APPENDIX C

Material Properties and Uses

Appendix C-1 ***Physical Properties of Common Metals***

Metal	Modulus of Elasticity, *E*		Modulus of Rigidity, *G*		Poisson's Ratio, ν	Unit Weight, w (lb/in.^{3})	Density, ρ (Mg/m^3)	Coefficient of Thermal Expansion, α		Thermal Conductivity		Specific Heat	
	Mpsi	GPa	Mpsi	GPa				10^{-6}/°F	10^{-6}/°C	Btu/h-ft-°F	W/m-°C	Btu/lbm-°F	J/kg-°C
Aluminum alloy	10.4[a]	72	3.9	27	0.32	0.10	2.8	12.0	22	100	173	0.22	920
Beryl. copper	18.5	127	7.2	50	0.29	0.30	8.3	9.3	17	85	147	0.10	420
Brass, Bronze	16	110	6.0	41	0.33	0.31	8.7	10.5	19	45	78	0.10	420
Copper	17.5	121	6.6	46	0.33	0.32	8.9	9.4	17	220	381	0.10	420
Iron, gray cast[b]	15	103	6.0	41	0.26	0.26	7.2	6.4	12	29	50	0.13	540
Magnesium alloy	6.5	45	2.4	17	0.35	0.065	1.8	14.5	26	55	95	0.28	1170
Nickel alloy	30	207	11.5	79	0.30	0.30	8.3	7.0	13	12	21	0.12	500
Steel, carbon	30	207	11.5	79	0.30	0.28	7.7	6.7	12	27	47	0.11	460
Steel, alloy	30	207	11.5	79	0.30	0.28	7.7	6.3	11	22	38	0.11	460
Steel, stainless	27.5	190	10.6	73	0.30	0.28	7.7	8.0	14	12	21	0.11	460
Titanium alloy	16.5	114	6.2	43	0.33	0.16	4.4	4.9	9	7	12	0.12	500
Zinc alloy	12	83	4.5	31	0.33	0.24	6.6	15.0	27	64	111	0.11	460

[a] Values given are representative. Exact values may vary with composition and processing, sometimes greatly.
[b] See Appendix C-3 for more detailed elastic properties of cast irons.
Note: See Appendix C-18 for physical properties of some plastics.

Appendix C-2 *Tensile Properties of Some Metals*

	Ultimate Strength, S_u		Yield Strength, S_y		σ_0[a]			
Material	**ksi**	**MPa**	**ksi**	**MPa**	**ksi**	**MPa**	m[a]	ϵ_{Tf}[a]
Carbon and alloy steels								
1002 A[b]	42	290	19	131	78	538	0.27	1.25
1010 A	44	303	29	200	82	565	0.23	1.20
1018 A	49.5	341	32	221	90	621	0.25	1.05
1020 HR	66	455	42	290	115	793	0.22	0.92
1045 HR	92.5	638	60	414	140	965	0.14	0.58
1212 HR	61.5	424	28	193	110	758	0.24	0.85
4340 HR	151	1041	132	910	210	1448	0.09	0.45
52100 A	167	1151	131	903	210	1448	0.07	0.40
Stainless steels								
302 A	92	634	34	234	210	1448	0.48	1.20
303 A	87	600	35	241	205	1413	0.51	1.16
304 A	83	572	40	276	185	1276	0.45	1.67
440C A	117	807	67	462	180	1241	0.14	0.12
Aluminum alloys								
1100-0	12	83	4.5	31	22	152	0.25	2.30
2024-T4	65	448	43	296	100	690	0.15	0.18
7075-0	34	234	14.3	99	61	421	0.22	0.53
7075-T6	86	593	78	538	128	883	0.13	0.18
Magnesium alloys								
HK31XA-0	25.5	176	19	131	49.5	341	0.22	0.33
HK31XA-H24	36.2	250	31	214	48	331	0.08	0.20
Copper alloys								
90-10 Brass A	36.4	251	8.4	58	83	572	0.46	—
80-20 Brass A	35.8	247	7.2	50	84	579	0.48	—
70-30 Brass A	44	303	10.5	72	105	724	0.52	1.55
Naval Brass A	54.5	376	17	117	125	862	0.48	1.00

[a] Defined in Section 3.4.
[b] A = annealed, HR = hot-rolled.
Note: Values are from single tests and believed typical. Actual values may vary through small differences in composition and processing; hence, some values here do not agree with values in other Appendix C tables.
Source: J. Datsko, *Materials in Design and Manufacturing*, Mallory, Inc., Ann Arbor, Mich. 1977.

Appendix C-3a *Typical Mechanical Properties and Uses of Gray Cast Iron*[a]

ASTM Class[a]	Tensile Strength		Torsional Shear Strength		Compressive Strength		Reversed Bending Fatigue Limit		Brinell Hardness, H_B	Tensile Modulus		Torsional Modulus		Typical Uses
	MPa	ksi[a]	MPa	ksi	MPa	ksi	MPa	ksi		GPa	10^6 psi	GPa	10^6 psi	
20	152	22	179	26	572	83	69	10	156	66 to 97	9.6 to 14.0	27 to 39	3.9 to 5.6	Miscellaneous soft iron castings
25	179	26	220	32	669	97	79	11.5	174	79 to 102	11.5 to 14.8	32 to 41	4.6 to 6.0	Cylinder heads and blocks, housings
30	214	31	276	40	752	109	97	14	210	90 to 113	13.0 to 16.4	36 to 45	5.2 to 6.6	Brake drums, clutch plates, flywheels
35	252	36.5	334	48.5	855	124	110	16	212	100 to 119	14.5 to 17.2	40 to 48	5.8 to 6.9	Heavy-duty brake drums, clutch plates
40	293	42.5	393	57	965	140	128	18.5	235	110 to 138	16.0 to 20.0	44 to 54	6.4 to 7.8	Cylinder liners, camshafts
50	362	52.5	503	73	1130	164	148	21.5	262	130 to 157	18.8 to 22.8	50 to 55	7.2 to 8.0	Special high-strength castings
60	431	62.5	610	88.5	1293	187.5	169	24.5	302	141 to 162	20.4 to 23.5	54 to 59	7.8 to 8.5	Special high-strength castings

[a] Minimum values of S_u (in ksi) are given by the class number.

Appendix C-3b *Mechanical Properties and Typical Uses of Malleable Cast Iron*[a]

Specification Number	Class or Grade	Tensile Strength MPa	Tensile Strength ksi	Yield Strength MPa	Yield Strength ksi	Brinell Hardness, H_B	Elongation[b] (%)	Typical Uses
Ferritic								
ASTM A47, A338; ANSI G48.1; FED QQ-1-666c	32510	345	50	224	32	156 max	10	General purpose at normal and elevated temperatures; good machinability, excellent shock resistance
	35018	365	53	241	35	156 max	18	
ASTM A197	—	276	40	207	30	156 max	5	Pipe flanges, valve parts
Pearlitic and Martensitic								
ASTM A220; ANSI G48.2; MIL-I-11444B	40010	414	60	276	40	149–197	10	General engineering service at normal and elevated temperatures
	45008	448	65	310	45	156–197	8	
	45006	448	65	310	45	156–207	6	
	50005	483	70	345	50	179–229	5	
	60004	552	80	414	60	197–241	4	
	70003	586	85	483	70	217–269	3	
	80002	655	95	552	80	241–285	2	
	90001	724	105	621	90	269–321	1	
Automotive								
ASTM A602; SAE J158	M3210[c]	345	50	224	32	156 max	10	Steering gear housing, mounting brackets
	M4504[d]	448	65	310	45	163–217	4	Compressor crankshafts and hubs
	M5003[d]	517	75	345	50	187–241	3	Parts requiring selective hardening, as gears
	M5503[e]	517	75	379	55	187–241	3	For machinability and improved induction hardening
	M7002[e]	621	90	483	70	229–269	2	Connecting rods, universal joint yokes
	M8501[e]	724	105	586	85	269–302	1	Gears with high strength and good wear resistance

[a] Condensed from *ASM Metals Reference Book*, American Society for Metals, Metals Park, Ohio, 1981.
[b] Minimum in 50 mm (2 in.).
[c] Annealed.
[d] Air quenched and tempered.
[e] Liquid quenched and tempered.

Appendix C-3c *Average Mechanical Properties and Typical Uses of Ductile (Nodular) Iron*

Grade[a]	Brinell Hardness, H_B	Elongation (%) (in 50 mm)	Poisson's Ratio	Tensile Modulus		Typical Uses
				GPa	10^6 psi	
60-40-18	167	15.0	0.29	169	24.5	Valves and fittings for steam and chemicals
65-45-12	167	15.0	0.29	168	24.4	Machine components subject to shock and fatigue
80-55-06	192	11.2	0.31	168	24.4	Crankshafts, gears, rollers
120-90-02	331	1.5	0.28	164	23.8	Pinions, gears, rollers, slides

Grade	Tensile Strength: Ultimate		Tensile Strength: Yield		Compressive Strength: Ultimate		Torsional Strength: Ultimate		Torsional Strength: Yield	
	MPa	10^6 psi	MPa	10^6 psi	MPa	10^6 psi	MPa	10^6 psi	MPa	10^6 psi
60-40-18	461	66.9	329	47.7	359	52.0	472	68.5	195	28.3
65-45-12	464	67.3	332	48.2	362	52.5	475	68.9	297	30.0
80-55-06	559	81.8	362	52.5	386	56.0	504	73.1	193	28.0
120-90-02	974	141.3	864	125.3	920	133.5	875	126.9	492	71.3

[a] The first two sections of grade number indicate minimum values (in ksi) of tensile ultimate and yield strengths.

Source: ASM Metals Reference Book, American Society for Metals, Metals Park, OH, 1981.

Appendix C-4a *Mechanical Properties of Selected Carbon and Alloy Steels*

I: AISI Number[a]	Treatment	Tensile Strength		Yield Strength		Elongation (%)	Reduction in Area (%)	Brinell Hardness, H_B	Izod Impact Strength	
		MPa	ksi	MPa	ksi				J	ft · lb
1015	As-rolled	420.6	61.0	313.7	45.5	39.0	61.0	126	110.5	81.5
	Normalized	424.0	61.5	324.1	47.0	37.0	69.6	121	115.5	85.2
	Annealed	386.1	56.0	284.4	41.3	37.0	69.7	111	115.0	84.8
1020	As-rolled	448.2	65.0	330.9	48.0	36.0	59.0	143	86.8	64.0
	Normalized	441.3	64.0	346.5	50.3	35.8	67.9	131	117.7	86.8
	Annealed	394.7	57.3	294.8	42.8	36.5	66.0	111	123.4	91.0
1030	As-rolled	551.6	80.0	344.7	50.0	32.0	57.0	179	74.6	55.0
	Normalized	520.6	75.5	344.7	50.0	32.0	60.8	149	93.6	69.0
	Annealed	463.7	67.3	341.3	49.5	31.2	57.9	126	69.4	51.2
1040	As-rolled	620.5	90.0	413.7	60.0	25.0	50.0	201	48.8	36.0
	Normalized	589.5	85.5	374.0	54.3	28.0	54.9	170	65.1	48.0
	Annealed	518.8	75.3	353.4	51.3	30.2	57.2	149	44.3	32.7
1050	As-rolled	723.9	105.0	413.7	60.0	20.0	40.0	229	31.2	23.0
	Normalized	748.1	108.5	427.5	62.0	20.0	39.4	217	27.1	20.0
	Annealed	636.0	92.3	365.4	53.0	23.7	39.9	187	16.9	12.5
1095	As-rolled	965.3	140.0	572.3	83.0	9.0	18.0	293	4.1	3.0
	Normalized	1013.5	147.0	499.9	72.5	9.5	13.5	293	5.4	4.0
	Annealed	656.7	95.3	379.2	55.0	13.0	20.6	192	2.7	2.0
1118	As-rolled	521.2	75.6	316.5	45.9	32.0	70.0	149	108.5	80.0
	Normalized	477.8	69.3	319.2	46.3	33.5	65.9	143	103.4	76.3
	Annealed	450.2	65.3	284.8	41.3	34.5	66.8	131	106.4	78.5

Appendix C-4a *(continued)*

I: AISI Number[a]	Treatment	Tensile Strength MPa	Tensile Strength ksi	Yield Strength MPa	Yield Strength ksi	Elongation (%)	Reduction in Area (%)	Brinell Hardness, H_B	Izod Impact Strength J	Izod Impact Strength ft · lb
3140	Normalized	891.5	129.3	599.8	87.0	19.7	57.3	262	53.6	39.5
	Annealed	689.5	100.0	422.6	61.3	24.5	50.8	197	46.4	34.2
4130	Normalized	668.8	97.0	436.4	63.3	25.5	59.5	197	86.4	63.7
	Annealed	560.5	81.3	360.6	52.3	28.2	55.6	156	61.7	45.5
4140	Normalized	1020.4	148.0	655.0	95.0	17.7	46.8	302	22.6	16.7
	Annealed	655.0	95.0	417.1	60.5	25.7	56.9	197	54.5	40.2
4340	Normalized	1279.0	185.5	861.8	125.0	12.2	36.3	363	15.9	11.7
	Annealed	744.6	108.0	472.3	68.5	22.0	49.9	217	51.1	37.7
6150	Normalized	939.8	136.3	615.7	89.3	21.8	61.0	269	35.5	26.2
	Annealed	667.4	96.8	412.3	59.8	23.0	48.4	197	27.4	20.2
8650	Normalized	1023.9	148.5	688.1	99.8	14.0	40.4	302	13.6	10.0
	Annealed	715.7	103.8	386.1	56.0	22.5	46.4	212	29.4	21.7
8740	Normalized	929.4	134.8	606.7	88.0	16.0	47.9	269	17.6	13.0
	Annealed	695.0	100.8	415.8	60.3	22.2	46.4	201	40.0	29.5
9255	Normalized	932.9	135.3	579.2	84.0	19.7	43.4	269	13.6	10.0
	Annealed	774.3	112.3	486.1	70.5	21.7	41.1	229	8.8	6.5

[a] All grades are fine-grained except for those in the 1100 series, which are coarse-grained. Heat-treated specimens were oil-quenched unless otherwise indicated.

Note: Values tabulated are approximate median expectations for 1-in. round sections. Individual test results may differ considerably.

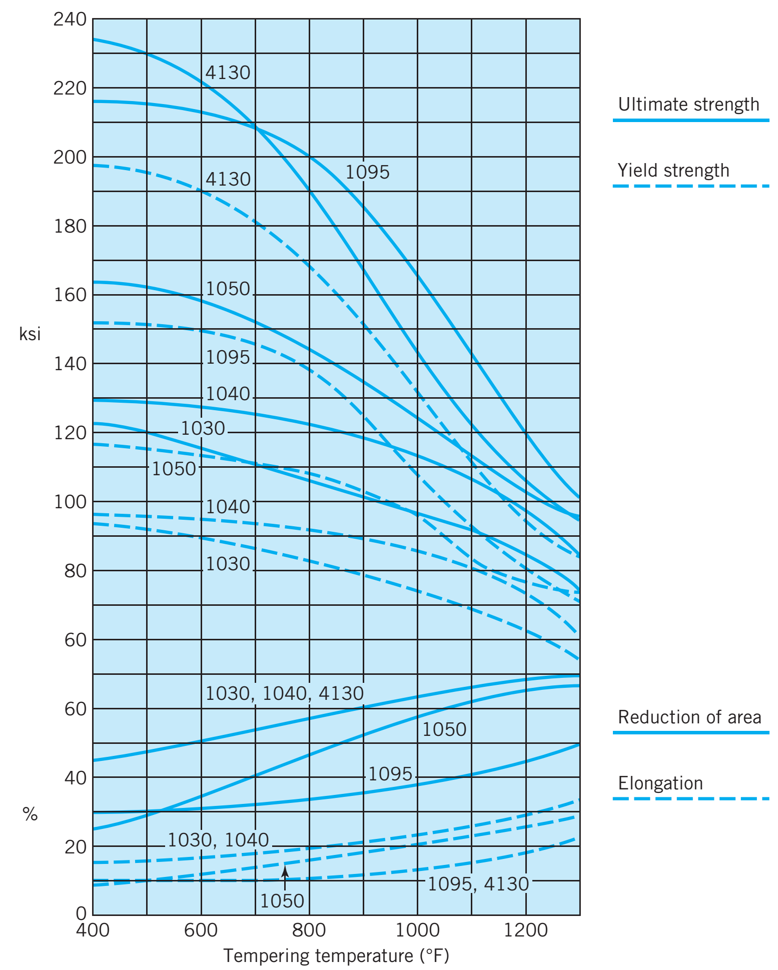
Source: ASM Metals Reference Book, American Society for Metals, Metals Park, Ohio, 1981.

Appendix C-4b *Typical Uses of Plain Carbon Steels*

Carbon (%)	Typical Uses
0.05–0.10	Stampings, rivets, wire, cold-drawn parts
0.10–0.20	Structural shapes, machine parts, carburized parts
0.20–0.30	Gears, shafts, levers, cold-forged parts, welded tubing, carburized parts
0.30–0.40	Shafts, gears, connecting rods, crane hooks, seamless tubing (This and higher hardnesses can be heat-treated.)
0.40–0.50	Gears, shafts, screws, forgings
0.60–0.70	Hard-drawn spring wire, lock washers, locomotive tires
0.70–0.90	Plowshares, shovels, leaf springs, hand tools
0.90–1.20	Springs, knives, drills, taps, milling cutters
1.20–1.40	Files, knives, razors, saws, wire-drawing dies

Appendix C-5a *Properties of Some Water-Quenched and Tempered Steels*

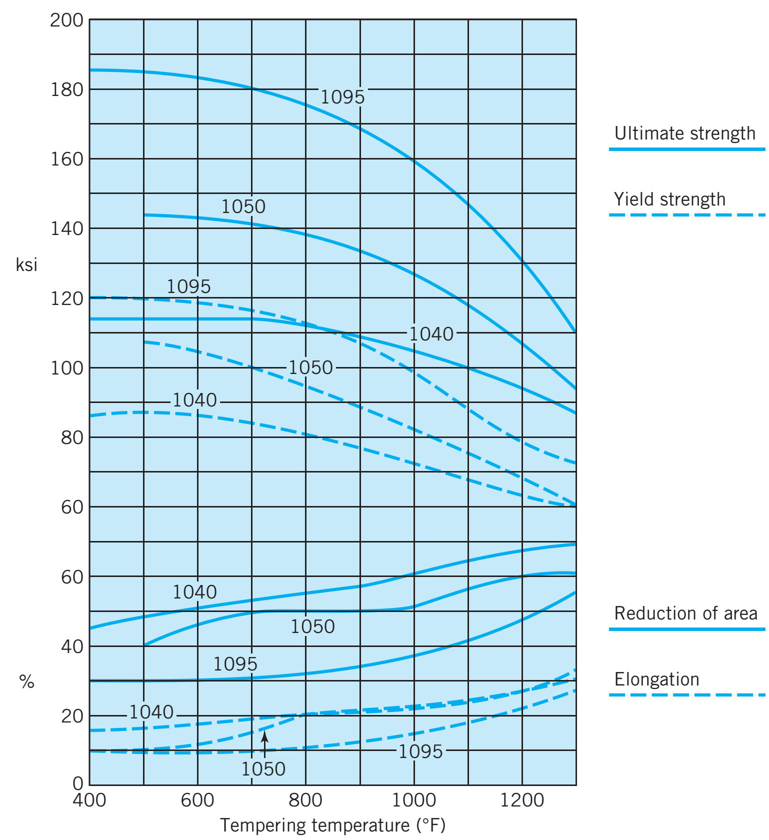
Steel	Diameter Treated (in.)	Diameter Tested (in.)	Normalized Temperature (°F)	Reheat Temperature (°F)	As Quenched, H_B
1030	1.0	0.505	1700	1600	514
1040	1.0	0.505	1650	1550	534
1050	1.0	0.505	1650	1525	601
1095	1.0	0.505	1650	1450	601
4130	0.53	0.505	1600	1575	495



Source: Modern Steels and Their Properties, Bethlehem Steel Corporation, Bethlehem, Pa., 1972.

Appendix C-5b *Properties of Some Oil-Quenched and Tempered Carbon Steels*

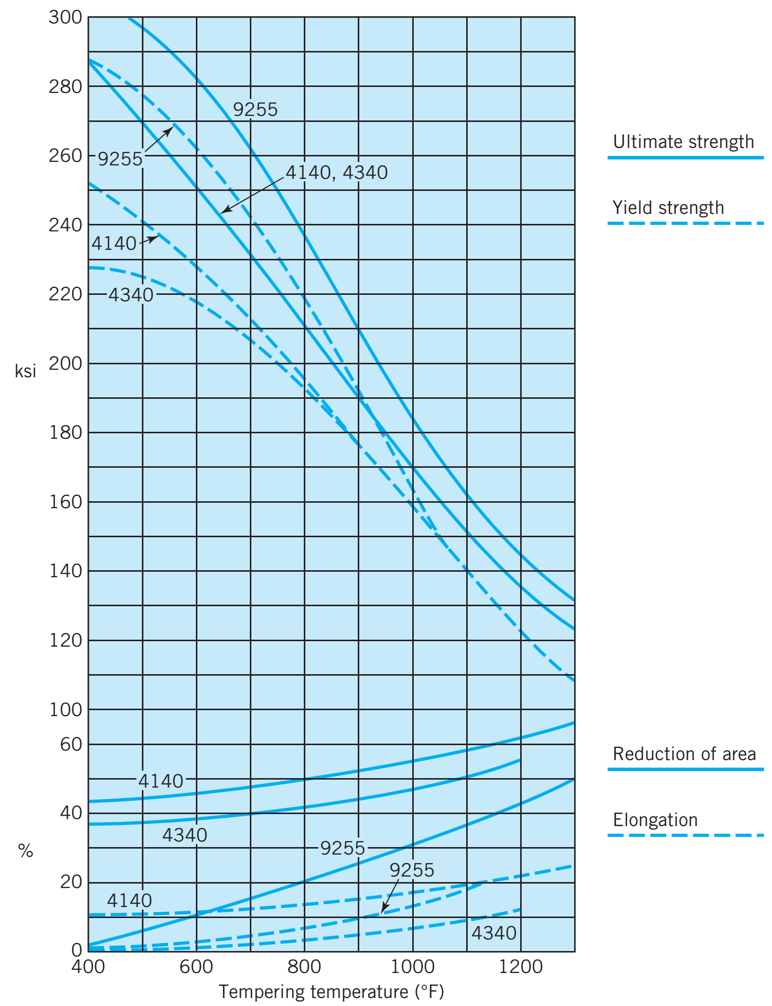
Steel	Diameter Treated (in.)	Diameter Tested (in.)	Normalized Temperature (°F)	Reheat Temperature (°F)	As Quenched, H_B
1040	1.0	0.505	1650	1575	269
1050	1.0	0.505	1650	1550	321
1095	1.0	0.505	1650	1475	401



Source: Modern Steels and Their Properties, Bethlehem Steel Corporation, Bethlehem, Pa., 1972.

Appendix C-5c *Properties of Some Oil-Quenched and Tempered Alloy Steels*

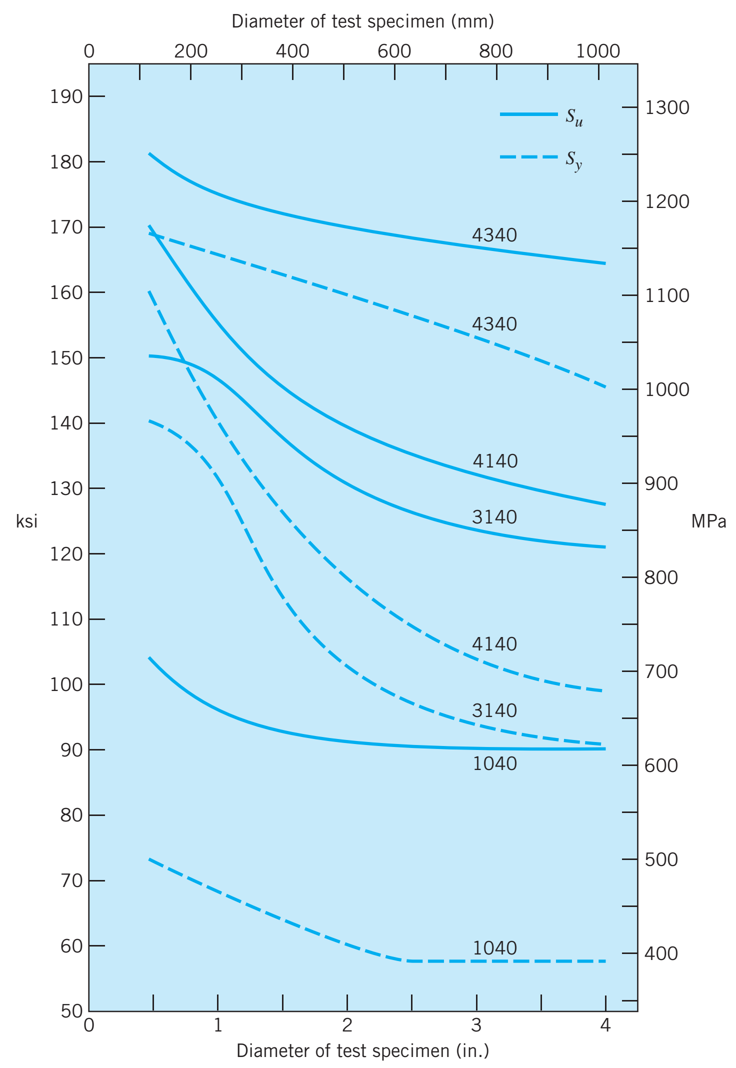
Steel	Diameter Treated (in.)	Diameter Tested (in.)	Normalized Temperature (°F)	Reheat Temperature (°F)	As Quenched, H_B
4140	0.53	0.505	1600	1525	555
4340	0.53	0.505	1600	1550	601
9255	1.0	0.505	1650	1625	653



Source: Modern Steels and Their Properties, Bethlehem Steel Corporation, Bethlehem, Pa., 1972.

Appendix C-6 *Effect of Mass on Strength Properties of Steel*

All specimens oil-quenched and tempered at 1000°F (538°C)



Source: Modern Steels and Their Properties, Bethlehem Steel Corporation, Bethlehem, Pa., 1972.

Appendix C-7 *Mechanical Properties of Some Carburizing Steels*

	Core									Case		
		Tensile Strength				Ductility		Impact Strength Izod			Thickness	
		Ultimate, S_u		Yield, S_y								
Steel AISI	Hardness, H_B	ksi	MPa	ksi	MPa	Elongation in 2 in. (%)	Reduction of Area (%)	ft · lb	J	Hardness, R_C	in.	mm
1015[a]	149	73	503	46	317	32	71	91	123	62	0.048	1.22
1022[a]	163	82	565	47	324	27	66	81	110	62	0.046	1.17
1117[a]	192	96	662	59	407	23	53	33	45	65	0.045	1.14
1118[a]	229	113	779	76	524	17	45	16	22	61	0.065	1.65
4320[b]	293	146	1006	94	648	22	56	48	65	59	0.075	1.91
4620[b]	235	115	793	77	531	22	62	78	106	59	0.060	1.52
8620[b]	262	130	896	77	531	22	52	66	89	61	0.070	1.78
E9310[b]	352	169	1165	138	952	15	62	63	85	58	0.055	1.40

[a] 1-in. round section treated, 0.505-in. round section tested. Single quench in water, tempered 350°F (177°C).
[b] 0.565-in. round section treated, 0.505-in. round section tested. Double quench in oil, tempered 450°F (232°C). (Tempering at 300°F gives greater case hardness but less core toughness.)
Note: Values tabulated are approximate median expectations.
Source: Modern Steels and Their Properties, Bethlehem Steel Corporation, Bethlehem, Pa., 4th ed., 1958, and 7th ed., 1972.

Appendix C-8 *Mechanical Properties of Some Wrought Stainless Steels (Approximate Median Expectations)*

	Ultimate Strength, S_u (ksi)			Yield Strength S_y (ksi)			Elongation (%)			Izod Impact (ft · lb)						
AISI Type	An.	CW	H&T	An.	CW	H&T	An.	CW	H&T	An.	CW	H&T	Drawability	Machinability	Weldability	Typical Uses
Austenitic																
302	85	110		35	75		60	35		110	90		VG	P	G	General purpose; springs
303	90	110		35	80		50	22		85	35		G	G	P	Bolts, nuts, rivets, aircraft fittings
304	85	110		35	75		60	55		110	90		VG	P	G	General purpose; welded construction
310, 310S	95			45			50			110			G	P	G	Turbine, furnace, heat exchanger parts
347, 348	90	110		35	65		50	40		110			VG	P	G	Jet engine, nuclear energy parts
384 (wire)	75			35			55						E			Severely cold-worked parts; fasteners
Martensitic																
410	75	105	115	40	85	85	35	17	23	90	75	80	F	F–	F	Machine parts, shafts, bolts, cutlery
414	115	130[a]	160	90	110[a]	125	20	15[a]	17	50		45		F	F	Machine parts, springs, bolts, cutlery
416, 416Se	75	100[b]	110	40	85[b]	85	30	13[b]	18	70	20[b]	25	P	G	P	Cutlery, fasteners, tools, screw machine parts
431	125	130[a]	165	95	110[a]	125	20	15[a]	17	50		40		P–	F	High-strength bolts, aircraft fittings
440 A,B,C	105	115[a]	260	60	90[a]	240	14	7[a]	3	2	2[a]	2		VP	P	Balls, bearing parts, nozzles, cutlery (highest H&T hardness of any stainless)
Ferritic																
430, 430F	75	83		43	63		27	20					G	F–G	F	Decorative trim, mufflers, screw machine parts
446	83	85		53	70		23	20		2			P	F	F	Parts subjected to high-temperature corrosion

[a] Annealed and cold-drawn.
[b] Tempered and cold-drawn.
Note: An., CW, H&T mean annealed, cold-worked, and hardened and tempered, respectively.
E, VG, G, F, P, VP mean excellent, very good, good, fair, poor, very poor, respectively.
Sources: Metal Progress Databook 1980, American Society for Metals, Metals Park, Ohio, Vol. 118, No. 1 (mid-June 1980); *ASME Handbook Metal Properties*, McGraw-Hill, New York, 1954; *Materials Engineering*, 1981 Materials Selector Issue, Penton/IPC, Cleveland, Vol. 92, No. 6 (Dec. 1980); *Machine Design*, 1981 Materials Reference Issue, Penton/IPC, Cleveland, Vol. 53, No. 6 (March 19, 1981).

Appendix C-9 *Mechanical Properties of Some Iron-Based Superalloys*

AISI Grade	Ultimate Strength, S_u (ksi)		Yield Strength S_y (ksi)		Elongation (%)		Rupture Strength, 100 h @ 1000°F (ksi)	Creep Strength, 0.0001%/h @ 1000°F (ksi)	Charpy Impact Strength, @ 70°F (ft · lb)
	70°F	1000°F	70°F	1000°F	70°F	1000°F			
Martensitic									
604 (Chromalloy)	125–138	110	95–108	85	7	—	75	—	—
610 (H-11)	135–310	180	100–240	140	3–17	11	95–115	—	10–32
Austenitic									
635 (Stainless W)	220–225	75–80	215–290	37–50	1–5	47–58	32	—	4–106
650 (16-12-G)	110–140	90	50–100	33	20–45	58	78	26	15
653 (17-24 CuMo)	86–112	65	40–90	29	30–45	37	48	10	8–26
665 (W-545)	176–187	154	123–142	120	19	13	120	—	—

Note: Values tabulated are approximate median expectations.
Source: Machine Design, 1981 Materials Reference Issue, Penton/IPC, Cleveland, Vol. 53, No. 6 (March 19, 1981).

Appendix C-10 *Mechanical Properties, Characteristics, and Typical Uses of Some Wrought Aluminum Alloys*

Alloy	Brinell Hardness, H_B	Tensile Strength: Ultimate, S_u ksi	Tensile Strength: Ultimate, S_u MPa	Tensile Strength: Yield, S_y ksi	Tensile Strength: Yield, S_y MPa	Elongation in 2 in. (%)	Corrosion Resistance	Cold Work	Machine	Braze	Gas Weld	Arc Weld	Resistance Weld	Typical Uses
1100-0	23	13	90	5	34	45	A	A	E	A	A	A	B	Spinnings, drawn shapes, heat
-H14	32	18	125	17	115	20	A	A	D	A	A	A	A	exchangers, cooking
-H18	44	24	165	22	150	15	A	B	D	A	A	A	A	utensils, tanks
2011-T3	95	55	380	43	295	15	D	C	A	D	D	D	D	Screw machine parts
-T8	100	59	405	45	310	15	D	D	A	D	D	D	D	
2014-0	45	27	185	14	97	18	—	—	D	D	D	D	B	Heavy-duty forgings, aircraft
-T4	105	62	425	42	290	20	D	C	B	D	D	B	B	structures and fittings,
-T6	135	70	485	60	415	13	D	D	B	D	D	B	B	truck frames
2024-0	47	27	185	11	76	22	—	—	D	D	D	D	D	Aircraft structures, truck wheels,
-T4	120	68	470	47	325	19	D	C	B	D	C	B	B	screw machine parts
6061-0	30	18	125	8	55	30	B	A	D	A	A	A	B	Boats, rail cars, pipe, flanges,
-T6	95	45	310	40	275	17	B	C	C	A	A	A	A	trailers
6063-0	25	13	90	7	48	—	A	A	—	A	A	A	A	Furniture tube, doors, windows,
-T6	73	35	240	31	215	12	A	C	C	A	A	A	A	pipe, fuel tanks
7075-0	60	38	230	15	105	16	—	—	D	D	D	C	B	Aircraft structures and skins,
-T6	150	83	570	73	505	11	C	D	B	D	D	C	B	skis, railings

Note: Values are approximate median expectations for sizes about $\frac{1}{2}$ in. The H_B values were obtained from 500-kg load and 10-mm ball. Letters A, B, C, D indicate relative ratings in decreasing order of merit.

Source: ASM Metals Reference Book, American Society for Metals, Metals Park, Ohio, 1981.

Appendix C-11 *Tensile Properties, Characteristics, and Typical Uses of Some Cast-Aluminum Alloys*

Alloy	Casting Type	Tensile Strength Ultimate, S_u MPa	Ultimate, S_u ksi	Yield, S_y MPa	Yield, S_y ksi	Elongation (%)	Corrosion Resistance	Machining	Weldability	Anodized Appearance	Typical Uses
201-T4	Sand	365	53	215	31	20					Aircraft components
-T6	Sand	485	70	435	63	7					
208-F	Sand	145	21	97	14	2.5	4	3	2	3	Manifolds, valve bodies, pressure tight parts
295-T4	Sand	220	32	110	16	8.5	4	3	2	2	Crankcases, wheels, housings, spring hangers, fittings
-T6	Sand	250	36	165	24	5.0					
355-T6	Sand	240	35	175	25	3.0	3	3	1	4	Cylinder heads, water jackets, housings, impellers, timing gears, meter parts
-T6	Permanent mold	290	42	190	27	4.0					
356-T6	Sand	230	33	165	24	3.5	2	3	1	4	Automotive housings, aircraft and marine fittings, general-purpose castings
-T6	Permanent mold	265	38	185	27	5.0					
A390-F	Sand	180	26	180	26	<1.0					Automotive engine blocks, pumps, pulleys, brake shoes
-T6	Sand	280	40	280	40	<1.0					
-F	Permanent mold	200	29	200	29	<1.0					
-T6	Permanent mold	310	45	310	45	<1.0					
520-T4	Sand	330	48	180	26	16	1	1	4	1	Aircraft fittings, levers, brackets, parts requiring shock resistance

Note: Values are approximate median expectations for sizes about $\frac{1}{2}$ in. Characteristics are comparably rated from 1 to 5; 1 is the highest or best possible rating.

Sources: ASM Metals Reference Book, American Society for Metals, Metals Park, Ohio, 1981. *1981 Materials Selector*, Materials Engineering, Penton/IPC, Cleveland, Vol. 92, No. 6 (Dec. 1980).

Appendix C-12 *Temper Designations for Aluminum and Magnesium Alloys*

Temper	Process
F	As cast
0	Annealed
Hxx	Strain-hardened. First digit indicates the specific combination of operations, second digit indicates the degree of strain hardening; thus H18 indicates a greater degree of hardening than does H14 or H24
T3	Solution-heat-treated, cold-worked, and naturally aged
T4	Solution-heat-treated and naturally aged
T5	Cooled from an elevated-temperature shaping process and artificially aged
T6	Solution-heat-treated and artificially aged
T8	Solution-heat-treated, cold-worked, and artificially aged

Appendix C-13 *Mechanical Properties of Some Copper Alloys*

	Alloy	UNS Designation	Composition	Tensile Strength: Ultimate, S_u ksi	Tensile Strength: Ultimate, S_u MPa	Tensile Strength: Yield, S_y ksi	Tensile Strength: Yield, S_y MPa	Elongation in 2 in. (%)
Wrought Alloys	Leaded beryllium copper	C17300		68–200	469–1379	25–178	172–1227	43–3
	Med leaded brass	C34000	(65Cu–34Zn)	50–55	345–379	19–42	131–290	60–40
	Free cutting brass	C36000		49–68	338–469	18–45	124–310	53–18
	Leaded phos bronze	C54400	(88Cu–4Zn)	68–75	469–517	57–63	393–434	20–15
	Aluminum silicon-bronze	C64200	(91Cu–7Al–2Si)	75–102	517–703	35–68	241–469	32–22
	Silicon bronze	C65500	(97Cu–3Si)	58–108	400–745	22–60	152–414	60–13
	Manganese bronze	C67500		65–84	448–579	30–60	207–414	33–19
Cast Alloys	Leaded red brass	C83600	(85Cu–5Zn–5Sn–5Pb)	37	255	17	117	30
	Leaded yellow brass	C85200		38	262	13	90	35
	Manganese bronze	C86200		95	655	48	331	20
	Navy M bronze	C92200		40	276	20	138	30
	Leaded Ni–Sn bronze	C92900		47	324	26	179	20
	Bearing bronze	C93200		35	241	18	124	20
	Aluminum bronze	C95400		85–105	586–724	35–54	241–372	18–8
	Copper nickel	C96200	(90Cu–10Ni)	45	310	25	172	20

Note: Values tabulated are approximate median expectations.

Source: Machine Design, 1981 Materials Reference Issue, Penton/IPC, Cleveland, Vol. 53, No. 6 (March 19, 1981).

Appendix C-14 *Mechanical Properties of Some Magnesium Alloys*

Alloy	Form	Tensile Strength: Ultimate, S_u ksi	Ultimate, S_u MPa	Yield, S_y ksi	Yield, S_y MPa	Elongation in 2 in. (%)
AZ91B-F	Die casting	34	234	23	159	3
AZ31B-F ZK60A-T5	Extrusion	38–53	262–365	28–44	193–303	11–15
AZ31B-F HM21A-T5 AZ80A-T5 ZK60A-T6	Forging	34–50	234–345	22–39	152–269	6–11
AZ31B-H24 HK31A-H24 HM21A-T8	Sheet, plate	33–42	228–290	21–32	145–221	9–21

Note: Values tabulated are approximate median expectations.
Source: Machine Design, 1981 Materials Reference Issue, Penton/IPC, Cleveland, Vol. 53, No. 6 (March 19, 1981).

Appendix C-15 *Mechanical Properties of Some Nickel Alloys*

		Tensile Strength				Creep Strength, 0.0001%/h			Impact Strength Notched Charpy	
		Ultimate, S_u		Yield, S_y				Elongation in 2 in.		
Alloy	Form	ksi	MPa	ksi	MPa	ksi	MPa	(%)	ft · lb	J
Wrought nickel	CD annealed bar	55–80	379–552	15–30	103–207	12	83	55–40	228	309
Duranickel 301	CD annealed bar	90–120	621–827	30–60	207–414			55–35		
	CD aged bar	170–210	1172–1448	125–175	862–1207			25–15		
Monel 400	Annealed bar	70–90	483–621	25–50	173–345	24	165	60–35	216	293
	Hot-rolled bar	80–110	552–758	40–100	276–690	25	172	60–30	219	297
Monel K-500	Aged bar	140–190		110–150		87		30–20	39	53
Hastelloy B[a]	As-cast bar	134	924	67	462			52		
Udimet HX[a]	Sheet (0.109 in.)	114 (70°F)	786	52 (70°F)	359			43 (70°F)		
Unitemp HK[a]		13 (2000°F)	89	8 (2000°F)	55			50 (2000°F)		
Hastelloy X[a]										
Rene 95[a]	Forging	235 (70°F)	1620	190 (70°F)	1310			15 (70°F)		
		225 (1000°F)	1551	182 (1000°F)	1255			13 (1000°F)		
Inconel 600[a]	Annealed bar	96 (70°F)	662	41 (70°F)	283	40 (800°F)	276	45 (70°F)	180	244
		37 (1400°F)	255	25 (1400°F)	172	2.0 (1600°F)	14	68 (1400°F)		
Inconel 625[a]	Annealed bar	140 (70°F)	965	71 (70°F)	490	12 (1400°F)	83	50 (70°F)	49	66
		78 (1400°F)	538	61 (1400°F)	421	3.9 (1600°F)	27	45 (1400°F)		
Inconel X-750[a]	Aged bar	184 (70°F)	1269	126 (70°F)	869	63 (1200°F)	434	25 (70°F)	37	50
		143 (1200°F)	986	110 (1200°F)	758			7 (1200°F)		
Incoloy 800[a]	Annealed bar	87 (70°F)	600	43 (70°F)	296	6.0 (1400°F)	41	44 (70°F)	107	145
		33 (1400°F)	228	23 (1400°F)	159	3.5 (1600°F)	24	84 (1400°F)		

[a] "Superalloys," noted for high-temperature strength and corrosion resistance. Used in jet engines, turbines, and furnaces.
Note: Values tabulated are approximate median expectations. CD means cold-drawn.
Source: Machine Design, 1981 Materials Reference Issue, Penton/IPC, Cleveland, Vol. 53, No. 6 (March 19, 1981).

Appendix C-16 *Mechanical Properties of Some Wrought-Titanium Alloys*

		Tensile Strength					Charpy Impact Strength	
		Ultimate, S_u		Yield, S_y		Elongation in 2 in.		
Alloy	Designation	ksi	MPa	ksi	MPa	(%)	ft · lb	J
Commercially pure alpha Ti	Ti-35A	35	241	25	172	24	11–40	15–54
Commercially pure alpha Ti	Ti-50A	50	345	40	276	20	11–40	15–54
Commercially pure alpha Ti	Ti-65A	65	448	55	379	18	11–40	15–54
Alpha alloy	Ti-0.2Pd	50	345	40	276	20	—	—
Alpha–beta alloy	Ti-6Al-4V	130–160[a]	896–1103[a]	120–150[a]	827–1034[a]	10-7	10–20	14–27
Beta alloy	Ti-3Al-13V-11Cr	135–188[a]	931–1296[a]	130–175[a]	896–1207[a]	16-6	5–15	7–20

[a] Depending on heat treatment.

Note: Values tabulated are approximate median expectations.

Source: Machine Design, 1981 Materials Reference Issue, Penton/IPC, Cleveland, Vol. 53, No. 6 (March 19, 1981).

Appendix C-17 *Mechanical Properties of Some Zinc Casting Alloys*

Alloy Designation			Tensile Strength				Elongation in 2 in. (%)	Charpy Impact Strength		Brinell Hardness, H_B
			Ultimate, S_u		Yield, S_y					
ASTM	SAE	ADCI	ksi	MPa	ksi	MPa		ft · lb	J	
AG40A[a]	903	No. 3	41	283			10	43	58	82
AC41A[a]	925	No. 5	47	324			7	48	65	91
ZA-12										
Sand-cast			40–45	276–310	30	207	1–3			105–120
Permanent mold			45–50	310–345	31	214	1–3			105–125
Die-cast			57	393	46	317	2			110–125

[a] Die-cast.

Note: Values tabulated are approximate median expectations.

Sources: Machine Design, 1981 Materials Reference Issue, Penton/IPC, Cleveland, Vol. 53, No. 6 (March 19, 1981); *Metal Progress, Databook 1980*, American Society for Metals, Metals Park, Ohio, Vol. 118, No. 1 (mid-June, 1980).

Appendix C-18a *Representative Mechanical Properties of Some Common Plastics*

Plastic	Tensile Strength, S_u		Elongation in 2 in. (%)	Izod Impact Strength		Friction Coefficient	
	ksi	MPa		ft · lb	J	With Self	With Steel
ABS (general purpose)	6	41	5–20	6.5	8.8		
Acrylic (standard molding)	10.5	72	6	0.4	0.5		
Cellulosic (cellulose acetate)	2–7	14–48		1–7	1.4–9.5		
Epoxy (glass-filled)	10–20	69–138	4	2–30	2.7–41		
Fluorocarbon (PTFE)	3.4	23	300	3	4.1		0.05
Nylon (6/6)	12	83	60	1	1.4	0.04–0.13	
Phenolic (wood–flour-filled)	7	48	0.4–0.8	0.3	0.4		
Polycarbonate (general purpose)	9–10.5	62–72	110–125	12–16	16–22	0.52	0.39
Polyester (20 to 30 percent glass-filled)	16–23	110–90	1–3	1.0–1.9	1.4–2.6	0.12–0.22	0.12–0.13
Polypropylene (unmodified resin)	5	34	10–20	0.5–2.2	0.7–3.0		

Note: Values shown are typical; both higher and lower values may be commercially obtainable. Also see Appendix C-18b.

Sources: Machine Design, 1981 Materials Reference Issue, Penton/IPC, Cleveland, Vol. 53, No. 6 (March 19, 1981); *Materials Engineering*, 1981 Materials Selector Issue, Penton/IPC, Cleveland, Vol. 92, No. 6 (Dec. 1980).

Appendix C-18b *Properties of Some Common Glass-Reinforced and Unreinforced Thermoplastic Resins*

Base Resin ASTM Test →	Tensile Strength, ksi D638	Flexural Modulus, Mpsi D790	Izod Impact Strength, ft · lb/in. D256 Notched	Izod Impact Strength, ft · lb/in. D256 Unnotched	Specific Gravity D792	Mold Shrinkage (%) D955	Water Absorption (in 24 h) D570	Thermal Expansion, 10^{-5}/°F D696	Deflection Temperature, °F (264 psi) D648
ABS	14.5 (6.0)	1.10 (0.32)	1.4 (4.4)	6–7	1.28 (1.05)	0.1 (0.6)	0.14 (0.30)	1.6 (5.3)	220 (195)
Acetal	19.5 (8.8)	1.40 (0.40)	1.8 (1.3)	8–10 (20)	1.63 (1.42)	0.3 (2.0)	0.30 (0.22)	2.2 (4.5)	325 (230)
Fluorocarbon PTFE	14.0 (6.5)	1.10 (0.20)	7.5 (>40)	17–18	1.89 (1.70)	0.3 (1.8)	0.20 (0.02)	1.6 (4.0)	460 (160)
Nylon 6/12	22.0 (8.8)	1.20 (0.295)	2.4 (1.0)	20	1.30 (1.06)	0.4 (1.1)	0.21 (0.25)	1.5 (5.0)	41 (194)
Polycarbonate	18.5 (9.0)	1.20 (0.33)	3.7 (2.7)	17 (60)	1.43 (1.20)	0.1 (0.6)	0.07 (0.15)	1.3 (3.7)	300 (265)
Polyester[a]	19.5 (8.5)	1.40 (0.34)	2.5 (1.2)	16–18	1.52 (1.31)	0.3 (2.0)	0.06 (0.08)	1.2 (5.3)	430 (130)
Polyethylene[b]	10.0 (2.6)	0.90 (0.20)	1.1 (0.4)	8–9	1.17 (0.95)	0.3 (2.0)	0.02 (0.02)	2.7 (6.0)	260 (120)
Polypropylene[c]	9.7 (4.9)	0.55 (0.18)	3.0 (0.4)	11–12	1.12 (0.91)	0.4 (1.8)	0.03 (0.01)	2.0 (4.0)	295 (135)
Polystyrene	13.5 (7.0)	1.30 (0.45)	1.0 (0.45)	2–3	1.28 (1.07)	0.1 (0.4)	0.05 (0.10)	1.9 (3.6)	215 (180)

[a] Polybutylene terephthalate (PBT) resin.
[b] High density (HD).
[c] Impact-modified grade.

Note: Values in parentheses pertain to unreinforced resins. Other values are typical of 30 percent glass reinforcement formulas. All values shown are typical; both higher and lower values may be commercially obtainable.

Source: Machine Design, 1981 Materials Reference Issue, Penton/IPC, Cleveland, Vol. 53, No. 6 (March 19, 1981).

Appendix C-18c *Typical Applications of Common Plastics*

Application / Plastic	Thermoplastic																	Thermoset		
	ABS	Acetal	Acrylic	Cellulosics	Fluoroplastics	Nylon	Phenylene oxide	Polycarbonate	Polyester	Polyethylene	Polyimide	Polyphenylene sulfide	Polypropylene	Polystyrene	Polysulfone	Polyurethane	Polyvinyl chloride	Phenolic	Polyester	Polyurethane
Structural, mechanical: gears, cams, pistons, rollers, valves, pump impellers, fan blades, rotors, washing machine agitators		X				X							X					X		
Light-duty mechanical and decorative: knobs, handles, camera cases, pipe fittings, battery cases, auto steering wheels, trim moldings, eyeglass frames, tool handles	X		X	X						X				X	X		X	X		
Small housings and hollow shapes: phone and flashlight cases, helmets; housings for power tools, pumps, small appliances	X			X			X	X	X	X				X	X			X	X	
Large housings and hollow shapes: boat hulls, large appliance housings, tanks, tubs, ducts, refrigerator liners	(Foam)						(Foam)		(Foam)	(H.D. Foam)				(Foam)	(Foam)		(Foam)		(Glass-filled)	(Foam)
Optical and transparent parts: safety glasses, lenses, safety and vandals-resistant glazing, snowmobile windshields, signs, refrigerator shelves			X	X				X							X	X				
Parts for wear applications: gears, bushings, bearings, tracks, chute liners, roller skate wheels, wear strips		X			X	X				(UHMW)	X	X				X			X	X

Note: H.D. means high-density; UHMW means ultrahigh molecular weight.

Source: Machine Design, 1987 Materials Reference Issue, Penton/IPC, Cleveland, Vol. 59, No. 8 (April 16, 1987).

Appendix C-19 *Material Classes and Selected Members of Each Class*

Class	Members	Abbreviation
Engineering Alloys	Aluminum alloys	Al alloys
(Engineering metals and alloys)	Cast irons	Cast irons
	Copper alloys	Cu alloys
	Lead alloys	Lead alloys
	Magnesium alloys	Mg alloys
	Molybdenum alloys	Mo alloys
	Nickel alloys	Ni alloys
	Steels	Steels
	Tin alloys	Tin alloys
	Titanium alloys	Ti alloys
	Tungsten alloys	W alloys
	Zinc alloys	Zn alloys
Engineering Polymers	Epoxies	EP
(Engineering thermoplastics and thermosets)	Melamines	MEL
	Polycarbonate	PC
	Polyesters	PEST
	Polyethylene, high density	HDPE
	Polyethylene, low density	LDPE
	Polyformaldehyde	PF
	Polymethylmethacrylate	PMMA
	Polypropylene	PP
	Polytetrafluorethylene	PTFE
	Polyvinylchloride	PVC
Engineering Ceramics	Alumina	Al_2O_3
(Fine ceramics capable of load-bearing application)	Diamond	C
	Sialon	Sialon ($Si_{6-x}Al_xO_xN_{8-x}$)
	Silicon carbide	SiC
	Silicon nitride	Si_3N_4
	Zirconia	ZrO_2
Engineering Composites	Carbon fiber reinforced polymer	CFRP
(A distinction is drawn between the properties of a ply—"UNIPLY"— and of a laminate—"LAMINATES")	Glass fiber reinforced polymer	GFRP
	Kevlar fiber reinforced polymer	KFRP
Porous Ceramics	Brick	
(Traditional ceramics, cements, rocks, and minerals)	Cement	
	Common rocks	
	Concrete	
	Porcelain	
	Pottery	
Glasses	Borosilicate glass	B-glass
(Ordinary silicate glass)	Soda glass	Na-glass
	Silica	SiO_2
Woods	Ash	
(Separate envelopes describe properties parallel to the grain and normal to it, and wood products)	Balsa	
	Fir	
	Oak	
	Pine	
	Wood products (plywood, etc.)	

Appendix C-19 *(continued)*

Class	Members	Abbreviation
Elastomers	Natural rubber	Rubber
(Natural and artificial rubbers)	Hard butyl rubber	Hard butyl
	Polyurethanes	PU
	Silicone rubber	Silicone
	Soft butyl rubber	Soft butyl
Polymer Foams	Cork	Cork
(Engineering foamed polymers)	Polyester	PEST
	Polystyrene	PS
	Polyurethane	PU

Source: Ashby, M. F., *Materials Selection in Mechanical Design*, Pergamon Press, 1992.

Appendix C-20 *Designer's Subset of Engineering Materials*

Metals—steels and cast iron

Carbon steels:	B1112, 1010, 1020, 1040, 1050, 1090
Alloy steels:	4140, 4340, 4620, 9310
Stainless steels:	302, 303, 304, 316, 410, 414, 416, 420, 431, 440
Tool steels:	A2, D2, M2, S1, S7
Cast irons:	Class 20, Class 30, Class 35, Ductile 60-40-18, Ductile 60-45-10, Ductile 80-55-06, Ductile 120-90-06

Metals—other

Aluminum alloys:	1100, 2011, 2014, 2024, 6061, 7075, 355, 390
Copper alloys:	Leaded beryillium copper (C17300), Free cutting brass (C36000), Leaded phosphor bronze (C54400), Bearing bronze (C93200), Aluminum bronze (C95400),
Nickel alloys:	Duranickel, Hastelloy, Inconel, Monel, Wrought nickel
Zinc:	AG40A, ZA-12
Magnesium:	AZ31, AZ91
Titanium:	Pure Ti (Ti-50A), Ti-6Al-4V

Plastics

- Acetal
- Acrylic
- Nylon
- Phenolic
- Polycarbonate
- Polyethylene
- Polyimide
- Polytetrafluoroethylene (PTFE)
- Polyvinylchloride

Elastomers

- Neoprene
- Silicones
- Urethanes

Ceramics

- Aluminum oxide
- Cemented carbide
- Silicon carbide
- Silicon nitride

Appendix C-21 *Processing Methods Used Most Frequently with Different Materials*

Form	Irons	Steels (carbon, low alloy)	Heat & corr. res. alloys	Aluminum alloys	Copper alloys	Lead alloys	Magnesium alloys	Nickel alloys	Precious metals	Tin alloys	Titanium alloys	Zinc alloys
Sand castings	■	■	■	■	■	□	■	■		□		□
Shell mold castings	■	□	□	■	■			□				
Full-mold castings	■	■	□	□	□	□		■				
Permanent-mold castings	■	□		■	□	□	■	□		□		□
Die castings				■	□	■	■			□		■
Plaster mold castings				■	■							
Ceramic mold castings	■	■	■	□	□		□	■				□
Investment castings		■	□	■	■		□	■	□			
Centrifugal castings	■	■	■	□	□			□				
Continuous castings		□		■	■[d]	□						
Open die forgings	□	■	■	□	□		□	□			□	
Closed die forgings Blocker type		■	■	□	□		□	□			□	
Conventional type		■	■	□	□		□	□			□	
Upset forgings		■	■	□	□		□	□			□	
Cold headed parts		■	□	■	■	□		□	□			
Stampings, drawn parts		■	□	■	■		□	■	□		□	□
Spinnings		■	□	■	■	□	□	■	□		□	□
Screw machine parts	□	■	□	■	■		□	■	□		□	□
Powder metallurgy parts[b]	■	■	□	□	■			□	□		□	
Electroformed parts[c]	□			□	■	□		■	□	□		□
Cut extrusions		□		■	■	□	■	□		□	□	
Sectioned tubing		■	■	■	■		■	■			■	
Photofabricated parts		■	□	■	■	□	■	■	■	□	■	■

[a] ■ = Materials most frequently used
□ = Materials also currently being used

[b] Iron-copper and iron-copper-carbon most frequently used.
[c] Most frequently used materials are pure nickel and copper.
[d] Particularly tin-bronze and tin-lead-bronze.

Source: Material Selector, Material Engineering Magazine, Penton/IPC, Cleveland, Ohio.

Appendix C-22 *Joinability of Materials*

Material	Arc welding	Oxyacetylene welding	Resistance welding	Brazing	Soldering	Adhesive bond (thermoset, thermoplastic, elastomeric)	Adhesive bond (modified comp. - epoxy, etc.)	Threaded fastening	Riveting and metal stitching
Cast iron	Common	Recommended	Seldom used	Difficult	Seldom used	TS (Common) / TP (Seldom used)	Common	Common	Recommended
Carbon steels	Recommended	Recommended	Recommended	Recommended	Difficult	TS (Common) / TP (Seldom used)	Common	Recommended	Recommended
Stainless steel	Recommended	Common	Recommended	Recommended	Common	TS (Common) / TP (Seldom used)	Common	Recommended	Common
Aluminum, magnesium	Common	Common	Common	Common	Seldom used	TS (Common) / (Seldom used)	Recommended	Common	Common
Copper	Common	Common	Common	Recommended	Recommended	TS (Common) / TP (Seldom used)	Common	Common	Common
Nickel	Recommended	Common	Recommended	Recommended	Common	TS (Common) / TP (Seldom used)	Common	Recommended	Common
Titanium	Common	Not used	Common	Difficult	Seldom used	TS (Seldom used) / TP (Not used)	Common	Common	Not used
Lead, zinc	Common	Common	Lead (Not used) / Zinc (Seldom used)	Not used	Recommended	Recommended	Recommended	Recommended	Recommended
Thermoplastics	Recommended	Recommended	Common	Not used	Not used	Common	Seldom used	Seldom used	Recommended
Thermosets	Not used	Not used	Not used	Not used	Not used	TS (Common)	Common	Common	Common
Elastomers	Not used	Not used	Not used	Not used	Not used	Recommended	Common	Seldom used	Recommended
Ceramics	Not used	Seldom used	Not used	Not used	Not used	Recommended	Recommended	Common	Seldom used
Glass	Seldom used	Common	Not used	Not used	Not used	TS (Not used) / Elast (Recommended)	Recommended	Common	Seldom used
Wood	Not used	Not used	Not used	Not used	Not used	Recommended	Recommended	Common	Common
Leather	Not used	Not used	Not used	Not used	Not used	Elast (Recommended) / TS (Common)	Recommended	Seldom used	Recommended
Fabric	Not used	Not used	Not used	Not used	Not used	Elast (Recommended)	Recommended	Seldom used	Recommended
Dissimilar metals	Difficult	Difficult	Difficult	Difficult / Common	Recommended	TS (Recommended)	Recommended	Common	Common
Metals to nonmetals	Not used	Not used	Not used	Not used	Not used	Recommended	Recommended	Common	Recommended
Dissimilar nonmetals	Difficult	Difficult	Not used	Not used	Not used	Recommended	Recommended	Seldom used	Recommended
Dissimilar thickness	Common	Common	Common	Recommended	Recommended	Recommended	Recommended	Recommended	Recommended

Recommended | Common | Difficult | Seldom used | Not used

Source: Hill, P. H., *The Science of Engineering Design*, Holt, Rinehart and Winston, New York, 1970.

Appendix C-23 *Materials for Machine Components*

Component or Tool	Candidate Materials
Balls	440 stainless steel
Bare plates	ASTM Class 25 gray cast iron, 1020
Bearing parts	440 stainless steel
Bearings	Acetal, Fluoroplastics, Nylon, UHMW Polyethylene, Polyimide, Polyurethane
Bolts	Acetal, 303, 410, 414, and 431 stainless steels, 1020, 1040, 4140, 4340
Brackets	6061 T6 aluminum, Class M3210 annealed malleable cast iron
Brake drums	ASTM Class 30 and 35 gray cast iron
Bushings	Acetal, Fluoroplastics (PTFE), Nylon, UHMW Polyethylene, Polyimide, Polyurethane, PTFE filled Nylon, Cloth—reinforced phenolic, P/M bronze
Cams	Acetal, Nylon, Phenolic
Camshafts	ASTM Class 40 gray cast iron
Chutes	PVC, 304 stainless steel, 1020
Chute liners	Acetal, Fluoroplastics, Nylon, UHMW Polyethylene, Polyimide, Polyurethane
Clutch plates	ASTM Class 30 and 35 gray cast iron
Connecting rods	Class M7002 heat treated malleable cast iron, 1030, 1040
Crane hooks	1030, 1040
Crankshafts	Class M4504 heat treated malleable cast iron, Grade 80-55-06 ductile (nodular) iron
Cylinder blocks	ASTM Class 25 gray cast iron
Cylinder heads	ASTM Class 25 gray cast iron
Cylinder liners	ASTM Class 40 gray cast iron
Dies	A2, D2, M2, Sl, S7 tool steels
Drills	1090, 10100, 10120; M2 tool steel
Fan blades	Acetal, Nylon, Phenolic
Fasteners	384, 416 stainless steels
Files	10120, 10130
Fittings	Grade 60-40-18 ductile (nodular) iron
Flanges	6061 aluminum
Flywheels	ASTM Class 30 gray cast iron
Forgings	1040, 1050
Gears	Acetal, Nylon, Phenolic, Fluoroplastics, Polyethylene, Polyimide, Polyurethane, MoS_2 filled Nylon, Class M5003 and M8501 heat treated malleable cast irons, 1020, 1030, 1040, 1050, 4340, carbonized 4615 steel, Grade 80-55-06 ductile (nodular) iron, Grade 120-90-02 ductile (nodular) iron
Guards	Acrylic, Polycarbonate, 1020, expanded metal
Hammers	1080, S7 tool steel
Hand tools	1070, 1080, 1090
Housings	ASTM Class 25 gray cast iron
Hubs	Class M4504 heat treated malleable cast iron
Knives	1090, 10100, 10120, 10130; A2, D2, M2, S1, S7 tool steels
Leaf springs	1070, 1080, 1090
Levers	1020, 1030
Lock washers	1060, 1070
Milling cutters	1090, 10100, 10120
Nozzles	440 stainless steel
Nuts	303 stainless steel
Pipe	6061 and 6030 aluminum
Pump impellers	Acetal, Nylon, Phenolic
Pumps	ABS, Polycarbonate, Polyethylene, Phenolic
Razors	10120, 10130
Rivets	303 stainless steel, 1005, 1010
Rollers	Acetal, Nylon, Phenolic, Grade 80-55-06 ductile (nodular) iron, Grade 120-90-02 ductile (nodular) iron
Rolls	6061 T6 aluminum, 1020, 4340, D2 tool steel
Saws	10120,10130

Appendix C-23 *(continued)*

Component or Tool	Candidate Materials
Screws	1040, 1050,
Shafts	410 stainless steel, 1020, 1030, 1040, 1050, 4140, 4340
Shovels	1070, 1080, 1090
Slides	Grade 120-90-02 ductile (nodular) iron
Small housings	ABS, Polycarbonate, Polyethylene, Phenolic
Spring wire	1060, 1070
Springs	302, 414 stainless steels, 1080, 1090, 6150, 10100, 10120
Stampings	1005, 1010
Steering gear housing	Class M3210 annealed malleable cast iron
Tanks	1100 aluminum
Taps	1090,10100,10120
Tools	416 stainless steel, 1050; S1, S7 tool steels
Truck frames	2014 aluminum
Truck wheels	2024 aluminum
Universal joint yokes	Class M7002 heat treated malleable cast iron
Valves	Grade 60-40-18 ductile (nodular) iron
Wear strips	Acetal, Fluoroplastics, Nylon, UHMW Polyethylene, Polyimide, Polyurethane
Welded tubing	1020, 1030
Windshields	Polycarbonate
Wire	1005, 1010
Wire-drawing dies	10120, 10130
Worm gears	Aluminum bronze, Phosphor bronze

Appendix C-24 *Relations Between Failure Modes and Material Properties*

	Material property													
Failure mode	**Ultimate tensile strength**	**Yield strength**	**Comprensive yield strength**	**Shear yield strength**	**Fatigue properties**	**Ductility**	**Impact energy**	**Transition temperature**	**Modulus of elasticity**	**Creep rate**	**K_{Ic}**	**Electrochemical potential**	**Hardness**	**Coefficient of expansion**
Gross yielding		■		■										
Buckling			■						■					
Creep										■				
Brittle fracture							■	■			■			
Fatigue, low cycle					■	■								
Fatigue, high cycle	■				■									
Contact fatigue			■											
Fretting			■									■		
Corrosion												■		
Stress-corrosion cracking	■											■		
Galvanic corrosion												■		
Hydrogen embrittlement	■													
Wear													■	
Thermal fatigue										■				■
Corrosion fatigue					■							■		

Shaded block at intersection of material property and failure mode indicates that a particular material property is influential in controlling a particular failure mode.

Source: Smith, C. O., and B. E. Boardman, *Metals Handbook*, American Society for Metals, Metals Park, Ohio, 9th ed., vol. I, p. 828, 1980.