity	Tensile Strength ksi	Tensile Strength MPa	Modulus of Elast., Tension 10^2 ksi	Modulus of Elast., Tension 10^2 MPa	Impact Strength Izod[c] ft-lb	Impact Strength Izod[c] J	Max use Temp. no Load °F	Max use Temp. no Load °C	Max use (no Load) °F	Max use (no Load) °C	HDT at 254 psi[d] °F	HDT at 254 psi[d] °C	Chemical Resistance(e) Weather res	Weak acid	Strong acid	Weak alkali	Strong alkali	Solvents
Cellulosics	Acetate	1.23–1.34	3.0–8.0	(21–55)	1.05–2.55	(7–18)	1.1–6.8	(1.5–9)	140–220	(60–105)	120–209	(50–100)	111–195	(45–90)	S	S	D	S	D	D-S
	Butyrate	1.15–1.22	3.0–6.9	(21–48)	0.7–1.8	(5–12)	3.0–10.0	(4–14)	140–220	(60–105)	130–227	(55–110)	113–202	(45–95)	S	S	D	S	D	D-S
Cellulosics	E. cellulose	1.10–1.17	3–8	(21–55)	0.5–3.5	(3–24)	1.7–7.0	(2.3–9.5)	115–185	(45–85)	– 190	–	115–	(45–90)	S	S	D	R	S	D
	Nitrate	1.35–1.40	7–8	(48–55)	1.9–2.2	(13–15)	5–7	(7–9)	140	(60)	– 160	–	140–	(60–70)	E	S	D	S	D	D
	Propionate	1.19–1.22	4.0–6.5	(28–45)	1.1–1.8	(8–12)	1.7–9.4	(2.3–13)	155–220	(70–105)	147–250 111–228	(65–120)		(45–110)	S	S	D	S	D	D-S
Ch. polyether		1.4	5.4	(37)	1.5	(10)	0.4	(0.5)	290	(140)	285	(140)	–	–	R-S	R	A[k]	R	R	R
Eth. copolymers	EEA	0.93	2.0	(14)	0.05	(0.3)	NB	–	190	(90)	–	–	–	–	S	R	A[k]	R	R	A-D
EVA		0.94	3.6	(25)	0.02–0.12	(0.14–0.8)	NB	–	–	–	140–147	(60–65)	93	(35)	S	R	A	R	R	A-D
Fluoropolymers	FEP	2.14–2.17	2.5–3.9	(17–27)	0.5–0.7	(3–5)	NB	–	400	(208)	158	(70)	–	–	R	R	R	R	R	R
	PTFE	2.1–2.3	1.4	(7–28)	0.38–0.65	(2.6–4.5)	2.5–4.0	(3.4–5.4)	550	(290)	250	(120)	–	–	R	R	R	R	R	R
CTFE		2.10–2.15	4.6–5.7	(32–39)	1.8–2.0	(12–14)	3.5–3.6	(4.7–4.9)	350–390	(180–200)	256	(125)	–	–	R	R	R	R	R	S(m)
PVF2		1.77	7.2	(50)	1.7	(12)	3.8	(5.2)	300	(150)	300	(150)	195	(90)	S	R	A[l]	R	R	R

Thermoplastics		Specific Gravity	Tensile Strength ksi	Tensile Strength MPa	Modulus of Elast., Tension 10^2 ksi	Modulus of Elast., Tension 10^2 MPa	Impact Strength Izod[c] ft-lb	Impact Strength Izod[c] J	Max use Temp no Load ˚F	Max use Temp no Load ˚C	Max use no Load ˚F	Max use no Load ˚C	HDT at 254 psi[d] ˚F	HDT at 254 psi[d] ˚C	Weather res	Chemical Resistance(e) Weak acid	Strong acid	Weak alkali	Strong alkali	Solvents
ETFE & ECTFE		1.68–1.70	6.5–70.	(45–48)	2–2.5	(14–17)	NB	–	300	(150)	220	(105)	160	(70)	R	R	R	R	R	R
Methylpentene		0.83	3.3–3.6	(23–25)	1.3–1.9	(10–13)	0.95–3.8	(1.3–5.2)	275	(135)	-	-	-	-	E	R	A[l]	R	R	A
Nylons	6/6	1.13–1.15	9–12	(62–83)	3.85	(27)	2.0	(2.7)	180–300	(80–150)	360–470	(180–240)	150–220	(65–105)	R	R	A	R	R	R-D[o]
	6	1.14	12.5	(86)	–	–	1.2	(1.6)	180–250	(80–120)	300–365	(150–185)	140–155	(60–70)	R	R	A	R	R	R-A[o]
	6/10	1.07	7.1	(49)	2.8	(19)	1.6	(2.2)	180	(80)	300	(150)	–	–	R	R	A	R	R	R-A[o]
	8	1.09	3.9	(27)	–	–	> 16	(> 22)							R	R	A	R	R	R-A[o]
	12	1.01	6.5–8.5	(45–59)	1.7–2.1	(12–14)	1.2–4.2	(1.6–5.7)	175–260	(80–125)	–	–	120–130	(50–55)	R	R	A	R	R	R-A[o]
	Copolymers	1.08–1.14	7.5–11.0	(52–76)	–	–	1.5–19	(2–26)	180–250	(80–120)	–	–	130–350	(55–180)	R	R	A	R	R	R-A[o]
Polyesters	PET	1.37	10.4	(72)	–	–	0.8	(1.1)	175	(80)	240	(115)	185	(85)	R	R	A[k]	R	A	R-A[o]
	PBT	1.31	8.0–8.2	(55–57)	3.6	(25)	1.2–1.3	(1.6–1.8)	280	(140)	310	(155)	130	(55)	R	R	R	R	A	R
	PTMT	1.31	8.2	(57)	–	–	1.0	(1.4)	270	(130)	302	(150)	122	(50)	R	R	R	R	A	R
	Copol.	1.2	7.3	(50)	–	–	1.0	(1.4)	–	–	–	–	154	(70)	–	–	–	–	–	–
Polyaryl ether		1.14	7.5	(52)	3.2	(22)	10	(14)	250	(120)	320	(160)	300	(150)	E	R	R	R	R	A

Thermoplastics		Specific Gravity	Tensile Strength ksi	Tensile Strength MPa	Modulus of Elast., Tension 10^2 ksi	Modulus of Elast., Tension 10^2 MPa	Impact Strength Izod(c) ft-lb	Impact Strength Izod(c) J	Max use Temp no Load ˚F	Max use Temp no Load ˚C	Max use no Load ˚F	Max use no Load ˚C	HDT at 254 psi(d) ˚F	HDT at 254 psi(d) ˚C	Weather res	Chemical Resistance(e) Weak acid	Strong acid	Weak alkali	Strong alkali	Solvents
Polyaryl sulfone		1.36	13	(90)	3.7	(26)	2	(2.7)	500	(260)	–	–	525	(275)	Darkens	R	R	R	R	R
Polybutylene		0.910	3.8	(26)	0.26	(1.8)	NB	–	225	(105)	215	(100)	130	(55)	E	R	A(k)	R	R	–
Polycarbonate		1.2	9	(62)	3.45	(24)	12–16	(16–22)	250	(120)	270–290	(130–145)	265–285	(130–140)	R	R	A(k)	A	A	A
PC/ABS		1.14	8.2	(57)	3.7	(26)	10	(14)	220	(105)	235	(115)	220	(105)	R-E	R	A(k)	R	S	A
Polyetheylenes	LD	0.91–9.93	0.9–2.5	(6–17)	0.20–0.27	(1.4–1.9)	NB	–	180–212	(80–100)	100–120	(40–50)	90–105	(30–40)	E	R	A(k)	R	R	R
	HD	0.95–0.96	2.9–5.4	(20–37)	–	–	0.4–14	(0.5–19)	175–250	(80–120)	140–190	(60–90)	110–130	(45–55)	E	R	R-A(k)	R	R	R
	HMW	0.945	2.5	(17)	1	(7)	NB	–	–	–	155–180	(70–80)	105–180	(40–80)	E	R	A(k)	R	R	R
Ionomer		0.94–0.95	3.4–4.5	(23–31)	0.3–0.7	(2–5)	6–NB	(8–	160–180	(70–80)	110	(45)	100–120	(40–50)	E	A	A(k)	R	R	R
Phenylene oxide based mtls.		1.06–1.10	7.8–9.6	(54–66)	3.5–3.8	(24–26)	5.0	(68)	175–220	(80–105)	230–280	(110–140)	212–265	(100–130)	R	R	R	R	R	R-A
Polyphenylene sulfide		1.34	10	(69)	4.8	(33)	0.3	(0.4)	500	(260)	-	-	278	(135)	R	R	A(k)	R	R	R
Polyimide		1.43	5–7.5	(34–52)	5.4	(37)	5–7	(7–9)	500	(260)	-	-	680	(360)	-	R	R	A	A	R
Polypropylenes	GP	0.90–0.91	4.8–5.5	(33–38)	1.6–2.2	(11–15)	0.4–2.2	(0.5–3.0)	225–300	(105–150)	200–230	(95–110)	125–140	(50–60)	E	R	A(k)	R	R	R

Thermoplastics	Specific Gravity	ensile Strength ksi	MPa	Modulus of Elast., Tension 10^2 ksi	10^2 MPa	Impact Strength Izod[c] ft-lb	J	Max use Temp no Load ˚F	˚C	Max use no Load ˚F	˚C	HDT at 254 psi[d] ˚F	˚C	Chemical Resistance(e) Weather res	Weak acid	Strong acid	Weak alkali	Strong alkali	Solvents
Hi. imp.	0.90–0.91	3–5	(21–34)	1.3 12	(9)	1.5–	(2–16)	200–250	(95–120)	160–200	(70–95)	120–135	(50–60)	E	R	A[k]	R	R	A
Propylene copolymer	0.91	4	(28)	1.0–1.7	(7–12)	1.1	(1.5)	190–240	(90–115)	185–230	(85–110)	115–140	(45–60)	E	R	A[k]	R	R	R
Polystyrenes GP	1.04–1.07	6.0–7.3	(41–50)	4.5	(31)	0.3	(0.4)	150–170	(65–80)	–	–	180–220	(80–105)	S	R	A[k]	R	R	D
Hi. imp.	1.04–1.07	2.8–4.6	(20–32)	2.9–4.0	(20–28)	0.7–1.0	(0.9–1.4)	140–175	(60–80)	–	–	175–210	(80–100)	S	R	A[k]	R	R	D
Polysulfone	1.24	10.2	(70)	3.6	(25)	1.2	(1.6)	300	(150)	360	(180)	345	(175)	S	R	R	R	R	R-A
Polyurethanes	1.11–1.25	4.5–8.4	(31–58)	0.1–3.5	(0.7–24)	NB	–	190	(90)	–	–	–	–	R-S	S-D	S-D	S-D	S-D	R
Vinyl Rigid	1.3–1.5	5–8	(34–55)	3.5	(21–34)	0.5–20	(0.7–27)	150–175	(65–80)	135–180	(60–80)	130–175	(55–80)	R	R	R-S	R	R	R-A
Vinyl Flexible	1.2–1.7	1.4	(7–28)	-	-	0.5–20	(0.7–27)	140–175	(60–80)	–	–	–	–	S	R	R-S	R	R	R-A
Rigid CPVC	1.49–1.58	7.5–9.0	(52–62)	3.6–4.7	(25–32)	1.0–5.6	(1.4–7.6)	230 245	(110) 120)	215–235	(100–115)	200–	(95–	R	R	R	R	R	R
PVC/acrylic	1.30–1.35	5.5–6.5	(38–45)	2.75–3.35	(19–23)	15	(20)	–	–	180	(80)	170	(80)	R	R	S	R	R	A
PVC/ABS	1.10–1.21	2.6–6.0	(18–41)	0.8–3.4	(6–23)	10–15	(14–20)	–	–	–	–	–	–	S	R	R-S	R	R	R-D
SAN	1.08	10–12	(69–83)	5.0–5.6	(34–39)	0.4–0.5	(0.5–0.7)	140–200	(60–95)	–	–	190–220	(90–105)	S-E	R	A	R	R	A

Polyethylene may stress crack in HF service.
(a) All values at room temperature unless otherwise listed. [b]Per ASTM. [c]Notched samples. [d]Heat deflection temperature. [e]Ac is acid and Al is alkali; R is resistant; A is attacked; S is slight effects; E is embrittles and D is decomposes. [j]Chalks slightly. [k]By oxidizing acids. [l]By fuming sulfuric. [m]By ketones, esters, and chlorinated and aromatic hydrocarbons. [n]Halogenated solvents cause swelling. [o]Dissolved by phenols and formic acid.
Source: Berins, Plastics Engineering Handbook of the Society of the Plastics Industry Inc., 5th ed., 1991, Kluwer Academic Publishers.

PROPERTIES OF ELASTOMERS

Property	NR Natural Rubber (Cis- polyisoprene)	SBR Butadiene- styrene (GR-S)	IR Synth etic (Polyisoprene)	COX Butadiene- Acrylo- nitrile (Nitrile)	CR Chloroprene (Neoprene)	ITR Butyl (Isobutylene- isoprene)	BR Polybuta- diene	T Poly- sulfide	Silicone (Poly- silox- ane)
Physical Properties:									
Specific gravity (ASTM D792)	0.93	0.91	0.93	0.98	1.25	0.90	0.91	1.35	1.1–1.6
Thermal conductivity Btu/(h)(ft.^{2})(˚F/ft.) (ASTM C 177)	0.082	0.143	0.082	0.143	0.112	0.053	–	–	0.13
Coefficient of thermal expansion (cubical), 10^{-5} per ˚F (ASTM D 696)	37	37	–	39	34	32	37.5	–	45
Electrical insulation	Good	Good	Good	Fair	Fair	Good	Good	Fair	Excellent
Flame resistance	Poor	Poor	Poor	Poor	Good	Poor	Poor	Poor	Good
Min. recommended service temp. ˚F	−60	−60	−60	−60	−40	−50	−150	−60	−178
Max. recommended service temp. ˚F	180	180	180	300	240	300	200	250	600
Mechanical Properties									
Tensile strength, lb./in.^{2}:									
Pure gum (ASTM D 412)	2,500–3,500	200–300	2,500–3,500	500–900	3,000–4,000	2,500–3,000	200–1,000	250–400	600–1,300
Black (ASTM D412)	3,500–4,500	2,500–3,500	3,500–4,500	3,000–4,500	3,000–4,000	2,500–3,000	2,000–3,000	1,000	–
Elongation, % Pure gum (ASTM D 412)	750–850	400–600	–	300–700	800–900	750–950	400–1,000	450–650	100–500
Black (ASTM D412)	550–650	500–600	300–700	300–650	500–600	650–850	450–600	150–450	–
Hardness (durometer)	A30–90	A40–90	A40–80	A40–95	A20–95	A40–90	A40–90	A40–85	A30–90

Property	NR Natural Rubber (Cis- polyisoprene)	SBR Butadiene- styrene (GR-S)	IR Synth etic (Polyisoprene)	COX Butadiene- Acrylo-nitrile (Nitrile)	CR Chloroprene (Neoprene)	ITR Butyl (Isobutylene-isoprene)	BR Polybuta-diene	T Poly- sulfide	Silicone (Poly- silox-ane)
Pure gum (ASTM D 412)	2,500–3,500	200–300	2,500–3,500	500–900	3,000–4,000	2,500–3,000	200–1,000	250–400	600–1,300
Black (ASTM D 412)	3,500–4,500	2,500–3,500	3,500–4,500	3,000–4,500	3,000–4,000	2,500–3,000	2,000–3,000	1,000	-
Elongation, % Pure gum (ASTM D 412)	750–850	400–600	-	300–700	800–900	750–950	400–1,000	450–650	100–500
Black (ASTM D412)	550–650	500–600	300–700	300–650	500–600	650–850	450–600	150–450	-
Hardness (durometer)	A30–90	A40–90	A40–80	A40–95	A20–95	A40–90	A40–90	A40–85	A30–90
Mechanical Properties									
Rebound:Cold	Excellent	Good	Excellent	Good	Very good	Bad	Excellent	Good	Very good
Hot	Excellent	Good	Excellent	Good	Very good	Very good	Excellent	Good	Very good
Tear resistance	Excellent	Fair	Excellent	Good	Fair to good	Good	Fair	Poor	Fair
Abrasion resistance	Excellent	Good to excellent	Excellent	Good to excellent	Good	Good to excellent	Excellent	Poor	Poor
Chemical Resistance:									
Sunlight aging	Poor	Poor	Fair	Poor	Very good	Very good	Poor	Very	Excellent
Oxidation	Good	Good	Excellent	Good	Excellent E	Excellent	Good	Very good	Excellent
Heat aging	Good	Very good	Good	Excellent	xcellent	Excellent	Good	Fair	Excellent
Solvents:									
Aliphatic hydrocarbons	Poor	Poor	Poor	Excellent	Good	Poor	Poor	Excellent	Fair
Aromatic hydrocarbons	Poor	Poor	Poor	Good	Fair	Poor	Poor	Excellent	Poor
Oxygenated, alcohols	Good	Good	Good	Good	Very good	Very good	–	Very good	Excellent
Oil, Gasoline	Poor	Poor	Poor	Excellent	Good	Poor	Poor	Excellent	Poor
Animal, vegetable oils	Poor to good	Poor to good	–	Excellent	Excellent	Excellent	Poor to good	Excellent	Excellent
Acids:									
Dilute	Fair to good	Fair to good	Fair to good	Good	Excellent	Excellent	–	Good	Very good
Concentrated	Fair to good	Fair to good	Fair to good	Good	Good	Excellent	–	Good	Good
Permeability to gases	Low	Low	Low	Very low	Low	Very low	Low	Very low	High
Water-swell resistance	Fair	Excellent	Excellent	Excellent	Fair to Excellent	Excellent	Excellent	Excellent	Excellent

PROPERTIES OF ELASTOMERS

Property	ECO, CO Epichlorohydrin Homopolymer and Copolymer	Fluorosilicone	EPDM Ethyiene Propylene	CSM Chloro-Sulfonated Polyethylene	FPM Fluorocarbon Elastomers
Physical Properties:					
Specific gravity	1.32–1.49	1.4	0.86	1.11–1.26	1.4–1.95
Thermal conductivity, Btu/(h)(ft.^{2})(˚F/ft.)	–	0.13	–	0.065	0.13
Coefficient of thermal expansion, 10^{-5} / ˚F	–	45	–	27	8.8
Flame resistance	Fair	Poor	Poor	Good	Excellent
Colorability	Good	Good	Excellent	Excellent	Good
Mechanical Properties:					
Hardness (Shore A)	30–95	40–70	30–90	45–95	65–90
Tensile strength, 1,000 lb./in.^{2}					
Pure gum	–	1	< 1	4	< 2
Reinforced	2–3	< 2	0.8–3.2	1.5–2.5	1.5–3
Reinforced	320–350	200–400	200–600	250–500	100–450
Resilience	Poor to excellent	Good to fair	Good	Good	Fair
resistance	Very good	–	Good	Fair to good	Good to excellent
Hysteresis resistance	Good	Good	Good	Good	Good
resistance	Very good	Good	Good	Good	Good
Slow rate	Very good	Good	Good	Good	Good
Fast rate	Good	Good	Good	Good	Good
Tear strength	Good	Fair	Poor to fair	Fair to good	Poor to fair
Abrasion resistance	Fair to good	Poor	Good	Excellent	Good
Electrical Properties					
Dielectric strength	Fair	Good	Excellent	Excellent	Good
Electrical insulation:	Fair	Good	Very good	Good	Fair to good
Thermal Properties:					
Service temp. ˚F:					
Min for continuous use					
Max for continuous	−15 to −80	−90	−60	−40	−10
use	300	400	< 350	< 325	< 500

PROPERTIES OF ELASTOMERS

Property	ECO, CO Epichlorohydrin Homopolymer and Copolymer	Fluorosilicone	EPDM Ethylene Propylene	CSM Chloro-Sulfonated Polyethylene	FPM Fluorocarbon Elastomers
Corrosion Resistance:					
Weather	Excellent	Excellent	Excellent	Excellent	Excellent
Oxidation	Very good	Excellent	Excellent	Excellent	Outstanding
Ozone	Good to excellent	Excellent	Excellent	Excellent	Excellent
Radiation	–	Good	Excellent	Fair to Good	Fair to Good
Water	Good	Excellent	Good to Good excellent	Good	
Acids	Good	Very good to excellent	Good to excellent	Excellent	Good to excellent
Alkalies	Good	Very good	Good to excellent	Excellent	Poor to good
Aliphatic hydrocarbons	Excellent	Excellent	Poor	Fair	Excellent
Aromatic hydrocarbons	Very good	Excellent	Fair	Poor to fair	Excellent
Halogenated hydrocarbons	Good	–	Poor	Poor to fair	Good
Alcohol	Good	–	Good		Very good
Excellent Synthetic lubricants (diester)	Fair to good	Excellent	Poor to fair	Poor	Fair to good
Hydraulic fluids:					
Silicates	Very good	Excellent	Fair to good	Good	Good
Phosphates	Poor to fair	Excellent	Good to excellent	Poor to fair	Poor

Source: C.H. Harper, H*andbook of Plastics & Elastomers,* 4th ed. (New York, NY, USA: McGraw-Hill, 2002), Table 35. Reprinted with permission from The McGraw-Hill Companies.

PROPERTIES OF SELECTED CHEMICALLY REACTIVE ADHESIVES

Property	Epoxy	Polyurethane	Modified Acrylic	Cyanoacrylate	Anaerobic
Substrates bonded	Most	Most smooth, nonporous	Most smooth, nonporous	Most nonporous metals or plastics	Metals, glass, thermosets
Service temperature range, ˚C (˚F)	−55 to 121 (−67 to 250)	−157 to 79 (−250 to 175)	−73 to 121 (−100 to 250)	−55 to 79 (−67 to 175)	−55 to 149 (−67 to 300)
Impact resistance	Poor	Excellent	Good	Poor	Fair
Tensile shear strength, MPa (ksi)	15.4(2.20)	15.4(2.20)	25.9(3.70)	18.9(2.70)	17.5(2.50)
T-peel strength, N/m (lbf/in.)	<525(3)	14,000(80)	5,250(30)	<525(3)	1,750(10)
Heat cure or mixing required	Yes	Yes	No	No	No
Solvent resistance	Excellent	Good	Good	Good	Excellent
Moisture resistance	Excellent	Fair	Good	Poor	Good
Gap limitation, mm (in.)	None	None	0.762(0.030)	0.254(0.010)	0.635 (0.025)
Odor	Mild	Mild	Strong	Moderate	Mild
Toxicity	Moderate	Moderate	Moderate	Low	Low
Flammability	Low	Low	High	Low	Low

Source: GEM 2001, "Guide to Engineering Materials: Advanced Materials and Processes" (Materials Park, OH, USA: ASM International, 2000), p. 162. Reprinted with permission from ASM International.

.

PROPERTIES OF HOT-MELT ADHESIVES

Property	Ethylene/Vinyl Acetate and Polyolefin Homopolymers and Copolymers	Polyvinyl Acetate	Polyurethane	Polyamide Polyamides	Aromatic Copolymer	Polyamide
Brookfield viscosity, Pa-s	1–30	1.6–10	2	0.5–7.5	11	2.2
Viscosity test temperature, ˚C (˚F)	204 (400)	121 (250)	104 (220)	204 (400)	230 (446)	204 (400)
Softening temperature, ˚C (˚F)	99–139	–	–	93–154 (200–310)	–	129–140 (265–285)
Application temperature, ˚C (˚F)	–	121–177 (250–350)	–	–	–	–
Service temperature range ˚C (˚F)	−34–80 (−30–176)	−1–120 (30–248)	–	−40–185 (−40–365)	–	–
Relative cost(a)	Lowest	Low to medium	Medium to high	High	High	High
Bonding substrates	Paper, wood, selected thermoplastics, selected metals, selected glasses	Paper, wood, leather, glass, selected plastics, selected metals	Plastics	Wood, leather, selected, plastics, selected metals	Selected metals, selected plastics	Selected metals, selected plastics
Applications	Bookbinding, packaging, toys, automotive, furniture, electronics	Tray forming, packaging, binding, sealing cases and cartons, bottle labels, cans, jars	Laminates	Packaging, electronics, furniture, footwear	Packaging, electronics binding	Electronics, packaging, binding

[a]Relative to other hot-melt adhesives.

Source: GEM 2001, "Guide to Engineering Materials: Advanced Materials and Processes" (Materials Park, OH, USA: ASM International, 2000), p. 162. Reprinted with permission from ASM International.

OXYGEN AND WATER PERMEABILITY IN PLASTIC FILMS

Plastic	Permeability to O_2 cm³-mil/100 in.²/ 24 hr. 25 °C ASTM D1434	Rate of H_2O Vapor Trans. g-mil/100 in.²/ 24 hr. 38 °C ASTM E96
Acrylonitrite-Butadiene-Styrene (ABS)	50–70	-
Ethylene-Chlorotrifluoroethylene Copolymer	25	0.6
Ethylene-Tetrofluoroethylene Copolymer	100	1.7
Fluorinated Ethylene-Propylene Copolymer	750	0.4
Polyvinyl Fluoride	3	3.2
Polycarbonate	300	11
Polyester (PE Terephthalate)	3–6	1.0–1.3
Nylon 6/6	5	3–8
Nylon 11	34	0.32–0.85
Nylon 12	52–92	0.07
Polyethylene, low dens.	500	1.0–1.5
Polyethylene, med. dens.	250–535	0.7
Polyethylene, high dens.	185	0.3
Polyimide	25	5.4
Polypropylene	150–240	0.7
Polystyrene	350	7–10
Polysulfone	230	18
Vinyl Chloride-Acetate Copolymer (Non-plasticized)	15–20	4
Vinyl Chloride-Acetate Copolymer (Plasticized)	20–150	5–8
Vinylidene Chloride-Vinyl Chloride Copolymer	0.8–6.9	0.2–0.6
Polyvinyl Chloride-(Non-Plasticized)	5–20[a]	0.9–5.1
Polyvinyl Chloride-(Plasticized)	2–4,000	5–30
Polyurethane Elastomer	75–327	40–75

[a]50% R. H.

Source: Adapted from J. Agranoff, *Modern Plastics Encyclopedia* 1985-1986 (New York: NY, USA: McGraw-Hill, 1985), pp. 481–485.

DIMENSIONS OF POLYETHYLENE LINE PIPE (API)

(All Dimensions are in Inches) (inches × 25.40 = mm)

		Minimum Wall Thickness								
Nominal Pipe Size	Outside Diameter	SDR 32.5	SDR 26	SDR 21	SDR 17	SDR 13.5	SDR 11	SDR 9	SDR 7.3	SDR 7
1/2	0.840	–	–	0.062	0.062	0.062	0.076	0.083	0.115	–
3/4	1.050	–	–	0.062	0.062	0.078	0.095	0.117	0.144	–
1	1.315	–	–	0.062	0.077	0.097	0.119	0.146	0.180	–
1 1/4	1.660	–	–	0.079	0.098	0.123	0.151	0.184	0.227	–
1 1/2	1.900	–	–	0.090	0.112	0.141	0.173	0.211	0.260	–
2	2.375	–	–	0.113	0.140	0.176	0.216	0.264	0.325	–
3	3.500	–	–	0.167	0.206	0.259	0.318	0.389	0.479	0.500
4	4.500	–	–	0.214	0.264	0.333	0.409	0.500	0.616	0.643
5	5.563	–	–	0.265	0.328	0.413	0.506	0.618	0.762	0.795
6	6.625	0.204	0.255	0.316	0.390	0.491	0.603	0.736	0.908	0.946
8	8.625	0.265	0.332	0.410	0.508	0.639	0.785	0.985	1.182	1.232
10	10.750	0.331	0.413	0.511	0.633	0.797	0.978	1.194	1.473	1.536
12	12.750	0.392	0.490	0.608	0.745	0.945	1.160	1.417	1.747	1.821

See API Spec 15LE for dimensions of pipe sizes 14–36 in.

Source: Some material gathered from API Spec 941 "Specification for Polyethylene Line Pipe (PE)," 3rd ed. (Washington DC, USA: American Petroleum Institute, 1995).

POLYETHYLENE LINE PIPE (API)

Mechanical Properties

Property	Method of Test ASTM	Minimum Strength psi	MPa
Short-Term Hydrostatic Hoop Strength	D1599*	2,520	17.4
Long-Term Hydrostatic Hoop Strength (PE2406, 3406)	D1598	1,320	9.1
(PE3408)		1,600	11.0
Elevated Temperature, Hydrostatic Hoop Strength	D1598	(see table below)	

*Ring Tensile ASTM D2290 may be used as alternate on sizes above 4" OD.

Source: Some material gathered from API Spec 941 "Specification for Polyethylene Line Pipe (PE)," 3rd ed. (Washington DC, USA: American Petroleum Institute, 1995).

80 °C (176 °F) Sustained Pressure Requirements for Water Pipe

Pipe Test Category	Base Resin Melt Index, D1238 (g/10 min)	Base Resin Density, D1505 (g/cc)	Minimum Average Hours to Failure S=725 psi (5 MPa)	S=580 psi (4 MPa)	S=435 psi (3 MPa)
C1	<0.05	0.941–0.948	100	200	-
C2	<0.05	0.935–0.940	100	200	-
C3	0.05–0.25	0.941–0.948	60	150	-
C4	0.05–0.25	0.935–0.940	60	150	-
C5	>0.25	0.941–0.948	45	100	-
C6	>0.25	0.935–0.940	45	100	-
C7	>0.50	0.926–0.940	-	80	150

DIMENSIONS OF POLY (VINYL CHLORIDE) AND CHLORINATED POLY (VINYL CHLORIDE) LINE PIPE (API)

(All Dimensions are in Inches) (inches × 25.40 = mm)

Nominal Pipe Size	Outside Diameter	Minimum Wall Thickness							
		Schedule 40	Schedule 80	SDR 32.5	SDR 26	SDR 21	SDR 17	SDR 13.5	SDR 11
1/2	0.840	0.109	0.147	-	-	0.062	0.062	0.062	0.076
3/4	1.050	0.113	0.154	-	-	0.090	0.090	0.090	0.095
1	1.315	0.133	0.179	-	-	0.090	0.090	0.097	0.119
1 1/4	1.660	0.140	0.191	-	-	0.090	0.098	0.123	0.151
1 1/2	1.900	0.145	0.200	-	-	0.090	0.112	0.141	0.173
2	2.375	0.154	0.218	-	-	0.113	0.140	0.176	0.216
2 1/2	2.875	0.203	0.276	-	-	0.137	0.169	0.213	0.261
3	3.500	0.216	0.300	-	-	0.167	0.206	0.259	0.318
3 1/2	4.000	0.226	0.318	-	-	0.190	0.236	0.296	0.363
4	4.500	0.237	0.337	-	-	0.214	0.264	0.333	0.409
5	5.563	0.258	0.375	-	-	0.265	0.328	0.413	0.506
6	6.625	0.280	0.432	0.204	0.255	0.316	0.390	0.491	0.603
8	8.625	0.322	0.500	0.265	0.332	0.410	0.508	0.639	0.785
10	10.750	0.365	0.593	0.331	0.413	0.511	0.633	0.797	0.978
12	12.750	0.406	0.687	0.392	0.490	0.608	0.745	0.945	1.160

Source: Some material gathered from API Spec 15LP "Specification for Thermoplastic Line Pipe (PVC and CPVC)," 6th ed. (Washington DC, USA: American Petroleum Institute, 1987).

PVC AND CPVC LINE PIPE (API)

Mechanical Properties

Property	Method of Test	PVC and CPVC	
		psi	MPa
Short-Term Hydrostatic Hoop Strength, min.	ASTM D1599	6,400	44
Long-Term Hydrostatic Hoop Strength, min.	ASTM D1598	4,200	29
Ring Tensile Strength, min.	ASTM D2513	6,400	44

*Test specimens for long-term hydrostatic hoop strength shall include representative fittings in the center of each specimen. Minimum strength listed is for the 1,000-hour test.

Source: Some material gathered from API Spec 15LP "Specification for Thermoplastic Line Pipe (PVC and CPVC)," 6th ed. (Washington DC, USA: American Petroleum Institute, 1987).

Minimum Impact Strength, ft.-lbs. (Joules) at 32 °F (0–2 °C)

Nominal Pipe Size		Schedules 40 and 80	SDR 17	SDR 21	SDR 26
1/2		16(21.7)			
3/4		20(27.1)			
1		20(27.1)			
1 1/4		20(27.1)	20(27.1)		
1 1/2		30(40.7)	30(40.7)	30(40.7)	
2		40(54.2)	40(54.2)	40(54.7)	40(54.7)
2 1/2		40(54.2)	40(54.2)	40(54.7)	40(54.7)
3		40(54.2)	40(54.2)	40(54.7)	40(54.7)
4		40(54.2)	40(54.2)	40(54.7)	40(54.7)
6		55(74.5)	55(74.5)	55(74.5)	55(74.5)
8		60(81.3)	60(81.3)	60(81.3)	60(81.3)
	Fittings all Sizes and Types	5(6.8)			

Source: ASTM D2444 "Standard Test Method for Determination of the Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight)" (West Conshohocken, PA, USA: ASTM International, 2010).

FIBER REINFORCED PLASTIC THERMOSETTING RESIN LINE PIPE-DIMENSIONS

API Specification

Nominal Size (Inches)	Outside[1] Dia. (Inches)	Inside[2] Dia. (Inches) Minimum
2	2.375	2.00
2 1/2	2.875	2.40
3	3.500	3.00
4	4.500	4.00
6	6.625	5.80
8	8.625	8.20
10	10.750	10.30
12	12.750	11.90
14	(3)	13.50
16	(3)	15.40

Notes:

(1) The outer diameters are applicable to
 (a) Sizes 2” through 5” with 300 psi cyclic pressure ratings.
 (b) Sizes 8” through 12” with 150 psi cyclic pressure ratings.
 (c) All centrifugal cast pipe.
 (d) Other outside diameters shall be permitted by agreement between purchaser and manufacturer.

(2) The minimum inside diameters are applicable to all filament wound pipe with cyclic pressure ratings greater than pipe covered by Note (1).

(3) The minimum inside diameters are applicable to all pressure ratings of 14” and 16” diameter pipe.

Source: Some material gathered from API Specification 15LR “Specification for Low-Pressure Fiberglass Line Pipe,” 5th ed. (Washington DC, USA: American Petroleum Institute, 1986).

Typical Values

Nominal Pipe Size		Pipe OD	Pipe ID	Nominal Wall Thickness*	Pipe Weight
(in.)	(mm)	(in.)	(in.)	(in.)	(lb./ft.)
2	50	2.37	2.09	0.157	0.8
3	80	3.50	3.22	0.157	1.2
4	100	4.50	4.14	0.203	2.0
6	150	6.62	6.26	0.203	3.0
8	200	8.62	8.22	0.226	4.3
10	250	10.75	10.35	0.226	5.4
12	300	12.75	12.35	0.226	6.4

*Determined in accordance with ASTM D2996, "Standard Specification for Filament-Wound 'Fiberglass' (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe."

Source: Ameron (1985).

FIBER REINFORCED PLASTIC THERMOSETTING RESIN LINE PIPE

Typical Physical Properties

Pipe Property	Units	Value	Method ASTM
Thermal conductivity	Btu-in./(h·ft.^{2}·°F)	1.7	C177
Thermal expansion (linear)	10^{-6} in./in./°F	8.5	D696
Flow coefficient	Hazen-Williams	150	-
Absolute roughness	10^{-6}ft.	50	-
Specific gravity	-	1.81	D792
Bore of hardness	Impressor 934-1	65	D2583

Typical Mechanical Properties

Property	Units	Value*	Method ASTM
Tensile strength			
Longitudinal	10^3 psi	25.0	D2105
Circumferential	10^3 psi	50.0	D1599
Tensile modulus			
Longitudinal	10^6 psi	2.0	D2105
Circumferential	10^6 psi	3.0	–
Compressive strength			
Longitudinal	10^3 psi	25.0	–
Compressive modulus			
Longitudinal	10^6 psi	2.0	–
Long-term hydrostatic design basis			
Static	10^3 psi	31.5	D2992(B)
Poisson's ratio**			
v_{yx}	–	0.11	–
v_{xy}	–	0.19	–

*Based on structural wall thickness.

**The first subscript denotes the direction of contraction and the second that of the applied stress.

x denotes longitudinal direction.

y denotes circumferential direction.

Source: Ameron (1985).

TYPES OF PORTLAND CEMENT

Type **Non-Air-Entraining**

I. For general concrete construction when special properties specified for the other types are not required. When no type is indicated, it is assumed to be Type I.

II. For general concrete construction exposed to moderate sulfate action or where moderate heat of hydration is required.

III. For construction when high early strength is required.

IV. For construction when a low heat of hydration is required. This type is not generally carried in stock.

V. For construction when high sulfate resistance is required. This type is not generally carried in stock.

Air-Entraining

IA. Same as corresponding Types I, II, and III of non-air-entraining cement, but imparting to the

IIA. concrete properties of greatly improved resistance to (1) severe weathering, and (2) the

IIIA. deleterious effect of applications of sodium or calcium salts to pavement surfaces for snow and ice removal.

CHEMICAL REQUIREMENTS FOR PORTLAND CEMENTS*

Cement Type	I and IA	II and IIA	III and IIIA	IV	V
Silicon dioxide (SiO_2), min, %	…	20.0	…	…	…
Aluminum oxide (Al_2O_3), max,%	…	6.0	…	…	…
Ferric oxide (Fe_2O_3), max, %	…	6.0	…	6.5	…
Magnesium oxide (MgO), max, %	6.0	6.0	6.0	6.0	6.0
Sulfur trioxide (SO_3), max, %					
When (C_3A) is 8% or less	3.0	3.0	3.5	2.3	2.3
When (C_3A) is more than 8%	3.5		4.5		
Loss on ignition, max, %	3.0	3.0	3.0	2.5	3.0
Insoluble residue, max, %	0.75	0.75	0.75	0.75	0.75
Tricalcium silicate (C_3S) max, %	…	…	…	35	…
Dicalcium silicate (C_2S) min, %	…	…	…	40	…
Tricalcium aluminate (C_3A) max, %	…	8	15	7	5
Tetracalcium aluminoferrite plus twice the tricalcium aluminate ($C_4AF + 2(C_3A)$), or solid solution ($C_4AF + C_2F$), as applicable, max, %	…	…	…	…	25

OPTIONAL CHEMICAL REQUIREMENTS

Cement Type	I and IA	II and IIA	III and IIIA	IV	V	Remarks
Tricalcium aluminate (C_3A), max, %	…	…	8	…	…	for moderate sulfate resistance
Tricalcium aluminate (C_3A), max, %	…	…	5	…	…	for high sulfate resistance
Sum of tricalcium silicate and tricalcium aluminate, max, %	…	58	…	…	…	for moderate heat of hydration
Alkalies ($Na_2O + 0.658K_2O$), max, %	0.60	0.60	0.60	0.60	0.60	low-alkali cement

The expressing of chemical limitations by means of calculated assumed compounds does not necessarily mean that the oxides are actually or entirely present as such compounds. When expressing compounds, C = CaO, S = SiO_2, A = $Al2O_3$, F = Fe_2O_3. For example, $C_3A = 3CaO{\cdot}Al_2O_3$.

*Summarized from ASTM C150, "Standard Specification for Portland Cement." For additional details see the current edition of that standard.

HYDRAULIC CEMENTS

Some typical properties of mortars (1 Cements 3 Sand- Water/Cement: 0.32)	Portland Cement	High-Alumina Cement
Specific gravity	2.2	2.2
Tensile strength, MPa*	3.5–4.1	4.0–4.4
Compressive strength, MPa*	38–50	68–70
Modulus of elasticity, MPa	14,100–15,200	
Linear coeff. of thermal expansion/°C	about 11×10^{-6}	
Maximum working temperature, °C	Above about 100 °C, decrease in tensile and compressive strength. However, useful in concrete up to 300–400 °C depending on composition and preparation of the concrete.	used in refractory concrete

*After hardening for about one month in water.

Chemical Resistance	Portland Cement	High-Alumina Cement
Water	+	+
Acids	minimum pH 6.5	minimum pH 5.5
Phenol	–	+
Alkalis	+	5% NaOH:–
Salt solutions:		
sodium chloride	+	+
sodium sulfate 0.07%	+	
sodium sulfate 0.7%	+	
sodium sulfate 2% or	–	
more calcium chloride 5%	–	–
magnesium chloride 1%	+	5–15%:+
Hydrocarbons		
aliphatic	+	+
aromatic	+	+
chlorinated	+	+
Alcohols	–	+
Esters	+	+
Ketones	+	+

High-alumina cement has a normal setting time, but shows extremely rapid hardening and development of high strength (24 hrs.) as compared with Portland cement. Concrete to be used in seawater is made with blast furnace cement.
+ Resistant – Notresistant

CHEMICAL RESISTANT MORTARS AND GROUTS

	Furan	Epoxy	Polyes-ter	Vinyl Ester	Phenolic	Silicate	Sulfur
Density, lb./ft.^{3}	95–120	110–125	100–125	110–125	95–120	130	135
Tensile strength, psi	1,000	1,800	2,300	2,300	1,200	500	600
Flexural strength, psi	2,800	3,800	4,800	4,200	2,800	900	1,300
Compressive strength, psi	8,800	12,000	10,000	10,000	9,000	5,800	8,000
Bond strength, psi	280	*	280	175	280	175	120
Thermal resistance, max F	380	200	225	180	380	2,000	200
Chemical resistance (ASTM C267)							
Acetic Acid, Glacial	R	NR	NR	NR	–	–	NR
Acetone	R	NR	NR	NR	–	–	NR
Chlorine Dioxide Solution	NR	NR	R	R	–	–	R
Chromic Acid, 10%	NR	NR	R	R	–	–	NR
Dichloracetic Acid, 10%	R	NR	R	R	–	–	NR
Ethyl Alcohol	R	R	R	R	–	–	R
Formic Acid, 20%	R	C	C	C	–	–	NR
Gasoline	R	R	R	R	–	–	NR
Hydrochloric Acid, 20%	R	R	R	R	–	–	R
Lactic Acid, 15%	R	C	R	R	–	–	R
Nitric Acid, 20%	NR	NR	R	R	–	–	R
Phosphoric Acid, 30%	R	R	R	R	–	–	R
Sodium Choride	R	R	R	R	–	–	R
odium Hydroxide, 25%	R	R	R	R	–	–	NR
Sodium Hypochlorite, 10%	NR	NR	R	R	–	–	NR
Sulfuric Acid, 20%	R	R	R	R	–	–	R
Trichloroethylene	R	NR	C	C	–	–	NR
Xylene	R	NR	C	C	–	–	NR

R Recommended NR Not Recommended C Conditional

	Furan	Epoxy	Polyester	Vinyl Ester	Phenolic	Silicate	Sulfur
Oxidizing Acids	P	P	E	E	P	E	E
Nonoxidizing Acids	E	E	E	E	E	E	E
Alkali	E	E	G	G	P	P	P
Alkaline Hypochlorite	P	P	E	E	P	P	P
Solvents	E	G	G	G	E	E	P

E Excellent G Good P Poor

*Brick failed

Source: Adapted from A.A. Boova, *Process Industries Corrosion, The Theory and the Practice* (Houston, TX, USA: NACE International, 1986), p. 657.

PROPERTIES OF SELECTED ENGINEERING CERAMICS

Material	Crystal Structure	Theoretical Density, g/cm^3	Hardness, HK or HV, GPa (10^6 psi)	Transverse Rupture Strength, MPa (ksi)	Fracture Toughness, $MPa \cdot \sqrt{m}$ ($ksi \cdot \sqrt{in.}$)	Young's Modulus, GPa (10^6 psi)	Poisson's ratio	Thermal Expansion Coefficient, $10^{-6}/K$	Thermal Conductivity, $W/m \cdot K$
Glass-ceramics	Variable	2.4–5.9	6–7 (0.9–1.0)	70–350 (10–51)	2.4 (2.2)	83–138 (12–20)	0.24	5–17	2.0–5.4[2]
Pyrex glass	Amorphous	2.52	5 (0.7)	69 (10)	0.75 (0.7)	70 (10)	0.2	4.6	1.3[2], 1.7[5]
TiO_2	Rutile tetragonal	4.25	7–11 (1.0–1.6)	69–103 (10–15)	2.5 (2.3)	283 (41)	0.28	9.4	8.8[2]
	Anatase tetragonal	3.84	–	–	–	–	–	–	3.3[6]
	Brookite orthorhombic	4.17	–	–	–	–	–	–	–
Al_2O_3	Hexagonal	3.97	18–23 (2.6–3.3)	76–1034 (40–150)	2.7–4.2 (2.5–3.8)	380 (55)	0.26	7.2–8.6	27.2,[2] 5.8[6]
Cr_2O_3	Hexagonal	5.21	29 (4.2)	>262 (>38)	3.9 (3.5)	>103 (>15)	-	7.5	10–33[7]

Material	Crystal Structure	Theoretical Density, g/cm^3	Hardness, HK or HV, GPa (10^6 psi)	Transverse Rupture Strength, MPa (ksi)	Fracture Toughness, MPa · √m (ksi · √in.)	Young's Modulus, GPa (10^6 psi)	Poisson's ratio	Thermal Expansion Coefficient, 10^{-6}/K	Thermal Conductivity, W/m · K
Mullite	Orthorhombic	2.8	-	185 (27)	2.2 (2.0)	145 (21)	0.25	5.7	5.2[2], 3.3[6]
Partially stabilized ZrO_2	Cubic, monoclinic, tetragonal	5.70–5.75	10–11 (1.5–1.6)	600–700 (87–102)	8–9 (7.3–8.2[8]) 6–6.5 (5.5–5.9[9]) 5 (4.6[10])	205 (30)	0.23	8.9–10.6	1.8–2.2
Fully stabilized ZrO_2	Cubic	5.56–6.1	10–15 (1.5–2.2)	245 (36)	2.8 (2.5)	97–207 (14–30)	0.23–0.32	13.5	1.7[2], 1.9[11]
Plasma sprayed ZrO_2	Cubic, monoclinic, tetragonal	5.6–5.7	-	6–80 (0.9–12)	1.3–3.2 (1.2–2.9)	4812 (7[12])	0.25	7.6–10.5	0.69–2.4
CeO_2	Cubic	7.28	-	-	-	172 (25)	0.27–0.31	13	9.6[2], 1.2[6]
TiB_2	Hexagonal	4.5–4.54	15–45 (1.5–6.5)	700–1,000 (102–145)	6–8 (5.5–7.3)	514–574 (75–83)	0.09–0.13	8.1	65–120[13] 33–80[14] 54–122[15]
TiC	Cubic	4.92	28–35 (4.0–5.1)	241–276 (35–40)	-	430 (62)	0.19	7.4–8.6	33[2], 43[6]

Material	Crystal Structure	Theoretical Density, g/cm^3	Hardness, HK or HV, GPa (10^6 psi)	Transverse Rupture Strength, MPa (ksi)	Fracture Toughness, $MPa \cdot \sqrt{m}$ ($ksi \cdot \sqrt{in.}$)	Young's Modulus, GPa (10^6 psi)	Poisson's ratio	Thermal Expansion Coefficient, $10^{-6}/K$	Thermal Conductivity, $W/m \cdot K$
TaC	Cubic	14.4–14.5	16–24	97–290	-	285	0.24	6.7	32[2], 40[6]
			(2.3–3.5)	(14–42)		(41)			
Cr_3C_2	Orthorhombic	6.70	10–18	49	-	373	-	9.8	19
			(1.5–2.6)	(7.1)		(54)			
Cemented carbides	Variable	5.8–15.2	8–20 (1.2–2.9)	758–3275 (110–475)	5–18 (4.6–16.4)	396–654 (57–95)	0.2–0.29	4.0–8.3	16.3–119
SiC	Alpha, hexagonal	3.21	20–30 (2.9–4.4)	96–520 (14–75)[16]	4.8 (4.4)[16] 2.6–5.0	207–483 (30–70)	0.19	4.3–5.6 21–33[6]	63–155[2]
				250 (36)[17]	(2.4–4.6)[17]				
				230–825	4.8–6.1				
				(33–120)[18]	(4.4–5.6)[18]				
				398–743	4.1–5.0				
				(58–108)[19]	(3.7–4.6)[19]				
	Beta, cubic	3.21	-	-	-	-	-	-	-

Material	Crystal Structure	Theoretical Density, g/cm^3	Hardness, HK or HV, GPa (10^6 psi)	Transverse Rupture Strength, MPa (ksi)	Fracture Toughness, $MPa \cdot \sqrt{m}$ ($ksi \cdot \sqrt{in.}$)	Young's Modulus, GPa (10^6 psi)	Poisson's ratio	Thermal Expansion Coefficient, $10^{-6}/K$	Thermal Conductivity, $W/m \cdot K$
HSiC (CVD)	Beta, cubic	3.21	28–44	1034–1380	5–7 (4.1–6.4)	415–441 (150–200)[13] 2060–2400 (300–350)[20]	0.16 (4.6–6.4)	5.5 (60-64)	121[2] 34.6[11]
						2060–2400 (300–350)[20]	5–7 (4.6–6.4)		
Si3 N4Alpha,	3.18 hexagonal	8–19	414–650	5.3	304 (1.2–2.8)	0.24 (60–94)[21] 700–1000 (100–145)[22] 250–345 (36–50)[23]	3.0 (4.8)[21] 4.1–6.0 (3.7–5.5)[22] 3.6 (3.3)[23]	9–30[2] (44)	
	Beta, hexagonal	3.19	-	-	-	-	-	-	–
TiN	Cubic	5.43–5.44	16–20	-	-	251 (2.3–2.9)	- (36)	8.0 67.8[24]	24[2] 56.9[25]

1. Source: R.L. Lehman "Overview of Ceramic Design and Process Engineering," Engineered Materials Handbook, vol. 4 (Materials Park, OH, USA: ASM International, 1991), p. 30.
2. At 400K, 127 ˚C, 260 ˚F
3. At 1,200K, 927 ˚C, 1,700 ˚F
4. Pyrex is a trademark of Corning Inc., Corning, N Y
5. At 800K, 527 ˚C, 9,280 ˚F
6. At 1,400K, 1,127 ˚C, 2,060 ˚F
7. At 350K, 77 ˚C, 170 ˚F
8. At 293K, 20 ˚C, 70 ˚F
9. At 723K, 450 ˚C, 840 ˚F
10. At 1,073K, 800 ˚C, 1,470 ˚F
11. At 1,600K, 1,327 ˚C, 2,420 ˚F
12. 21 GPa, 3×10^6 psi at 1,373K, 1,100 ˚C, 2,010 ˚F
13. At 300K, 27 ˚C, 80 ˚F
14. At 1,100K, 827 ˚C, 1,520 ˚F
15. At 2,300K, 2027 ˚C, 3,680 ˚F
16. Sintered, at 300K, 27 ˚C, 80 ˚F
17. Sintered, at 1,273K, 1,000 ˚C, 1,830˚F
18. Hot pressed, at 300K, 27 ˚C, 80 ˚F
19. Hot pressed, at 1,273K, 1,000 ˚C, 1,830 ˚F
20. At 1,473K, 1,200 ˚C, 2,190 ˚F
21. Sintered
22. Hot pressed
23. Reaction bonded
24. At 1,773K, 1,500 ˚C, 2730 ˚F
25. At 2,473K, 2,200 ˚C, 3990 ˚F

Source: GEM 2001, "Guide to Engineering Materials: Advanced Materials and Processes" (Materials Park, OH, USA: ASM International, 2000), pp. 159-160. Reprinted with permission from ASM International.

PROPERTIES OF GRAPHITE AND SILICON CARBIDE

	Graphite	Impervious Graphite	Impervious Silicon Carbide
Specific gravity	1.4–1.8	1.75	3.10
Tensile strength, MPa (psi)	3–10 (400–1,400)	18 (2,600)	143 (20,650)
Compressive strength MPa (psi)	14–42 (2,000–6,000)	72 (10,500)	1,000(150,000)
Flexural strength, MPa (psi)	5–21 (750–3,000)	32 (4,700)	–
Modulus of elasticity (× 10^6), MPa (psi)	0.3–12 × 10^4 (0.5–1.8)	1.6 × 10^4 (2.3)	39 × 10^4 (56)
Thermal expansion, mm/mm/˚C (in./in./˚F× 10^{-6})	1.3–3.8 (0.7–2.1)	4.5 (2.5)	3.4 (1.80)
Thermal conductivity, Watts/m,K (Btu/hr./ft.^{2}/˚F/ft.)	85–350 (15–97)	480 (85)	340 (60)
Max. working temp (inert atm) ˚C (˚F)	2,800 (5,000)	180 (350)	2,300 (4,200)
Max. working temp (oxidizing atm) ˚C (˚F)	350 (660)	180 (350)	1,650 (3,000)

Source: Carborundum Abrasives Company.

PROPERTIES OF GLASS AND SILICA

	Pyroceram	96% Silica	Borosilicate	Glass lining
Specific gravity, 25 ˚C (77 ˚ F)	2.60	2.18	2.23	2.56
Water absorption, %	0.00	0.00	0.00	
Gas permeability	Gastight	Gastight	Gastight	
Softening temp., ◦C (◦F)	1,250 (2,282)	1,500 (2,732)	820 (1,508)	
Specific heat, 25 ˚C (77 ˚ F), Joules/kgK (Btu/lb.) (˚F))	775(0.185)	746(0.178)	779(0.186)	
Mean specific heat (25 ˚C– 400 ˚C)	0.230	0.224	0.233	
Thermal conductivity, mean temp. 25 ˚C, Watts/m, K (Btu/(sq. ft.)(hr.)(˚F)/(in.))	3.6(25.2)	-	1.1(7.5)	
Linear thermal expansion, per ˚C x 10^{-6} (per ˚F, (77 ˚ –572 ˚F))	5.8 (3.2)	0.79(0.44)	3.2(1.8)	
Modulus of elasticity, MPa (ksi) × 10^3	119 (17.3)	66(9.6)	66 (9.5)	40–60 (6–9)
Poisson's ratio	0.245	0.17	0.20	
Modulus or rupture, MPa (ksi)	140 (20)	35–63 (5–9)	42–70 (6–10)	
Knoop hardness, 100 g	698	532	481	480
Knoop hardness, 500 g	619	477	442	
Adhesion strength MPa (ksi)	-	-	-	35–70 (5–10)
Max. operating temp., ˚C (˚ F)	-	-	-	260 (500)
Thermal shock resistance, temp. diff., ˚C (˚ F)	-	-	-	152 (305)

PROPERTIES OF HIGH TEMPERATURE REFRACTORIES

Item	Magnesia[1] F	Magnesia[1] C	Mullite F	Mullite C	SiliconStabilized Carbide F	SiliconStabilized Carbide C	Bonded Zirconia F	Bonded Zirconia C	99% Al_2O_3 F	99% Al_2O_3 C
Fusion Point	4,800	2,650	3,300	1,815	–	–	4,700	2,600	3,650	2,010
Use Limit, oxid.	4,170	2,300	3,000	1,650	3,000	1,650	4,400	2,430	3,300	1,815
Modulus of rupture, psi	2,500		1,500		2,000[3]		1,900		2,000	
MPa	17		10			14	13		14	
Moh's hardness[2]	6		6.5			9.6	7		9	
Thermal shock resist.	Poor		Good			Good	Fair		Fair	
Relative Cost	2.8		1			2.1	10		3.1	

(1) Basic refractories have poor resistance to hot acids.

(2) Scale 1 to 10. Talc = 1, low carbon steel = 4, diamond = 10.

(3) At 1,371 °C (2,500 °F).

Source: NACE International Basic Corrosion Course.

TYPICAL PROPERTIES OF CERAMIC BRICKS AND CHEMICAL STONEWARE

Composition	Regular Acid Brick	High Temp. Acid Brick	Chemical Stoneware	Silica Brick
SiO_2	68	66	71	98.–99.6
Al_2O_3	26	28	23	0.2–0.5
Fe_2O_3	1.3	1.3	0.6	0.02–0.3
TiO_2	7.5	1.5	0.9	-
CaO	0.2	0.2	0.4	0.02–0.03
MgO	0.5	0.5	1.1	0.02–0.1
$Na_2O + K_2O + Li_2O$	2.8	2.5	2.3	0.01–0.2
Density, g/cm^3	2.2	2.2	2.3	1.8–2.0
Apparent porosity, %	7–10	6–9	–	7–16
Water absorption, %	4.5–5.0	2.5–3.5	0.5–2.5	3–14
Acid solubility, %w	8.5–10.5	8.-10.5		1–4
Mod. of rupture, ksi	2.5–2.8	3.0–3.2	6–12	0.5–2
Compressive strength, ksi	6–10	7–12	70–80	2–12
MPa	40–70	50–80	500–550	14–80
Mod. of elasticity, ksi (× 10^3)	–	–	4–10	1–5
MPa (× 10^3)	–	–	30–70	7–35
Coefficient of thermal expansion				
in./in./°F (×$^-$6)	–	–	2	0.2–3
mm/mm/°C (× 10^{-6})	–	–	4	0.4–5

Sources: Adapted from W.L. Sheppard, *Corrosion and Chemical Resistant Masonry Materials Handbook* (Saddle River, NJ, USA: Noyes Publication, 1985), and B.J. Moniz, W.I. Pollock, *Process Industries Corrosion-The Theory and Practice* (Houston, TX, USA: NACE International, 1986), p. 644.