

Table 2.1 Summary of Thermal Expansion

Coefficient of Linear Thermal Expansion (CTE), Approximate Ranges at Room Temperature to 100 °C (212 °F), from Lowest to Highest CTE Value

CTE			CTE		
10 ⁻⁶ /K	10 ⁻⁶ /°F	Material	10 ⁻⁶ /K	10 ⁻⁶ /°F	Material
2.6–3.3	1.4–1.8	Pure Silicon (Si)	12	6.5	Structural steel
2.2–6.1	1.2–3.4	Pure Osmium (Os)	11–13	5.9–7.1	Air-hardening medium-alloy cold work tool steel
4.5–4.6	2.5–2.6	Pure Tungsten (W)	11–13	6.2–7.0	High-manganese carbon steel
0.6–8.7	0.3–4.8	Iron-cobalt-nickel alloys	10–14	5.6–7.6	Malleable cast iron
4.8–5.1	2.7–2.8	Pure Molybdenum (Mo)	12	6.6	Mold tool steel
5.6	3.1	Pure Arsenic (As)	8.8–15	4.9–8.4	Nonresulfurized carbon steel
6.0	3.3	Pure Germanium (Ge)	11–14	5.9–7.5	Chromium molybdenum alloy steel
6.1	3.4	Pure Hafnium (Hf)	9.4–15	5.2–8.2	Chromium alloy steel
5.7–7.0	3.2–3.9	Pure Zirconium (Zr)	12–13	6.5–7.0	Molybdenum/molybdenum sulfide alloy steel
6.3–6.6	3.5–3.7	Pure Cerium (Ce)	12	6.8	Chromium vanadium alloy steel
6.2–6.7	3.4–3.7	Pure Rhenium (Re)	11–14	5.9–7.6	Cold work tool steel
6.5	3.6	Pure Tantalum (Ta)	11–14	6.0–7.5	Ductile medium-silicon cast iron
4.9–8.2	2.7–4.6	Pure Chromium (Cr)	7.6–17	4.2–9.4	Nickel with chromium and/or iron, molybdenum
6.8	3.8	Pure Iridium (Ir)	11–14	6.2–7.5	Resulfurized carbon steel
2.0–12	1.1–6.7	Magnetically soft iron alloys	12–13	6.4–7.4	High strength low-alloy steel (HSLA)
7.1	3.9	Pure Technetium (Tc)	4.8–20	2.7–11	Pure Lutetium (Lu)
7.2–7.3	4.0–4.1	Pure Niobium (Nb)	10–15	5.6–8.3	Duplex stainless steel
5.1–9.6	2.8–5.3	Pure Ruthenium (Ru)	9.9–13	5.5–7.3	High strength structural steel
4.5–11	2.5–6.2	Pure Praseodymium (Pr)	9.0–16	5.0–8.9	Pure Promethium (Pm)
7.1–9.7	3.9–5.4	Beta and near beta titanium	12–13	6.5–7.4	Pure Iron (Fe)
8.3–8.5	4.6–4.7	Pure Rhodium (Rh)	11–14	5.9–8.0	Metal matrix composite aluminum
8.3–8.4	4.6–4.7	Pure Vanadium (V)	10–15	5.6–8.6	Cobalt alloys (including Stellite)
5.5–11	3.1–6.3	Zirconium alloys	6.0–20	3.3–11	Pure Yttrium (Y)
8.4–8.6	4.7–4.8	Pure Titanium (Ti)	11–15	6.0–8.5	Gray cast iron
8.6–8.7	4.8–4.8	Mischmetal	9.0–17	5.0–9.6	Precipitation hardening stainless steel
7.6–9.9	4.2–5.5	Unalloyed or low-alloy titanium	13	7.4	Pure Bismuth (Bi)
7.7–10	4.3–5.7	Alpha beta titanium	7.0–20	3.9–11	Pure Holmium (Ho)
4.0–14	2.2–7.8	Molybdenum alloys	11–16	6.1–8.6	Nickel copper
8.8–9.1	4.9–5.1	Pure Platinum (Pt)	13	7.4	Pure Nickel (Ni)
7.6–11	4.2–5.9	Alpha and near alpha titanium	14	7.5	Palladium alloys
9.3–9.6	5.2–5.3	High-chromium gray cast iron	12–14	6.8–7.7	Pure Cobalt (Co)
9.3–9.9	5.2–5.5	Ductile high-chromium cast iron	10–17	5.6–9.6	Cast austenitic stainless steel
9.1–10	5.1–5.6	Pure Gadolinium (Gd)	13–15	7.0–8.2	Gold alloys
8.4–11	4.7–6.3	Pure Antimony (Sb)	8.1–19	4.5–11	High-nickel gray cast iron
8.6–11	4.8–6.3	Maraging steel	14	7.8	Bismuth tin alloys
9.9	5.5	Protactinium (Pa)	7.0–20	3.9–11	Pure Uranium (U)
9.8–10	5.4–5.8	Water-hardening tool steel	14	7.8	Pure Gold (Au)
10–11	5.6–5.9	Molybdenum high-speed tool steel	10–19	5.3–11	Pure Samarium (Sm)
6.8–14	3.8–7.8	Niobium alloys	7.9–21	4.4–12	Pure Erbium (Er)
9.3–12	5.2–6.5	Ferritic stainless steel	13–16	7.0–9.0	Nickel chromium silicon gray cast iron
7.6–14	4.2–7.5	Pure Neodymium (Nd)	14	7.8	Tungsten alloys
11	5.9	Cast ferritic stainless steel	14–15	7.7–8.4	Beryllium alloys
8.9–12	4.9–6.9	Hot work tool steel	12–18	6.7–10	Manganese alloy steel
9.5–12	5.3–6.6	Martensitic stainless steel	10–20	5.6–11	Iron alloys
9.9–12	5.5–6.5	Cast martensitic stainless steel	9.7–19	5.4–11	Proprietary alloy steel
11	6.1	Cermet	15	8.5	White cast iron
10–12	5.6–6.6	Ductile silicon-molybdenum cast iron	12–19	6.7–10	Austenitic cast iron with graphite
10–12	5.6–6.5	Iron carbon alloys	8.8–22	4.9–12	Pure Thulium (Tm)
9.3–12	5.2–6.9	Pure Terbium (Tb)	14–18	7.5–9.8	Wrought copper nickel
9.8–13	5.4–6.9	Cobalt chromium nickel tungsten	13–19	7.0–10	Ductile high-nickel cast iron
10–12	5.8–6.7	High-carbon high-chromium cold work tool steel	4.5–27	2.5–15	Pure Lanthanum (La)
11	6.2	Tungsten high-speed tool steel	16–18	8.8–10	Wrought high copper alloys
8.5–14	4.7–7.8	Commercially pure or low-alloy nickel	17	9.4	Cast high copper alloys
11	6.3	Low-alloy special purpose tool steel	15–19	8.3–11	Wrought bronze
7.1–16	3.9–8.7	Pure Dysprosium (Dy)	17–18	9.2–9.8	Cast copper
9.3–13	5.2–7.2	Nickel molybdenum alloy steel	16–18	9.1–10	Wrought copper
11–12	6.1–6.6	Pure Palladium (Pd)	17	9.6	Cast copper nickel silver
11	6.3	Pure Thorium (Th)	9.8–25	5.4–14	Austenitic stainless steel
11	6.4	Wrought iron	16–19	8.9–11	Cast bronze
10–13	5.7–7.0	Oil-hardening cold work tool steel	16–19	8.9–11	Wrought copper nickel silver
7.6–15	4.2–8.5	Pure Scandium (Sc)	18	10	Pure Barium (Ba)
11–12	6.1–6.8	Pure Beryllium (Be)	18	10	Cast copper nickel
6.3–17	3.5–9.4	Carbide	18	10	Pure Tellurium (Te)
10–13	5.7–7.3	Nickel chromium molybdenum alloy steel	18–20	9.9–11	Silver alloys
11–12	6.1–6.9	Shock-resisting tool steel			

12 / Thermal Properties of Metals

Table 2.1 Summary of Thermal Expansion

Coefficient of Linear Thermal Expansion (CTE), Approximate Ranges at Room Temperature to 100 °C (212 °F), from Lowest to Highest CTE Value

CTE			CTE		
10 ⁻⁶ /K	10 ⁻⁶ /°F	Material	10 ⁻⁶ /K	10 ⁻⁶ /°F	Material
19	11	Pure Silver (Ag)	25–26	14–15	Wrought magnesium aluminum zinc
17–21	9.4–12	Wrought brass	25–26	14–15	Cast magnesium aluminum manganese
16–23	8.9–13	3xx.x series cast aluminum silicon+copper or magnesium	26	15	Cast magnesium rare earth
16–24	8.9–13	2xxx series wrought aluminum copper	17–36	9.2–20	Commercially pure tin
16–24	8.9–13	Zinc copper titanium alloys	25–27	14–15	Commercially pure magnesium
16–24	9.1–13	6xxx series wrought aluminum magnesium silicon	26	15	Pure Ytterbium (Yb)
20	11	Pure Strontium (Sr)	20–33	11–18	Pure Indium (In)
20–21	11–12	Cast brass	25–28	14–16	Lead tin solder
18–24	10–13	1xx.x series commercially pure cast aluminum	27–29	15–16	Commercially pure or low-alloyed lead
20–22	11–12	4xx.x series cast aluminum silicon	28	16	Tin silver
19–23	11–13	2xx.x series cast aluminum copper	23–34	13–19	9xx.x series cast aluminum plus other elements
12–32	6.4–18	Pure Gallium (Ga)	29	16	Pure Lead (Pb)
22	12	Manganese (Mn)	28–30	16–17	Pure Thallium (Tl)
12–22	6.9–12	4xxx series wrought aluminum silicon	26–32	14–18	Magnesium alloys
22	12	Pure Calcium (Ca)	20–40	11–22	Unalloyed or low-alloy zinc
21–24	12–13	7xxx series wrought aluminum zinc	22–40	12–22	5xxx series wrought aluminum magnesium
22–24	12–13	3xxx series wrought aluminum manganese	30–32	17–18	Pure Cadmium (Cd)
23	13	8xx.x series cast aluminum tin	33–35	18–19	Zinc copper
23	13	Unalloyed aluminum ingot	35	19	Pure Europium (Eu)
22–25	12–14	1xxx series commercially pure wrought aluminum	37–49	21–27	Pure Selenium (Se)
23–25	13–14	5xx.x series cast aluminum magnesium	56	31	Pure Lithium (Li)
24–25	13–14	7xx.x series cast aluminum zinc	64	36	Pure Sulfur (S)
21–29	12–16	Tin lead	69–71	38–39	Pure Sodium (Na)
22–28	12–15	Zinc aluminum	83	46	Pure Potassium (K)
23–27	13–15	Zinc copper aluminum	90	50	Pure Rubidium (Rb)
25–26	14–15	Cast magnesium aluminum zinc	14–203	7.8–113	Pure Plutonium (Pu)
25–26	14–15	Pure Magnesium (Mg)	125	70	Pure Phosphorus (P)
			97–291	54–162	Pure Cesium (Cs)

Table 2.2 Coefficient of Linear Thermal Expansion (CTE) of Metals and Alloys

Temperature		Density		CTE		Notes	Reference
°C	°F	kg/m ³	lb/in. ³	10 ⁻⁶ /K	10 ⁻⁶ /°F		
Carbide based material							
71WC-12.5TiC-12TaC-4.5Co, Cobalt-bonded cemented carbide							
RT	RT	12000 u	0.434 d			Medium grain	16
200	390			5.2 u	2.9 d	Medium grain	16
1000	1830			6.5 u	3.6 d	Medium grain	16
72WC-8TiC-11.5TaC-8.5Co, Cobalt-bonded cemented carbide							
RT	RT	12600 u	0.455 d			Medium grain	16
200	390			5.8 u	3.2 d	Medium grain	16
1000	1830			6.8 u	3.8 d	Medium grain	16
75WC-25Co, Cobalt-bonded cemented carbide							
RT	RT	13000 u	0.470 d			Medium grain	16
200	390			6.3 u	3.5 d	Medium grain	16
84WC-16Co, Cobalt-bonded cemented carbide							
RT	RT	13900 u	0.502 d			Fine, coarse grain	16
200	390			5.8 u	3.2 d	Coarse grain	16
1000	1830			7.0 u	3.9 d	Coarse grain	16
90WC-10Co, Cobalt-bonded cemented carbide							
RT	RT	14500 u	0.524 d			Coarse grain	16
RT	RT	14600 u	0.527 d			Fine grain	16
200	390			5.2 u	2.9 d	Coarse grain	16
94WC-6Co, Cobalt-bonded cemented carbide							
RT	RT	15000 u	0.54 d			Fine, medium, coarse grain	16
200	390			4.3 u	2.4 d	Fine, medium, coarse grain	16
1000	1830			5.6 u	3.1 d	Coarse grain	16
1000	1830			5.9 u	3.3 d	Fine grain	16
1000	1830			5.4 u	3.0 d	Medium grain	16
97WC-3Co, Cobalt-bonded cemented carbide							
RT	RT	15300 u	0.553 d			Medium grain	16
200	390			4.0 u	2.2 d	Medium grain	16
Cr₃C₂							
RT	RT	6660 th	0.241 d	10.3 u	5.7 d		16
HfC							
RT	RT	12760 th	0.461 d	6.6 u	3.7 d		16
Mo₂C							
RT	RT	9180 th	0.332 d	7.8 u	4.3 d		16
NbC							
RT	RT	7800 th	0.28 d	6.7 u	3.7 d		16
TaC							
RT	RT	14500 th	0.524 d	6.3 u	3.5 d		16
TiC							
RT	RT	4940 th	0.178 d	7.7 u	4.3 d		16
VC							
RT	RT	5710 th	0.206 d	7.2 u	4.0 d		16
ZrC							
RT	RT	6560 th	0.237 d	6.7 u	3.7 d		16
Cermet							
Cr-Al₂O₃, 77%Cr 23%Al₂O₃, Aluminum oxide cermet							
RT	RT	5900 u	0.21 u				16
25-800	77-1470			8.64 mean	4.80 mean		16
25-1000	75-1830			8.93 mean	4.96 mean		16
25-1315	77-2400			10.35 mean	5.75 mean		16
CrB-Cr-Mo, Boride-base cermet							
RT	RT	6770-7270 u	0.245-0.263 u				16
20-980	68-1800			9.90 mean	5.50 mean		16

RT, room temperature assumed if no temperature given; t, typical; d, derived; u, unstated; min, minimum; max, maximum. See Appendix for abbreviations and references.

14 / Thermal Properties of Metals

Table 2.2 Coefficient of Linear Thermal Expansion (CTE) of Metals and Alloys

Temperature		Density		CTE		Notes	Reference
°C	°F	kg/m ³	lb/in. ³	10 ⁻⁶ /K	10 ⁻⁶ /°F		
Cermet							
CrB-Ni, Boride-base cermet							
RT	RT	6160-6270 u	0.223-0.225 u				16
20-980	68-1800			9.81 mean	5.45 mean		16
TiB2, Boride-base cermet							
RT	RT	4500 u	0.163 u				16
20-760	68-1400			6.39 mean	3.55 mean		16
Type A, Chromium carbide cermet							
RT	RT	7000 u	0.253 u	10.71 mean	5.95 mean		16
Type B, Chromium carbide cermet							
RT	RT	6900 u	0.250 u	11.10 mean	6.17 mean		16
ZrB2, Boride-base cermet							
RT	RT	6100 u	0.221 u				16
20-760	68-1400			7.5 mean	4.17 mean		16
ZrB2-B, Boride-base cermet							
RT	RT	4970-5270 u	0.180-0.191 u				16
20-1205	68-2200			5.76 u	3.20 u		16
Cast Iron, Austenitic with Graphite							
BS 3468-F1, Flake graphite							
RT	RT	7300 u	0.264 d	18.7 u	10.4 d		72
BS 3468-F2, Flake graphite							
RT	RT	7300 u	0.264 d	18.7 u	10.4 d		72
BS 3468-F3, Flake graphite							
RT	RT	7300 u	0.264 d	12.4 u	6.9 d		72
BS 3468-S2, Spheroidal graphite							
RT	RT	7400 u	0.267 d	18.7 u	10.4 d		72
BS 3468-S2B, Spheroidal graphite							
RT	RT	7400 u	0.267 d	18.7 u	10.4 d		72
BS 3468-S2C, Spheroidal graphite							
RT	RT	7400 u	0.267 d	18.4 u	10.2 d		72
BS 3468-S2M, Spheroidal graphite							
RT	RT	7400 u	0.267 d	14.7 u	8.2 d		72
BS 3468-S2W, Spheroidal graphite							
RT	RT	7400 u	0.267 d	18.7 u	10.4 d		72
BS 3468-S3, Spheroidal graphite							
RT	RT	7400 u	0.267 d	12.6 u	7.0 d		72
BS 3468-S5S, Spheroidal graphite							
RT	RT	7600 u	0.275 d	12.1 u	6.7 d		72
BS 3468-S6, Spheroidal graphite							
RT	RT	7300 u	0.264 d	18.2 u	10.1 d		72
Cast Iron, Ductile							
100-70-03							
RT	RT	7110 d	0.257 u				67
20-200	68-390			10.8 d	6.0 u		67
120-90-02							
RT	RT	7110 d	0.257 u				67
20-200	68-390			11.7 d	6.5 u		67
20-26% Ni							
20-200	68-390			4.0-18.9 d	2.2-10.5 u	Austenitic	67
60-40-18							
RT	RT	7110 d	0.257 u				67
20-200	68-390			11.9 d	6.6 u		67

RT, room temperature assumed if no temperature given; t, typical; d, derived; u, unstated; min, minimum; max, maximum. See Appendix for abbreviations and references.

Table 2.2 Coefficient of Linear Thermal Expansion (CTE) of Metals and Alloys

Temperature		Density		CTE		Notes	Reference
°C	°F	kg/m ³	lb/in. ³	10 ⁻⁶ /K	10 ⁻⁶ /°F		
Cast Iron, Ductile							
60-45-10							
20-100	68-212			11.5 d	6.4 u	Ferritic	67
20-200	68-390			11.7-11.9 d	6.5-6.6 u	Ferritic	67
20-600	68-1112			13.5 d	7.5 u	Ferritic	67
80-55-06							
RT	RT	7110 d	0.257 u				67
20-200	68-390			11.0 d	6.1 u		67
80-60-03							
20-100	68-212			11.5 d	6.4 u	Pearlitic	67
20-200	68-390			11.9-12.6 d	6.6-7.0 u	Pearlitic	67
20-300	68-570			12.6 d	7.0 u	Pearlitic	67
20-400	68-750			13.1 d	7.3 u	Pearlitic	67
20-500	68-930			13.3 d	7.4 u	Pearlitic	67
20-600	68-1112			13.5 d	7.5 u	Pearlitic	67
20-700	68-1292			13.9 d	7.7 u	Pearlitic	67
Ferritic ductile iron							
20-100	68-212			11.2 u	6.23 u		15
20-200	68-390			12.2 u	6.78 u		15
20-300	68-570			12.8 u	7.12 u		15
20-400	68-750			13.2 u	7.34 u		15
20-500	68-930			13.5 u	7.51 u		15
20-600	68-1110			13.7 u	7.62 u		15
20-700	68-1290			13.8 u	7.67 u		15
20-760	68-1400			14.8 u	8.23 u		15
20-870	68-1600			15.3 u	8.51 u		15
High-chromium cast iron (ferritic), Heat resistant							
RT	RT	7300-7500 u	0.264-0.271 u				15, 58
21	70			9.3-9.9 u	5.2-5.5 u		15, 58
High-nickel ductile (20% Ni) cast iron, Heat resistant							
RT	RT	7400 u	0.268 u				15, 58
21	70			18.7 u	10.4 u		15, 58
High-nickel ductile (23% Ni) cast iron, Heat resistant							
RT	RT	7400 u	0.268 u				15, 58
21	70			18.4 u	10.2 u		15, 58
High-nickel ductile (30% Ni) cast iron, Heat resistant							
RT	RT	7500 u	0.270 u				15
20-205	68-400			12.6-14.4 u	7.0-8.0 d		15
High-nickel ductile (36% Ni) cast iron, Heat resistant							
RT	RT	7700 u	0.278 u				15
20-205	68-400			7.2 u	4.0 d		15
High-nickel ductile cast iron, Corrosion-resistant							
RT	RT	7400 u	0.267 u				15, 58
21	70			12.6-18.7 u	7.0-10.4 d		15, 58
Medium silicon ductile iron							
RT	RT	7100 u	0.257 u				58, 72
21	70			10.8-13.5 u	6.0-7.5 u		58, 72
Medium-silicon ductile cast iron, Heat resistant							
RT	RT	7100 u	0.257 u				15
21	70			10.8-13.5 u	6.0-7.5 d		15
Ni-resist type D-2							
RT	RT	7418 u	0.268 u				57, 67
RT	RT			17.6 d	9.8 u		67
21-204	70-400			14.4 d	8.0 u		67

RT, room temperature assumed if no temperature given; t, typical; d, derived; u, unstated; min, minimum; max, maximum. See Appendix for abbreviations and references.

16 / Thermal Properties of Metals

Table 2.2 Coefficient of Linear Thermal Expansion (CTE) of Metals and Alloys

Temperature		Density		CTE		Notes	Reference
°C	°F	kg/m ³	lb/in. ³	10 ⁻⁶ /K	10 ⁻⁶ /°F		
Cast Iron, Ductile							
Ni-resist type D-2B							
RT	RT	7474 u	0.270 u				67
20-200	68-390			18.7 d	10.4 u		67
Ni-resist type D-2C							
RT	RT	7418 u	0.268 u				67
20-200	68-390			18.4 d	10.2 u		67
Ni-resist type D-3							
RT	RT	7474 u	0.270 u	9.9 d	5.5 u		67
21-204	70-400			12.6 d	7.0 u		67
Ni-resist type D-4							
RT	RT	7474 u	0.270 u	13.1 d	7.3 u		67
21-204	70-400			18.7 d	10.4 u		67
Ni-resist type D-5							
RT	RT	7695 u	0.278 u	5.0 d	2.8 u		67
Pearlitic ductile iron							
20-100	68-212			10.6 u	5.89 u		15
20-200	68-390			11.7 u	6.51 u		15
20-300	68-570			12.4 u	6.89 u		15
20-400	68-750			13.0 u	7.23 u		15
20-500	68-930			13.3 u	7.39 u		15
20-600	68-1110			13.6 u	7.56 u		15
20-760	68-1400			14.8 u	8.23 u		15
20-870	68-1600			15.3 u	8.51 u		15
Silicon-molybdenum ductile iron							
RT	RT	6850 u	0.247 d	10.0-11.8 u	5.6-6.6 d		72
Cast Iron, Gray							
BS 1452 Grade 150							
RT	RT	7050 u	0.255 d				72
20-200	68-390			11.0 u	6.1 d		72
20-400	68-750			12.5 u	6.9 d		72
BS 1452 Grade 180							
RT	RT	7100 u	0.257 d				72
20-200	68-390			11.0 u	6.1 d		72
20-400	68-750			12.5 u	6.9 d		72
BS 1452 Grade 220							
RT	RT	7150 u	0.258 d				72
20-200	68-390			11.0 u	6.1 d		72
20-400	68-750			12.5 u	6.9 d		72
BS 1452 Grade 250							
RT	RT	7200 u	0.260 d				72
20-200	68-390			11.0 u	6.1 d		72
20-400	68-750			12.5 u	6.9 d		72
BS 1452 Grade 300							
RT	RT	7250 u	0.262 d				72
20-200	68-390			11.0 u	6.1 d		72
20-400	68-750			12.5 u	6.9 d		72
BS 1452 Grade 350							
RT	RT	7300 u	0.264 d				72
20-200	68-390			11.0 u	6.1 d		72
20-400	68-750			12.5 u	6.9 d		72
BS 1452 Grade 400							
RT	RT	7300 u	0.264 d				72
20-200	68-390			15.0 u	8.3 d	Acicular iron	72

RT, room temperature assumed if no temperature given; t, typical; d, derived; u, unstated; min, minimum; max, maximum. See Appendix for abbreviations and references.