TABLES 184-209.—PHYSICAL AND MECHANICAL PROPERTIES OF MATERIALS

Introduction and definitions.—The mechanical properties of most materials vary between wide limits; the following figures are given as being representative rather than what may be expected from an individual sample. Figures denoting such properties are commonly given either as specification or experimental values. Unless otherwise shown, the values below are experimental.

Credit for the information included on metals is due to the National Bureau of Standards [55] and the publications of the Aluminum Co. of America,[56] the American Brass Co., and the Chase Brass & Copper Co.[57]

Most of the data shown in these tables are as determined at ordinary room temperature, averaging 20°C (68°F). The properties of most metals and alloys vary considerably from the values shown when the tests are conducted at higher or lower temperatures.

The following definitions govern the more commonly confused terms shown in the tables. In all cases the stress referred to in the definitions is equal to the total load at that stage of the test divided by the original cross-sectional area of the specimen (or the corresponding stress in the extreme fiber as computed from the flexure formula for transverse tests).

Brinell hardness numeral (abbreviated B. h. n.).—Ratio of pressure on a sphere used to indent the material to be tested to the area of the spherical indention produced. The standard sphere used is a 10-mm-diameter hardened steel ball. The pressures used are 3000 kg for steel and 500 kg for softer metals, and the time of application of pressure is 30 seconds. Values shown in the tables are based on spherical areas computed in the main from measurements of the diameters of the spherical indentations, by the following formula:

$$\text{B. h. n.} = P \div \pi t D = P \div \pi D(D/2 - \sqrt{D^2/4 - d^2/4}).$$

P = pressure in kg, t = depth of indentation, D = diameter of ball, and d = diameter of indentation—all lengths being expressed in mm. Brinell hardness values have a direct relation to tensile strength, and hardness determinations may be used to define tensile strengths by employing the proper conversion factor for the material under consideration.

Elastic limit.—Stress which produces a permanent elongation (or shortening) of 0.001 percent of the gage length, as shown by an instrument capable of this degree of precision (determined from set readings with extensometer or compressometer). In transverse tests the extreme fiber stress at an appreciable permanent deflection.

Erichsen value.—Index of forming quality of sheet metal. The test is conducted by supporting the sheet on a circular ring and deforming it at the center of the ring by a spherical pointed tool. The depth of impression (or cup) in mm required to obtain fracture is the Erichsen value for the metal. Erichsen standard values for trade qualities of soft metal sheets are furnished by the manufacturer of the machine corresponding to various sheet thicknesses.

Alloy steels are commonly used in the heat-treated condition, as strength increases are not commensurate with increases in production costs for annealed alloy steels. Corresponding strength values are accordingly shown for annealed alloy steels and for such steels after having been given certain recommended heat treatments of the Society of Automotive Engineers. The heat

[55] Everhart, Lindlief, Kanegis, Weissler, and Siegel, Nat. Bur. Standards Circ. C-447, 1943.

[56] Selected from Nat. Bur. Standards Circ. C-447, Mechanical properties of metals and alloys, and from Alcoa's circular, Aluminum and its alloys.

[57] Chase Brass & Copper Co.'s circular, Copper and commercially important copper alloys, 1948; American Brass Co., Copper and copper alloys, 1945.

treatments followed in obtaining the properties shown are outlined on the pages immediately following the tables on steel. It will be noted that considerable latitude is allowed in the indicated drawing temperatures and corresponding wide variations in physical properties may be obtained with each heat treatment. The properties vary also with the size of the specimens heat treated. The drawing temperature is shown with the letter denoting the heat treatment, wherever the information is available.

Modulus of elasticity (Young's modulus).—Ratio of stress within the proportional limit to the corresponding strain—as determined with an extensometer. NOTE.—All moduli shown are obtained from tensile tests of materials, unless otherwise stated.

Modulus of rupture.—Maximum stress in the extreme fiber of a beam tested to rupture, as computed by the empirical application of the flexure formula to stresses above the transverse proportional limit.

Proportional limit (abbreviated P-limit).—Stress at which the deformation (or deflection) ceases to be proportional to the load (determined with extensometer for tension, compressometer for compression, and deflectometer for transverse tests).

Shore scleroscope hardness.—Height of rebound of diamond-pointed hammer falling by its own weight on the object. The hardness is measured on an empirical scale on which the average hardness of martensitic high carbon steel equals 100. On very soft metals a "magnifier" hammer is used in place of the commonly used "universal" hammer and values may be converted to the corresponding "universal" value by multiplying the reading by 4/7. The scleroscope hardness, when accurately determined, is an index of the tensile elastic limit of the metal tested.

Ultimate strength in tension or compression.—Maximum stress developed in the material during test.

Yield point.—Stress at which marked increase in deformation (or deflection) of specimen occurs without increase in load (determined usually by drop of beam or with dividers for tension, compression, or transverse tests).

TABLE 184.—INDUSTRIAL WOVEN-WIRE SCREENS *

Industrial wire cloth may be specified in any malleable metal, the physical characteristics of which will permit of its being commercially drawn into wire and woven into cloth. This industrial wire screen is manufactured with openings from about 15 inches to a very fine wire cloth with openings of .0017 inch, using for larger screens rods 2 inches in diameter and for the smaller-opening cloth, wire .0014 inch in diameter.

Industrial wire cloth specification, market grade

Mesh per lineal inch	Wire diameter inch	Opening inch	Percent open area	Mesh per lineal inch	Wire diameter inch	Opening inch	Percent open area
1 × 1	.080	.920	84.6	30 × 30	.013	.0203	37.1
2 × 2	.063	.437	76.4	35 × 35	.011	.0176	37.9
3 × 3	.054	.279	70.1	40 × 40	.010	.0150	36.0
4 × 4	.047	.203	65.9	50 × 50	.009	.0110	30.3
5 × 5	.041	.159	63.2	60 × 60	.0075	.0092	30.5
6 × 6	.035	.132	62.7	80 × 80	.0055	.0070	31.4
8 × 8	.028	.097	60.2	100 × 100	.0045	.0055	30.3
10 × 10	.025	.075	56.3	120 × 120	.0037	.0046	30.7
12 × 12	.023	.060	51.8	150 × 150	.0026	.0041	37.4
14 × 14	.020	.051	51.0	180 × 180	.0023	.0033	34.7
16 × 16	.018	.0445	50.7	200 × 200	.0021	.0029	33.6
18 × 18	.017	.0386	48.3	250 × 250	.0016	.0024	36.0
20 × 20	.016	.0340	46.2	270 × 270	.0016	.0021	32.2
24 × 24	.014	.0277	44.2	325 × 325	.0014	.0017	30.0

* Data furnished by the W. S. Tyler Co., Cleveland.

TABLE 185.—SOME PHYSICAL PROPERTIES OF THE ELEMENTS

Element	Relative hardness	Density at 20°C g/cm³	Melting point °C	Specific heat at r.-t. cal g⁻¹ °C⁻¹	Latent heat of fusion cal/g	Coeff. of linear thermal expansion °C at r.-t. × 10⁶	Thermal conductivity at r.-t. watts cm⁻¹	Electrical resistivity *microhm-cm*	Modulus of elasticity kg/mm²	Tensile strength kg/mm²
Actinium	...	...	1197*	...	...	...	...	...	...	...
Aluminum	2.9	2.70	660.1 ±.1	.226	93	22.9	2.18	2.65(20°C)	7250	6.3 (annealed)
Antimony	3	6.62	630.5 ±.1	.049	38.3	8.5–10.8†‡	.19	39.0(0°C)	7900	1.05 (wire)
Argon	...	1.6626[a]	−189.37±.5	.125	6.7	...	1.70[e]	...	...	...
Arsenic	3.5	5.73	817§	.082	...	4.7	...	35(20°C)	...	...
Barium	...	3.5	710 ±20	.068	...	...	...	...	...	...
Beryllium	3	1.82	1283 ±40	.425	...	11.4	1.64	5.88(0°C)	30000	12.0 (chill cast)
Bismuth	2.5	9.80	271.3 ±.1	.029	12.5	13.3	.084	106.8(0°C)	3200	...
Boron	9.5	2.3	2300 ±300	.309	...	2	...	1.8×10^{12}(0°C)	...	...
Bromine	...	3.12	−7.20±.2	.070	16.2	...	...	...	...	...
Cadmium	2.0	8.65	321.03±.1	.055	13.2	29.8	.91	6.83(0°C)	5500	7.2
Calcium	...	1.54	850 ±20	.157	...	25	...	3.43(0°C)	2100	5.7 (extruded)
Carbon (graphite)	10[a]	2.22	3700 ±100	.165	...	.6–4.3‖	.24	1375(0°C)	500	...
Cerium	2.5	6.9	864 ±50	.05	...	...	...	78(20°C)	...	9.05 (rolled)
Cesium	.2	1.9	28.64±2	.052	3.8	97	...	18.83(0°C)	...	...
Chlorine	...	...	−101.99±2	.226	23.0	...	.720[e]	...	...	...
Chromium	9	7.14	1903 ±50	.12	75.6	6.2	.69	14.1(20°C)	...	...
Cobalt	5	8.9	1492 ±20	.099	58.4	12.3	.69	5.60(0°C)	21000	24.4 (cast)
Copper	3.0	8.96	1083.0 ±.1	.092	50.6	16.5	3.94	1.67(20°C)	11000	22.5 (annealed)
Fluorine	...	...	−219.61±10	...	10.1	...	...	...	...	...
Gallium	1.5	5.91	29.80±.02	.079	19.2	18	...	53.4(0°C)	...	...
Germanium	6.2	5.36	938 ±10	.073	...	...	...	89×10^{3}(0°C)	...	...
Gold	2.5	19.3	1063.0 ±.0	.031	16.1	14.2	2.96	2.19(0°C)	7300	11.5 (rod cast)
Hafnium	...	11.4	2220*	...	...	...	...	...	...	...
Helium	...	.1664[d]	−271.4 ±.2¶	1.25	...	...	13.9[e]	...	...	...
Hydrogen	...	.08375[d]	−259.19±.1	3.415	15.0	...	17.0[e]	...	...	...
Indium	1.2	7.31	156.61±.1	.057	...	33	.24	8.37(0°C)	...	.30 (cast)
Iodine	...	4.93	113.6 ±1	.052	15.8	93	43.5[e]	1.3×10^{15}(20°C)	...	...
Iridium	6.5	22.4	2443 ±3	.032	...	6.5	.59	5.3(20°C)	52500	...
Iron	4	7.87	1535 ±3	.108	65	11.7	.79	9.71(20°C)	20000	20.5

* Computed. † Value depends on the crystal orientation in polycrystalline material. ‡ From 20° to 60°C. § At 36 atm. ‖ From 20° to 100°C. ¶ At 30 atm.
[a] Diamond. [d] $\times10^{-3}$. [e] $\times10^{-4}$.

(continued)

TABLE 185.—SOME PHYSICAL PROPERTIES OF THE ELEMENTS (continued)

Element	Relative hardness	Density at 20°C g/cm³	Melting point °C	Specific heat at r.-t. cal g⁻¹ °C⁻¹	Latent heat of fusion cal/g	Coeff. of linear thermal expansion °C at r.-t. × 10⁶	Thermal conductivity at r.-t. watts cm⁻¹	Electrical resistivity microhm-cm	Modulus of elasticity kg/mm²	Tensile strength kg/mm²
Krypton	...	3.488[d]	—157.3 ±.5	...	...	...	.89[e]	...	...	...
Lanthanum	...	6.15	920 ±5	.045	...	...	...	59(18°C)	...	...
Lead	1.5	11.34	327.3 ±.1	.030	6.3	28.7	.35	20.65(20°C)	1800	1.33
Lithium	.6	.53	180.55±5	.79	159	56	.71	8.55(0°C)	...	...
Magnesium	2	1.74	650 ±2	.249	70.0	25.2	1.55	4.33(18°C)	4600	9.15 (sand cast)
Manganese	5.0	7.44	1244 ±20	.107	64.8	23	...	...	16000	39.0 (annealed)
Mercury	1.5	13.55	—38.87±.02	.033	2.7	...	.084	94.1(0°C)	...	...
Molybdenum	6	10.2	2610 ±50	.065	...	4.9‖	1.46	5.17(0°C)	35000	120 (annealed wire)
Neodymium	...	7.05	1024 ±40	.045	...	...	...	79(18°C)	...	...
Neon	...	.8387[d]	—248.59±.3	...	...	...	4.57[e]	...	...	...
Nickel	5	8.9	1453 ±1	.112	73.8	13.3‖	.90	6.84(20°C)	21000	32.3
Niobium	...	8.57	2480 ±50	...	...	7.1	...	...	...	...
Nitrogen	...	1.1649[d]	—209.97±.3	.247	6.2	...	2.51[e]	...	...	...
Osmium	7.0	22.48	2700 ±200	.031	...	6.1	...	9.5(20°C)	...	...
Oxygen	...	1.3318[d]	—218.79±.3	.218	3.3	...	2.47[e]	...	...	...
Palladium	4.8	12.0	1552 ±1	.059	34.2	11.8	.70	10.8(20°C)	12000	14.0 (annealed)
Phosphorus (yellow)	...	1.82	44.2 ±.1	.177	5.0	125	...	10^{17}(11°C)	...	...
Platinum	4.3	21.45	1769 ±1	.032	27.1	8.9	.69	9.81(0°C)	15000	16 (annealed)
Polonium	...	...	254*	...	...	...	...	...	...	...
Potassium	.5	.86	63.2 ±1	.177	14.5	83	.99	6.15(0°C)	...	...
Praseodymium	...	6.63	935 ±50	.458	...	...	...	88(18°C)	...	...
Protactinium	...	...	3000*	...	...	...	...	...	...	...
Radium	...	5.0	700	...	...	...	...	...	...	...
Radon	...	4.40[b]	— 71	...	...	...	...	...	...	...
Rhenium	...	20	3150*	.035	...	...	...	...	...	...
Rhodium	6	12.44	1960 ±3	.060	...	8.1[c]	.88	4.3(0°C)	30000	...
Rubidium	.3	1.53	38.8 ±1	.080	6.1	90	...	12.5(20°C)	...	...
Ruthenium	6.5	12.2	2400 ±100	.061	...	9.1	...	10(18°C)	...	...

[b] At −62°C. [c] From 20° to 50°C.

(continued)

TABLE 185.—SOME PHYSICAL PROPERTIES OF THE ELEMENTS (concluded)

Element	Relative hardness	Density at 20°C g/cm³	Melting point °C	Specific heat at r.-t. cal g⁻¹ °C⁻¹	Latent heat of fusion cal/g	Coeff. of linear thermal expansion °C at r.-t. × 10⁶	Thermal conductivity at r.-t. watts cm⁻¹	Electrical resistivity microhm-cm	Modulus of elasticity kg/mm²	Tensile strength kg/mm²
Samarium	...	7.7	>1050	...	...	...	...	...	...	...
Scandium	...	2.5	1400	...	...	...	...	...	...	...
Selenium	2.0	4.81	217.4 ±5	.084	...	37	...	1.20(20°C)	...	...
Silicon	7.0	2.4	1410 ±20	.176	...	2.8–7.3	.84	85×10^{3}(20°C)	11000	...
Silver	2.7	10.49	960.8 ±.0	.056	24.3	18.9	4.08	1.62(20°C)	7200	15.1 (rod, annealed)
Sodium	.4	.97	97.82±.2	.295	27.5	71	1.35	4.2(0°C)	...	...
Strontium	1.8	2.6	770 ±10	...	25	...	...	22.76(20°C)	...	...
Sulfur (rhombic)	2.0	2.07	119 ±.2	.175	9.3	64‡	26.4[e]	2×10^{23}(20°C)	...	...
Tantalum	7	16.6	2980 ±100	.036	...	6.6	.54	14.6(18°C)	19000	50 (wire)
Technetium	...	...	2700*	...	...	...	...	...	...	...
Tellurium	2.3	6.24	450 ±10	.047	...	16.8‡	.060	...	2100	1.12 (wire)
Terbium	...	...	1450 ±5	...	...	...	...	...	...	...
Thallium	1.2	11.85	303.6 ±3	.031	7.2	28	.39	17.65(0°C)	...	...
Thorium	...	11.5	1695 ±150	.028	...	11.1‡	...	18.62(20°C)	...	56.0 (wire)
Tin	1.8	7.30	231.91±.1	.054	14.4	23	.64	11.5(20°C)	41100	1.4
Titanium	4.0	4.54	1675 ±100	.142	...	8.5	...	80(0°C)	8500	...
Tungsten	7	19.3	3380 ±20	.034	44	4.3	1.99	5.5(20°C)	35000	270 (wire)
Uranium	...	18.7	1132 ±1	.028	...	...	...	60(18°C)	...	...
Vanadium	...	5.68	1890 ±50	.115	...	...	...	...	...	...
Xenon	...	5.495[d]	—112.5 ±1	...	...	...	5.19[e]	...	...	...
Ytterbium	...	...	824	...	...	...	...	...	...	...
Yttrium	...	5.51	1490 ±200	...	...	...	...	...	...	...
Zinc	2.5	7.14	419.50±.1	.09	24.1	17–39†	1.1	5.92(20°C)	8400	10.5
Zirconium	4.5	6.4	1852 ±700	.066	...	5.6	...	41.0(0°C)	7500	30.0 (rod, annealed)

TABLE 186.—MECHANICAL PROPERTIES OF ALUMINUM AND ALUMINUM ALLOYS **

Composition	Condition	Density cgs	Thermal conductivity cgs	Resistivity microhm-cm	Thermal expansion $\times 10^6$ cgs	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit and cycles kg/mm²	Hardness number
Pure and commercial aluminum												
Al–99.95	Annealed	...	...	2.8	...	...	.70	2.1 (.2% offset)	6.3	60 (2 in.)		15
Cu–4.5	Sand-cast; h.-t. and aged (195–T6)	2.75	.33	3.45	22.8	7200	...	15.5 (.2% perm.)	25	5 (2 in.)	4.6†	80
Al (commercial)	Hard-drawn (93% red)	2.71	.53	3.75	23.6	...	...	...	34	2 (2 in.)	..	..
Aluminum-copper-magnesium alloys												
Cu–2.5, Mg–.3	Wrought; h.-t. and aged (A17S–T)	2.74	.37	4.3	23.5	7200	...	17 (.2% perm.)	30	27*	9.5†	70
Aluminum-copper-magnesium-manganese alloys												
Cu–4.0, Mg–.5, Mn–.5	Wrought; annealed (17S–O)	2.79	.41	3.8	23.5	7200	...	7.0 (.2% perm.)	18	22* (2 in.)	7.7†	45
Cu–4.32, Mg–1.44, Mn–.48, Fe–.16	Plate, ½ in. w.-q. from 920° F (24S–T)	2.77	.29	5.7	23.2	...	...	34.0	48	20	18	120
Cu–4.4, Fe–.81, Mg–.67, Mn–.64, Si–.22	Rod, ¾ in. diam. h.-t. and aged	...	...	...	...	7600	26.4	29.4 (.1% perm.)	42.0	19.7 ($4\sqrt{\text{area}}$)	..	..
Cu–4.4, Mn–.8, Si–.8, Mg–.4	Forged; h.-t. and aged (14S–T)	2.80	.37	4.3	23.0	7200	...	39 (.2% perm.)	49	14 (2 in.)	11†	135
Cu–4.5, Mg–1.5, Mn–.6	Sheet, h.-t. and cold-worked (24S–RT)	...	...	...	23.2	7200	...	39 (.2% perm.)	49	13 (2 in.)	..	116
Aluminum-copper-nickel alloys												
Cu–4.0, Ni–2.0, Mg–1.51	Sand-cast; aged (142–T571)	2.78	.32	5.1	22.5	7200	...	20 (.2% perm.)	22	.5 (2 in.)	5.6†	85

** For reference, see footnote 56, p. 187.
* Values apply in general to all wrought forms except large-sized extrusions; elongations apply to ½ in. diameter test specimens. † 5×10^8.

(continued)

TABLE 186.—MECHANICAL PROPERTIES OF ALUMINUM AND ALUMINUM ALLOYS (continued)

Composition	Condition	Density cgs	Thermal conductivity cgs	Resistivity microhm-cm	Thermal expansion $\times 10^6$ cgs	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit and cycles kg/mm²	Hardness number
Aluminum-copper-silicon alloys												
Cu–4.0, Si–3.0	Sand-cast (108)	2.73	.29	5.6	22.0	7200	. . .	10 (.2% perm.)	15	2 (2 in.)	6†	55
Cu–4.5, Si–2.5	Chill-cast: h.-t. (B195–T4)	2.78	.33	4.9	22.0	7200	. . .	13 (.2% perm.)	26	10 (2 in.)	6.7†	75
Cu–7.0, Si–2.0, Zn–1.5, Fe–1.2	Sand-cast	2.85	. . .	. . .	. . .	7200	. . .	9.8 (.2% offset)	13–16	0–1.5 (2 in.)	6.0†	55–80
Aluminum-copper-zinc alloys												
Cu–7.0, Zn–1.7, Fe–1.2	Sand-cast (112)	2.85	.29	5.7	22.0	7200	. . .	10.5 (.2% perm.)	17	1.5 (2 in.)	6.3†	70
Aluminum-magnesium alloys												
Mg–1.0, Si–.6 Cr–.25, Cu–.25	Wrought; ann. (61S–O)	2.70	.41	3.8	23.5	7200	. . .	5.6 (.2% perm.)	13	22 (2 in.)*	5.6†	30
Mg–1.3, Si–.7 Cr–.25	Wrought; h.-t. and aged (53S–T)	2.69	.37	4.3	23.5	7200	. . .	23 (.2% perm.)	27	20 (2 in.)*	7.7†	80
Mg–2.5, Cr–.25	Wrought; hard (52S–H)	2.68	.33	4.9	23.7	7200	. . .	25 (.2% perm.)	29	8 (2 in.)*	14.5†	85
Mg–3.8	Sand-cast (214)	2.61	.33	4.9	23.9	7200	. . .	8.4 (.2% perm.)	18	9 (2 in.)	3.9†	50
Mg–3.8, Zn–1.8	Chill-cast (A 214)	2.66	.32	5.1	23.9	. . .	. . .	11 (.2% perm.)	19	5 (2 in.)	. .	60
Mg–10.00	Sand-cast h.-t. (220–T4)	2.52	.21	8.2	24.5	7200	. . .	18 (.2% perm.)	32	14 (2 in.)	4.9†	75
Auminum-manganese alloys												
Mn–1.2	Wrought; ann. (3S–O)	2.73	.46	3.4	23.6	7200	. . .	4.2 (.2% perm.)	11	40 (2 in.)*	4.9†	28
Mn–1.25, Mg–1.0	Annealed	2.72	. . .	. . .	. . .	. . .	. . .	7	18	20 (2 in.)	9.8	45

(continued)

TABLE 186.—MECHANICAL PROPERTIES OF ALUMINUM AND ALUMINUM ALLOYS (concluded)

Composition	Condition	Density	Thermal conductivity	Resistivity microhm-cm	Thermal expansion × 10⁶	Modulus of elasticity	Proportional limit	Yield strength	Tensile strength	Elongation	Endurance limit and cycles	Hardness number
		cgs	cgs		cgs	kg/mm²	kg/mm²	kg/mm²	kg/mm²	percent	kg/mm²	
Aluminum-silicon alloys												
Si–5.0	Sand-cast (43)	2.64	.35	4.7	22.0	7200	...	6.3 (.2% perm.)	13	6 (2 in.)	4.6†	40
Si–12	Die-cast; ¼ in. diam. (13)	2.69	.37	4.4	20.0	7200	...	13 (.2% perm.)	23	1.8 (2 in.)	10.5†	..
Si–13	Die-cast (13)	...	.33	4.8	...	...	...	...	..	..	..	..
Aluminum-silicon-copper alloys												
Si–5.0, Cu–1.3, Mg–.5	Sand-cast; h.-t. and aged (355–T6)	2.66	.34	4.8	22.0	7200	...	18 (.2% perm.)	25	3.5 (2 in.)	6.0†	90
Si–5.0, Cu–4.0	Die-cast, ¼ in. diam. (85)	2.79	.27	6.1	20.9	7200	...	13 (.2% perm.)	25	2.7 (2 in.)	12†	..
Aluminum-silicon-magnesium alloys												
Si–1.0, Mg–.6	Heat-treated and aged	...	...	...	...	...	...	28 (.2% perm.)	24	14 (2 in.)	..	95
Si–7.0, Mg–.3	Sand-cast; aged (356–T51)	2.66	.40	4.0	21.4	7200	...	14 (.2% perm.)	18	2 (2 in.)	5.3†	60
Aluminum-silicon-nickel alloys												
Si–12, Ni–2.5, Mg–1.0, Cu–.8, Fe–.8	Chill-cast; aged (A132–T551)	2.70	.28	6.0	18.9	7200	...	20 (.2% perm.)	25	.5 (2 in.)	..	105
Aluminum-zinc alloys												
Zn–5.0, Mg–2.5, Cu–2.3, Ni–1.0, Ti–.1	Wrought; h.-t. and artificially aged	...	...	...	...	7000	...	44–52 (.1% offset)	50–60	10–16	19.5–20.5 (2×10^7)	160–180
Zn–25.0, Cu–3.0	Bar, ½ in. hot-rolled	3.29	...	...	...	7000	...	43.0 (yld. pt.)	50	21 (2 in.)	..	..

TABLE 187.—MECHANICAL PROPERTIES OF BRASSES AND BRONZES*

Name	Composition percent	Condition	Density g/cm³	Thermal conductivity at 20°C cgs	Resistivity microhm-cm	Thermal expansion cgs	Yield strength at ½% elongation under stress kg/mm²	Tensile strength kg/mm²	Elongation in 2 in. percent	Hardness No.
Brasses										
Muntz metal	Cu-61; Zn-39	.040″ strip; hot-rolled	8.48	.294	6.25	2.07×10^{-5}	14.1	38.0	45	F 80
		.040″ strip; cold-rolled					42.2	56.2	5	
Yellow brass	Cu-66; Zn-34	.040″ strip; .025mm ann.	8.47	.277	6.38	2.02×10^{-5}	14.1	36.5	56	F 73
		.040″ strip; .070mm ann.					10.5	32.3	64	F 60
		.040″ strip; hard (37%)					42.2	52.7	7	B 80
		.040″ strip; spring (60%)					45.7	63.2	3	B 88
		.100″ wire; rivet (10%)					31.6	42.2	30	...
		.100″ wire; spring (84%)					47.8	87.8	..	...
Cartridge brass, 70%......	Cu-70; Zn-30	.040″ strip; .025mm ann.	8.52	.294	6.25	1.98×10^{-5}	14.1	36.6	56	F 73
		.040″ strip; .070mm ann.					10.5	32.3	64	F 60
		.040″ strip; hard (37%)					42.2	53.4	7	B 83
		.040″ strip; spring (60%)					45.7	65.4	3	B 90
		.100″ wire; spring (84%)					47.8	90.0	..	...
Low brass, 80%..........	Cu-80; Zn-20	.040″ strip; .015mm ann.	8.67	.335	5.38	1.91×10^{-5}	12.6	33.1	47	F 75
		.040″ strip; .050mm ann.					10.5	30.2	55	F 60
		.040″ strip; hard (37%)					42.2	51.3	7	B 83
		.040″ strip; spring (60%)					45.7	63.2	3	B 90
		.100″ wire; spring (84%)					47.8	84.3	..	...
Jewelry bronze	Cu-87.5; Zn-12.5	.040″ strip; .015mm ann.	8.77	.413	4.20	1.85×10^{-5}	17.6	30.2	42	F 68
		.040″ strip; .030mm ann.					9.15	28.1	46	F 61
		.040″ strip; hard (37%)					40.1	47.1	5	B 73
		.040″ strip; spring (60%)					44.3	55.5	3	B 82
Commercial bronze, 90%..	Cu-90; Zn-10	.040″ strip; .015mm ann.	8.80	.45	3.92	1.84×10^{-5}	21.1	28.8	42	F 65
		.040″ strip; .030mm ann.					8.43	26.7	45	F 58
		.040″ strip; hard (37%)					38.7	43.6	5	B 70
		.040″ strip; spring (60%)					44.3	51.3	3	B 78

* For reference, see footnote 57, p. 187.

(continued)

TABLE 187.—MECHANICAL PROPERTIES OF BRASSES AND BRONZES (continued)

Name	Composition	Condition	Density	Thermal conductivity at 20°C	Resistivity microhm-cm	Thermal expansion	Yield strength at ½% elongation under stress	Tensile strength	Elongation in 2 in.	Hardness
	percent		g/cm^3	cgs		cgs	kg/mm^2	kg/mm^2	percent	No.
Gilding, 95%	Cu-95; Zn-5	.040″ strip; .015mm ann.	8.86	.55	3.08	1.80×10^{-5}	7.03	26.7	42	F 60
		.040″ strip; .030mm ann.					5.62	25.3	44	F 52
		.040″ strip; hard (37%)					33.7	38.6	6	B 62
		.040″ strip; spring (60%)					40.1	44.3	5	B 72
Conductivity bronzes										
80% conductivity bronze...	Cu-99; Cd-1.0	Hard-drawn	8.88	...	2.15	...	...	58.6	..	...
65% conductivity bronze...	Cu-99.5; Sn-.5	Hard-drawn	8.88	...	2.65	...	...	52.8	..	...
55% conductivity bronze...	Cu-98.7; Cd-.8; Sn-.5	Hard-drawn	8.88	...	3.13	...	...	63.3	..	...
Special brasses										
Naval brass	Cu-60; Zn-39.25; Sn-.75	.040″ strip; light ann.	8.42	.278	6.62	2.17×10^{-5}	21.1	43.6	40	B 60
		.040″ strip; quarter hard (11%)					40.8	49.2	17	B 75
		.50″ strip; as hot-rolled					17.6	38.7	50	B 55
		1″ rod; soft ann.					17.6	40.1	45	B 50
		1″ rod; light ann.					21.1	44.3	40	B 57
		1″ rod; quarter hard (9%)					35.2	49.2	28	B 78
		1″ rod; half hard (18%)					37.3	52.8	20	B 82
Antimonial Admiralty	Cu-71; Zn-27.97 Sn-1; Sb-.035	1″×.05″ tube; .025mm ann.	8.52	.265	6.89	2.02×10^{-5}	...	37.3	70	F 75
		1″×.05″ tube; hard (35%)					...	59.8	15	B 88
Bushing bronze	Cu-90; Zn-9.5; Sn-.5	.040″ strip; half hard	8.80	.45	4.53	1.84×10^{-5}	31.6	33.4	12.5	B 55
		hard					40.1	42.2	5	B 70
		extra hard					44.0	49.2	2.5	B 78
		light ann.					7.03	28.1	40	F 70

(continued)

TABLE 187.—MECHANICAL PROPERTIES OF BRASSES AND BRONZES (concluded)

Name	Composition percent	Condition	Density g/cm³	Thermal conductivity at 20°C cgs	Resistivity microhm-cm	Thermal expansion cgs	Yield strength at ½% elongation under stress kg/mm²	Tensile strength kg/mm²	Elongation in 2 in. percent	Hardness No.
Tin bronzes										
Phosphor bronze 5% (grade A)	Cu-95; Sn-4.75; P-.25	.040″ strip; .035mm ann.	8.85	.157	12.28	1.78×10^{-5}	14.1	34.5	58	F 75, B 28
		.040″ strip; hard (37%)					52.7	56.9	10	B 87
		.040″ strip; spring (60%)					56.2	70.3	4	B 93
		.100″ wire; spring (84%)					...	98.2	2	...
Phosphor bronze 8% (grade C)	Cu-92; Sn-7.75; P-.25	.040″ strip; .035mm ann.	8.80	.120	15.65	1.82×10^{-5}	16.9	40.8	65	F-80; B-50
		.040″ strip; hard (37%)					50.6	65.4	10	B 93
		.040″ strip; spring (60%)					...	78.7	3	B 98
		.100″ wire; spring (68%)					...	98.2	..	...
444 Bronze	Cu-88; Sn-4; Zn-4; Pb-4	.040″ strip; .035mm ann.	8.88	.206	9.07	1.72×10^{-5}	...	31.6	55	F 65
		1″ rod; hard (20%)					...	45.7	20	
Olympic bronze										
Olympic bronze, type A	Cu-96; Si-3; Zn-1	.040″ strip; .070mm ann.	8.52	.087	24.6	1.80×10^{-5}	14.75	39.4	63	F 75
		.040″ strip; spring (60%)					43.8	77.3	4	B 97
		1″ rod; extra hard (50%)					42.2	75.9	13	B 95
		.100″ wire; hard (60%)					45.7	87.9	5	...
		.100″ wire; spring (80%)					49.3	102.0	3	...
Special engineering alloy										
Tellurium copper	Cu-99.5; Te-.5	⅛″ rod, ½ hard (20%)	8.94	.848	1.915	1.79×10^{-5}	28.8	30.9	15	...

TABLE 188.—MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOYS **

Composition percent	Condition	Density cgs	Thermal conductivity cgs	Resistivity microhm-cm	Thermal expansion cgs	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit cycles kg/mm²	Hardness number
Pure and commercial copper												
Oxygen-free copper (OFHC); Cu–99.997	Rod, ½ in. diam., cold-drawn (29% red) from .125 mm grain size	8.95	.93	1.706*	17.6*	12,500	...	34.5(.5% extn.)	36.0	14†	12.0(3×10⁸)	R_B 37
Oxygen-free copper (OFHC); Cu–99.996	Rod, ¾ in. diam., cold-drawn (36% red) from .135 mm grain size	...	...	...	...	12,300	...	33 (.5% extn.)	33.5	20†	...	...
Oxygen-free copper (OFHC); Cu–99.99	Rod, hard-drawn	...	...	...	...	13,000	3.45	12.7(.01%)	29.0	29§	...	...
Cu–99.95	Sheet, .020 in., soft	...	...	...	...	...	4.8	...	22.0	35†	7.7(10⁸)	...
"	Sheet, .020 in., cold-worked (21% red)	...	...	...	...	...	11.0	...	31.2	7.8†	9.1(10⁸)	R_B 33
Cu–99.94; 0–.030	Rod, drawn (37% red)	...	...	...	...	12,100	3.4	10.0(.01%)	26.0	32§	...	...
Electrotough-pitch copper	Rod, 1 in. diam., hot-rolled	8.92	.93	1.706*	17.6*	9,300	...	4.55(.01% perm.)	22.0	59†	2.8‡	41
Electrotough-pitch copper	Cold-rolled	...	...	...	...	...	7.0	15 (.01% perm.)	36.5	13†	11.0	...
Copper-aluminum alloys												
Al–3.96	Cast, annealed	...	...	...	...	...	4.30	6.1(.5% extn.)	24.3	84†	...	...
"	Forged, annealed	...	...	...	...	...	5.75	8.8(.5% extn.)	33.0	81†	...	...
Al–8.0	Sheet or plate, soft	7.78	.17	11.8*	17.8*	...	...	17 (.5% extn.)	42	60†	...	R_B 30
"	Sheet or plate, hard	...	...	...	...	10,500	...	42 (.5% extn.)	84	4†	...	R_B 99

** For references, see footnotes 55 and 57, p. 187.

* $\times 10^{-6}$. † 2 in. ‡ Alternating torsion. § $4\sqrt{\text{area}}$.

(continued)

TABLE 188.—MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOYS (continued)

Composition	Condition	Density	Thermal conductivity	Resistivity microhm-cm	Thermal expansion	Modulus of elasticity	Proportional limit	Yield strength	Tensile strength	Elongation	Endurance limit cycles	Hardness number
percent		cgs	cgs		cgs	kg/mm²	kg/mm²	kg/mm²	kg/mm²	percent	kg/mm²	
Al-9.78	Cast; w.-q. from 1650°F, ½ hr at 1200°F, f.c.	...	...	...	...	13,600	17.5	...	54.5	14‖	18.0(7×10^7)	142
Al-10	Cast	7.5	...	...	...	8,500–10,500	7–8	14–17.5 (.5% perm.)	42–53	15–25†	...	90–100
Al-10.06, Fe-.13	Extruded to 1 9/32 in. diam., w.-q. from 1650°F at 1150°F, f.c.	7.57	...	...	...	14,000	11.9	...	54.5	36‖	24.0(6×10^7)	128
Copper-aluminum-iron alloys												
Al-5.39, Fe-5.14	Forged	...	...	...	...	...	...	34.0(yld. pt.)	61.0	32†	...	119
Al-8, Fe-2.5	Rod, soft	7.75	...	...	...	...	...	20.2(.5% extn.)	51	50†	...	R_B 52
Al-8.6, Fe-2.9	Sand-cast	...	...	...	...	...	9.8	15–19	42–50	22–27†	...	109–124
Al-9, Fe-3	Forged	...	...	...	...	...	12.6	23.6(yld. pt.)	60.0	42†	...	130
Copper-aluminum-iron-manganese alloys												
Al-7.18, Fe-.62, Mn-.58	Sand-cast	...	...	...	...	...	...	12.3(yld. pt.)	39.0	52†	...	69
Al-9.9, Fe-3.2 Mn-2.9	Round bar, die-cast at 2155°F	7.42	...	...	...	...	...	22.5(.15% perm.)	63.0	10†	...	...
Copper-aluminum-iron-nickel alloys												
Al-5.0, Fe-3.07, Ni-1.91, Mn-.33	Rod, 1¼ in., diam., forged (75% red)	...	...	...	...	...	...	25.2(yld. pt.)	51.0	34†	...	130
Al-9.73, Fe-5.42, Ni-4.97	Rod, ¾ in. diam., forged	...	...	...	...	13,200	3.8	54.5(.1% perm.)	82	11§	...	...
Al-10.7, Fe-4, Ni-4	Forged, h.-t.	7.75	...	...	...	...	21	39–42	67–72	10–15†	...	190–217

‖ 8 in.

(continued)

TABLE 188.—MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOYS (continued)

Composition	Condition	Density	Thermal conductivity	Resistivity microhm-cm	Thermal expansion	Modulus of elasticity	Pronortional limit	Yield strength	Tensile strength	Elongation	Endurance limit cycles	Hardness number
percent		cgs	cgs		cgs	kg/mm²	kg/mm²	kg/mm²	kg/mm²	percent	kg/mm²	
Copper-aluminum-manganese alloys												
Al–7, Mn–1	Sheet, .2 in., cold-rolled (50% red)	...	...	...	...	...	54.0	...	74	12†	...	...
Al–10, Mn–1	Chill-cast	...	...	...	...	...	...	25.0(yld. pt.)	62.5	25†	...	...
Copper-aluminum-nickel alloys												
Al–7, Ni–1	Sheet, .2 in., cold-rolled (50% red)	...	...	...	...	...	60.0	...	80.0	6†	...	...
Al–9.4, Ni–7.4, Fe–4.1	Rod, 1 in. diam., chill-cast	7.57	...	...	...	...	...	4.03(.15% perm.)	67	5†	...	188
Al–10.1, Ni–7.6, Si–.4	Rod, 1 in. diam., chill-cast	7.58	...	...	...	...	...	44 (.15% perm.)	63.5	2†	...	...
Copper-aluminum-silicon alloys												
Al–7.2, Si–1.88, Fe–.11	Rod, 1 in. square, chill-cast from 2055°F	...	...	...	...	...	...	22.0(yld. pt.)	53.0	19[a]	...	139
Al–7.2, Si–1.88, Fe–.11	Rod, $\frac{3}{4}$ in. diam., forged	...	...	...	...	...	...	42 (yld. pt.)	69.5	25[a]	...	186
Copper-aluminum-zinc alloys												
Al–8.89, Zn–1.40, Fe–.15	Rod, $\frac{3}{4}$ in. diam., extruded and drawn	...	...	...	...	12,300	12.4	29.3(.01% perm.)	25.2	37§	...	...
Copper-arsenic alloys												
As–.33, Ag–.10	Rod, $\frac{7}{8}$ in. diam., drawn (7% red)	...	...	...	...	...	20.4	7.7(.01% perm.)	25.2	47§	...	...
" "	Rod, $\frac{7}{8}$ in. diam., drawn (7% red) ann. 100 hr at 390°F	...	...	...	...	...	10.4	...	24.7	46§	...	...

[a] 1.3 in.

(continued)

TABLE 188.—MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOYS (continued)

Composition percent	Condition	Density cgs	Thermal conductivity cgs	Resistivity microhm-cm	Thermal expansion cgs	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit cycles kg/mm²	Hardness number
Copper-beryllium alloys												
Be–1.0	Quenched	8.6	...	...	...	...	...	14.7 (yld. pt.)	30–35	50–55¶	...	65–70
"	Quenched and work-hardened	...	...	...	...	...	...	71.5 (yld. pt.)	75	6¶	...	200
Be–2.2	Cast	...	...	...	...	...	...	30.0	44.0	14†	...	109
"	Cast, quenched from 1470°F, aged at 645°F	...	...	...	...	...	...	66.1	83.5	1†	...	400
Copper-beryllium-cobalt alloys												
Be–2, Co–.2	Soft, annealed	...	...	...	...	12,600	12.6	18.3 (.2% extn.)	46.5	50†	...	...
" "	Heat-treated	...	...	...	...	13,300	60.5	102 (.2% extn.)	123	8†	...	...
" "	Rolled (21% red), h.-t.	...	...	...	...	12,700	83	121 (.2% extn.)	135	4†	...	...
" "	Rolled (37% red), h.-t.	...	...	...	...	12,600	73	126 (.2% extn.)	141	3†	...	...
Copper-beryllium-nickel alloys												
Be–2.16, Ni–.22, Fe–.11	Rod, ¾ in. diam., quenched from 1515°F, cold-drawn (15% red)	...	...	...	...	11,900	...	56.0 (.5% extn.)	77	11†	...	...
Be–2.16, Ni–.22, Fe–.11	Rod, ¾ in. diam., quenched from 1515°F, cold-drawn (15% red) 3 hr at 570°F	...	...	...	...	13,000	...	64.5 (.5% extn.)	150	2.8†	...	...
Be–2.14, Ni–.28 Fe–.06	Sheet, .040 in., w.-q. from 1470°F, cold-rolled (37% red) 2 hr at 525°F	...	...	...	...	12,900	39.0	...	136	2.0†	19.5	R_G 104

¶ 10 diam.

(*continued*)

TABLE 188.—MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOYS (continued)

Composition percent	Condition	Density cgs	Thermal conductivity cgs	Resistivity microhm-cm	Thermal expansion cgs	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit cycles kg/mm²	Hardness number
Copper-cadmium alloys												
Cd–.8	Wire, cold-drawn	...	...	...	...	12,700	...	...	71	...	...	...
Copper-chromium alloys												
Cr–.88, Si–.09	Rod, ½ in. diam., cold-worked (92% red)	...	...	...	...	13,900	...	46.5(.5% extn.)	51.0	7.5†	18.1(3×10⁸)	R_B 73
Copper-chromium-beryllium alloys												
Cr–.4, Be–.1	Rod, 1 in. diam., cast, quenched from 1700°F, aged 1 hr at 935°F	...	...	...	...	...	10.5–11.5	...	21–25	10–15	...	80
Copper-cobalt-beryllium alloys												
Co–2.6, Be–.4	Rod, 1 in. diam., cast, 1 hr at 1650°F, w.-q. 2-4 hr at 930°F	...	...	...	...	12,000	31.6	...	63.0	10†	...	220
Co–2.6, Be–.4	Rod, forged, 1 hr at 1650°F., w.-q. 2-4 hr at 930°F	...	...	...	...	12,000	31.6	...	70.3	20†	...	220
" "	Quenched, work-hardened, h.-t.	...	...	...	...	11,500	...	57.5(yld. pt.)	75	15¶	...	210
Copper-iron alloys												
Fe–25	Wire, .040 in. diam., cold-drawn (96% red)	...	...	...	...	...	...	...	97	...	...	...
Fe–50	Wire, .040 in. diam., cold-drawn (96% red)	...	...	...	...	...	...	...	136	...	...	...
"	Sand-cast	...	...	...	...	...	...	22.5(yld. pt.)	39.0	25†	...	130

(continued)

TABLE 188.—MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOYS (continued)

Composition percent	Condition	Density cgs	Thermal conductivity cgs	Resistivity microhm-cm	Thermal expansion cgs	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit cycles kg/mm²	Hardness number
Copper-lead-tin alloys												
Pb-8.61, Sn-5.36, Zn-.82, Sb-.34, Ni-.14	Cast from 2040°F	8.83	...	...	...	7,650	...	10.3(.1% offset)	21.4	17†	...	52
Pb-10; Sn-10	Sand-cast from 1750-1900°F	8.9	...	...	...	6,000	6.7-8.1	13-14	19-23	7-12†	...	50-70
Copper-manganese alloys												
Mn-13; Al-9	Soft	7.2	...	...	...	...	...	...	67	19	...	300
" "	Hard-rolled	...	...	...	...	...	...	...	95.5	1	...	510
Copper-nickel alloys												
Ni-30.48, Mn-.22, Fe-.07	Rod, ¾ in. diam., cold-drawn (15% red) from .030 mm grain size	...	...	...	...	15,200	...	44.8(.5% extn.)	47.3	23†	...	...
Ni-30.48, Mn-.22, Fe-.07	Rod, ¾ in. diam, cold-drawn (15% red) from .030 mm grain size 2 hr at 840°F	...	...	...	...	15,600	...	38.4(.5% extn.)	46.2	30†	...	...
Constantan												
Ni-45	Sand-cast	8.6	...	...	...	...	...	14.8(.2% offset)	39.4	32†	...	80
Ni-45, Mn-.5-1.0, Fe-.27, C-.05	Rod, ann. 4 hr at 1400°F	...	...	...	...	17,400	14.2	18.3(yld. pt.)	46.8	46†	...	R_B 54
Ni-44.77, Mn-.89, Fe-.66, C-.078	Rod, 1 hr at 1450° F, f.-c.	...	...	...	...	...	14.8	17.8(.01% perm.)	48.6	48†	19.6	86
Ni-44.77, Mn-.89, Fe-.66, C-.078	Rod, cold-rolled	...	...	...	...	...	...	38.5(.01% perm.)	72.5	15†	30.2(4×10⁷)	159

(continued)

TABLE 188.—MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOYS (continued)

Composition percent	Condition	Density cgs	Thermal conductivity cgs	Resistivity microhm-cm	Thermal expansion cgs	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit cycles kg/mm²	Hardness number
Copper-nickel-beryllium alloys												
Ni–2.0, Be–.2	Quenched from 1650°F, cold-drawn, (56% red)	...	...	...	...	...	...	...	46.8	4.3†	...	...
" "	Quenched from 1650°F, ½ hr at 930°F, cold-drawn (56% red)	...	...	...	...	...	...	...	85.5	2.5†	...	...
Copper-nickel-manganese alloys												
Ni–13.5, Mn–5, Al–1.5	Rod, 1 in. diam., extruded, cold-drawn (10% red)	...	...	...	...	...	12.6	35.4(.2%)	48.6	36†	...	V 157
"	Rod, 1 in. diam., cold-drawn, 2 hr at 1110°F	...	...	...	...	...	49.0	60.0(.2%)	77.0	21†	...	V 240
Copper-nickel-silicon alloys												
Cu–94.15, Ni–5.14, Si–rem.	Sheet, .020 in., soft	...	...	...	...	11,500	37.4	...	72.5	4.0†	9.8(10^8)	...
Copper-nickel-tin alloys												
Ni–29.08, Sn–.95, Fe–.25, C–.07	Rod, 1 in. diam., cold-drawn	...	...	...	...	15,000	...	39.0(.01% perm.)	61.3	3.8†	23.5(5×10^7)	143
Copper-nickel-zinc alloys												
Ni–20, Zn–5	Sheet or plate, soft	8.86	...	...	...	...	...	14.0(.5% extn.)	35.1	35†	...	R_B 25
" "	Sheet or plate, hard	...	...	...	...	13,300	...	30.2(.5% extn.)	60.0	5†	...	R_B 88
Ni–20.22, Zn–5.26, Mn–.25, Fe–.08, Mg–.06	Rod, ¾ in. diam., cold-drawn (15% red) from .060 mm grain size, 2 hr at 840°F	...	...	...	...	14,600	...	32.0(.5% extn.)	41.0	32†	...	...

(continued)

TABLE 188.—MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOYS (continued)

Composition	Condition	Density	Thermal conductivity	Resistivity microhm-cm	Thermal expansion	Modulus of elasticity	Proportional limit	Yield strength	Tensile strength	Elongation	Endurance limit cycles	Hardness number
percent		cgs	cgs		cgs	kg/mm²	kg/mm²	kg/mm²	kg/mm²	percent	kg/mm²	
Copper-silicon-manganese alloys												
Si–1.41, Mn–.21, Fe–.06	Rod, ½ in. diam., cold-worked (72% red)	...	...	...	...	12,000	...	48.0(.5% extn.)	61.8	10 †	21.4(3×10⁸)	R_B 86
Si–3, Mn–1	Sheet, .040 in., ann.	8.53	...	...	...	10,500	...	17 (.5% extn.)	42	65 †	...	R_F 45
Copper-silver alloys												
Ag–.093, Fe–.007	Rod, 1 in. diam., drawn (10% red)	...	...	...	...	...	1.9	...	24.2	51 §	...	...
" "	Rod, 1 in. diam., drawn (10% red) 2 hr at 570°F	...	...	...	...	14,000	5.7	...	24.1	51 §	...	...
Copper-tin alloys												
Sn–.48	Rod, 1 in. diam., drawn (10% red)	...	...	...	...	13,600	3.16	...	32.4	33 §	...	...
"	Rod, 1 in. diam., drawn (10% red) 2 hr at 570°F	...	...	...	...	13,800	20.2	...	31.6	37 §	...	...
Sn–4.23, P–.13	Rod, ¾ in. diam., drawn ½ hr at 525°F	...	...	...	...	12,400	17.3	40.2(.1% extn.)	43.5	33 §	15.5(5×10⁷)	138
Copper-tin-lead alloys												
Sn–5.0, Pb–1, P–.1	Sheet, .04 in. hard	...	...	...	...	10,500	...	42.0(.5% extn.)	57.5	8 †	...	R_B 90
Copper-tin-nickel alloys												
Sn–3.88, Ni–2.33, S–.58, P–.37	Sheet, cold-rolled, quenched from 1470°F, aged 1 hr at 930°F	...	...	...	...	12,300	26.6	...	51.4	22 †	...	R_B 80

(continued)

TABLE 188.—MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOYS (continued)

Composition	Condition	Density	Thermal conductivity	Resistivity microhm-cm	Thermal expansion	Modulus of elasticity	Proportional limit	Yield strength	Tensile strength	Elongation	Endurance limit cycles	Hardness number
percent		cgs	cgs		cgs	kg/mm²	kg/mm²	kg/mm²	kg/mm²	percent	kg/mm²	
Copper-zinc alloys												
Zn-.48	Rod, 1 in. diam., drawn (10% red)	...	...	...	...	13,900	1.27	...	24.2	49 §	...	...
Zn-15	Sheet, .040 in., cold-drawn (37% red)	8.5	.38	4.7*	18.6*	...	...	...	50	5 †	...	R_B 78
Gilding metal; Zn-5	Sheet, .040 in. soft	8.85	.57	3.1*	18.1*	...	...	...	25	44 †	...	R_F 45
Cu-90.10, Zn-rem	Rod, ½ in. diam., ann.	8.8	.45	4.1*	18.3*	...	...	8.1 (.5% extn.)	26	54 †	...	R_F 53
Cu-71.68, Fe-.02, Pb-.01, Zn-rem	Sheet, .020 in., cold-worked (37% red)	...	...	...	...	11,200	16.2	...	52.8	7.5 †	13.3 (10^8)	R_B 82
Zn-30.2	Cast	8.2	.29	6.4*	19.8*	...	...	10.2 (yld. pt.)	26.2	58 †	...	55
Zn-33	Sheet, hard	...	...	...	...	...	...	...	59.5	4 †	...	153
Cu-66.12, Zn-rem	Sheet, .025 in. (grain size, .035 mm)	...	...	...	...	...	...	...	35.7	62 †	...	...
Zn-34.6, Fe < .1	Rod, rolled	...	...	...	...	...	...	29.2 (yld. pt.)	36.9	40 †	...	101
Zn-41.04	Cast	...	...	...	...	...	...	13.8 (yld. pt.)	39.2	45 †	...	90
Copper-zinc-aluminum alloys												
Zn-16.35, Al-6.16, Mn-4.39, Fe-2.30	Sand-cast	...	...	...	...	...	16.1	...	64.0	28 †	...	...
Cu-63.35, Al-4.12, Mn-2.74, Fe-1.73, Pb-.25, Ni-.2, Zn-rem.	Cast from 2,100°F	7.90	...	...	...	9,800	...	41.8 (.5% perm.)	69.5	10	...	179
Zn-31.45, Al-4.10, Ni-3.0, Fe-1.45	Bar, 2½ in. square, cast	...	...	...	...	...	...	36.8 (.5% perm.)	70.0	12 †	...	159
Zn-33.57, Al-3.95, Ni-3.13	Bar, 2½ in. square, cast	...	...	...	...	...	...	41.0 (.5% perm.)	66.8	6.0 †	...	185
Copper-zinc-arsenic alloys												
Zn-29.41, As-.49	Cast	...	...	...	...	...	...	8.35 (yld. pt.)	23.1	36 †	...	58

(continued)

TABLE 188.—MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOYS (concluded)

Composition percent	Condition	Density cgs	Thermal conductivity cgs	Resistivity microhm-cm	Thermal expansion cgs	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit cycles kg/mm²	Hardness number
Copper-zinc-iron alloys												
Zn–38.48, Fe–1.21, Sn–.72, Al–.1, Pb–.09	Rod, ½ in., hard-drawn	...	...	...	...	10,900	...	57.0	62.0	12†	...	178
Cu–56.85, Fe–1.50, Sn–.32, Al–.23, Mn–.20, Zn–rem.	Cast	8.26	...	...	...	10,000	9.15	...	49.0	33‖	12.0(2.5×10⁸)	93
Copper-zinc-manganese alloys												
Zn–33.1, Mn–4.2, Al–3.5	Round bar, die-cast from 1930°F	7.79	...	...	...	...	...	44.0(.15% perm.)	66.0	7†	...	187
Copper-zinc-nickel alloys												
Zn–9.89, Ni–2.32, Si–.57	Sheet, .020 in., quenched from 1470°F, aged 1 hr at 930°F	...	...	...	...	13,900	31.3	...	63.5	14†	13.0(10⁸)	R_B 86
Zn–19.8, Ni–2.37, Si–.57	Sheet, .020 in., quenched from 1470°F, aged 1 hr at 930°F	...	...	...	...	12,100	26.2	...	60.5	22†	11.2(10⁸)	R_B 85
Zn–30.12, Ni–2.36, Si–.66	Sheet, .040 in., hard-rolled	...	...	...	...	9,800	33.8	...	98.5	2.5†	...	R_B 98
Copper-zinc-tin alloys												
Zn–6, Sn–6	Sand-cast	8.65	...	...	...	...	...	11.2–12.6 (yld. pt.)	25–30	30–60	...	50–65
Admiralty brass: Zn–28, Sn–1	Sheet, ann.	8.53	...	...	...	10,500	...	...	31.6	60†	...	...
Naval brass: Cu–61.20, Sn–.43, Pb–.10, Zn–rem.	Rod, ¾ in. diam., rolled	8.42	...	...	...	10,800	23.5	...	48.0	27	14.8(10⁸)	...
Zn–41, Sn–1	Die-cast	8.47	...	...	...	...	...	21–25(yld. pt.)	39–42	15–20†	...	120–130

TABLE 189.—COPPER WIRE—SPECIFICATION VALUES

Copper wire: Hard-drawn (and **hard-rolled flat copper** of thicknesses corresponding to diameter of wire). Specification values. (A. S. T. M. B1-15, U. S. Navy Dept.) Specific gravity 8.89 at 20°C (68°F).

Diameter		Minimum tensile strength		Minimum elongation, percent in
mm	in.	kg/mm²	lb/in.²	254 mm (10 in.)
11.68	.460	34.5	49,000	2.75
10.41	.410	35.9	51,000	3.25
9.27	.365	37.1	52,800	2.80
8.25	.325	38.3	54,500	2.40
7.34	.289	39.4	56,100	2.17
6.55	.258	40.5	57,600	1.98
5.82	.229	41.5	59,000	1.79
				in 1524 mm (60 in.)
5.18	.204	42.2	60,100	1.24
4.62	.182	43.0	61,200	1.18
4.12	.162	43.7	62,100	1.14
3.66	.144	44.3	63,000	1.09
3.25	.128	44.8	63,700	1.06
2.90	.114	45.2	64,300	1.02
2.59	.102	45.7	64,900	1.00
2.31	.091	46.0	65,400	.97
2.06	.081	46.2	65,700	.95
1.83	.072	46.3	65,900	.92
1.63	.064	46.5	66,200	.90
1.45	.057	46.7	66,400	.89
1.30	.051	46.8	66,600	.87
1.14	.045	47.0	66,800	.86
1.02	.040	47.1	67,000	.85

NOTE.—P-limit of hard-drawn copper wire must average 55 percent of ultimate tensile strength for four largest-size wires in table, and 60 percent of tensile strength for smaller sizes.

TABLE 190.—COPPER WIRE—MEDIUM HARD-DRAWN

(A. S. T. M. B2-15) Minimum and maximum strengths.

Diameter		Tensile strength				Elongation,
		Minimum		Maximum		minimum percent
mm	in.	kg/mm²	lb/in.²	kg/mm²	lb/in.²	in 254 mm (10 in.)
11.70	.460	29.5	42,000	34.5	49,000	3.75
6.55	.258	33.0	47,000	38.0	54,000	2.50
						in 1524 mm (60 in.)
4.12	.162	34.5	49,000	39.5	56,000	1.15
2.59	.102	35.5	50,330	40.5	57,330	1.04
1.02	.040	37.0	53,000	42.0	60,000	.88

NOTE.—Representative values only from table in specifications are shown above. P-limit of medium hard-drawn copper averages 50 percent of ultimate strength.

TABLE 191.—COPPER WIRE—SOFT OR ANNEALED

(A. S. T. M. B3-15) Minimum values.

Diameter		Minimum tensile strength		Elongation in 254 mm (10 in.),
mm	in.	kg/mm²	lb/in.²	percent
11.70 to 7.37	.460 to .290	25.5	36,000	35
7.34 to 2.62	.289 to .103	26.0	37,000	30
2.59 to .53	.102 to .021	27.0	38,500	25
.51 to .08	.020 to .003	28.0	40,000	20

NOTE.—Experimental results show tensile strength of concentric-lay copper cable to approximate 90 percent of combined strengths of wires forming the cable.

TABLE 192.—MECHANICAL PROPERTIES OF IRON AND STEEL **

Composition percent	Condition	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit kg/mm²	Hardness number
Aluminum steel								
C–.30–.40, Al–.90–1.40, Cr–.90–1.40, Mn–.40–.60, Mo–.15–.25	quenched from 1750°F, tempered at 1100°F	—	—	96	109	15(2 in.)	—	310
Carbon steels								
C–.08, Mn–.41 (open-hearth rimming)	strip, .104 in., rolled	—	—	27.0 (yld. pt.)	37.0	35(2 in.)	—	R_B 55
C–.12, Mn–.84, S–.12, P–.099 (free-cutting steel)	bar, 1⅛ in. diam., cold-rolled	21,400	—	(.001% offset) 53.4	58.5	18(2 in.)	—	V 205
C–.15–.25, Mn–.30–.50	rod, ⅛ in., cold-drawn	21,100	—	76.0	81.5	11(10 in.)	37.3	—
C–.27, Mn–.72, Si–.21	wrought, ann., at 1450°F; f.-c.	19,300	—	26.4	47.4	46(2 in.)	—	153
"	wrought, w.-q. from 1600°F, tempered at 1100°F	20,800	—	38.6	64.0	42(2 in.)	—	191
C–.45, Mn–.77, Si–.21	normalized 1 hr at 1600°F; room:	20,500	—	44.4	79.5	17(2 in.)	—	R_C 16
	— 40°F	—	—	—	—	—	—	R_C 20
	—108°F	20,000	—	52.0	91.5	16(2 in.)	—	R_C 22
"	¾ hr at 1475°F, w.-q., tempered 1 hr at 1000°F; room:	20,800	—	88	95.0	12(2 in.)	—	R_C 27
	— 40°F	—	—	—	—	—	—	R_C 29
	—108°F	20,200	—	95.5	106.5	14(2 in.)	—	R_C 29
C–.57, Mn–.65, Si–.17	oil-quenched from 1490°F, tempered at 860°F	—	—	68.5 (yld. pt.)	102.5	16(2 in.)	—	293
C–.91, Mn–.38, Si–.16 (acid open-hearth)	oil-quenched from 1575°F, tempered at 940°F	21,200	—	101.5 (.01% perm.) 126 (.2% perm.)	159	7(2 in.)	56.2 36.5* 71.7†	444
C–1.04, Mn–.36, Si–.16	⅓ hr at 1550°F, quenched in oil at 120°F, tempered ¼ hr at 800°F	21,000	—	101.5 (.01% perm.) 136.5 (.2% perm.)	166.5	5(2 in.)	68.8 86.5†	430–470

** For reference, see footnote 55, p. 187. * Reversed torsion. † Zero to maximum torsion.

(continued)

TABLE 192.—MECHANICAL PROPERTIES OF IRON AND STEEL (continued)

Composition percent	Condition	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit kg/mm²	Hardness number
Chromium steel								
C-.20, Cr-.75, Mn-.57, Si-.21	bar, ¾ in. diam., normalized at 1700°F	—	—	39.4	53.5	35	—	131
C-.59, Cr-.82, Mn-.83, Si-.35	forged	—	—	60.0	101.5	7(2 in.)	—	286
Chromium-niobium steels								
C-.09, Cr-5.62, Nb-1.04	bar, 1 in. diam., rolled	—	—	69.0	77.3	16(2 in.)	—	192
Chromium-copper steels								
C-.11, Cr-.53, Cu-.37, Si-.82, P-.088	bar, 1 in. diam., normalized	—	—	39.7 (yld. pt.)	58	29(2 in.)	—	—
Chromium-molybdenum steels								
C-.08, Cr-5.81, Mo-.45	bar, ¾ in. diam., 4 hr at 1380°F, a.-c.	—	—	39.4 (yld. pt.)	60.5	29(2 in.)	—	149
C-.10, Cr-12.75, Mo-.35, Mn-.40, Si-.40, S-.30, Ni-.25	annealed	—	—	32.0 (.2% perm.)	52.7	30(2 in.)	30.3	152
	heat-treated	—	—	58.0 (.2% perm.)	73.8	20(2 in.)	39.0	217
Chromium-titanium steels								
C-.11, Cr-5.41, Ti-.75	bar, 1 in. diam., rolled 4 hr at 1380°F, a.-c.	—	—	19.7	43.0	37(2 in.)	—	112
Chromium-tungsten steels								
C-.46, Cr-11.94, W-4.80, Si-2.89, Mn-.49	oil-quenched from 1875°F, tempered at 1470°F	—	71.0	—	90.6	5(2 in.)	—	300
Chromium-vanadium steels								
C-.58, Cr-.73, V-.18, Mn-.68	annealed at 1500°F	—	34.8	—	65.0	28(2 in.)	—	163
"	water-quenched from 1650°F, tempered at 1050°F	—	—	98.5	127.5	14(2 in.)	—	351
C-.52, Cr-.88, V-.21, Mn-.66	¾ hr at 1600°F, quenched in oil at 130°F, tempered 1 hr at 810°F	21,200	—	98.5 (.01% perm.) 16.1 (.01% perm.)	167	11(2 in.)	73 52.7* 90.0†	477–488

(continued)

TABLE 192.—MECHANICAL PROPERTIES OF IRON AND STEEL (continued)

Composition percent	Condition	Modulus of elasticity kg/mm^2	Proportional limit kg/mm^2	Yield strength kg/mm^2	Tensile strength kg/mm^2	Elongation percent	Endurance limit kg/mm^2	Hardness number
Copper steels								
C-.08, Cu-.25, Mn-.38	sheet, .062 in., rolled	—	—	29.8	36.0	31 (8 in.)	—	R_B 60
Graphitic steel								
C-1.50, Si-1.0, Mo-.25	annealed	—	—	34.8 (yld. pt.)	59.4	25 (2 in.)	—	197
Iron								
TC-3.41, GC-2.85, CC-.56, Si-2.44, P-.63, Mn-.57, S-.070, Ti-.10	cast	5,620 (at ½ load)	—	—	14.1	—	6.60	159
Alloy cast iron: TC-2.61, GC-1.73, CC-.88, Si-2.38, Ni-1.08, Mn-.77, S-.105, Cr-.09	cast	11,400 (at ½ load)	—	—	36.1	—	17.0	270
Alloy cast iron: TC-2, Ni-18, Si-5, Cr-2, Mn-1, P-.01, S-.1	cast	—	—	—	12.9	1-4 (2 in.)	—	110-170
Malleable cast iron: TC-1.75-2.30, Si-.85-1.20, Mn-<.40, P-<.20, S-<.12	cast, annealed	17,550	—	26.3 (yld. pt.)	40.0	22 (2 in.)	17.6-18.6	110-145
Pure iron: Fe-99.99	rod, ¼ in., swaged ann. 4 hr at 1600°F	20,000	—	5.7-6.1 (.2% offset)	20-21	36-46 (2 in.)	—	60
Wrought iron: C-.017, Si-.122, P-.084	longitudinal	—	—	21.0	33.0	15 (2 in.)	21.5	—
Wrought iron: C-.017, Si-.122, P-.084	transverse	—	—	20.1	32.9	17 (2 in.)	19.7	—
Manganese steels								
C-.35, Mn-1.71, Si-.30	cast	—	27.4	—	56.8	2.1 (2 in.)	22.5	179
Molybdenum steels								
C-.23, Mo-.17, Mn-.67, Si-.52, Cu-.10	annealed at 1650°F	—	—	38.0	57.8	31 (5 diam.)	—	—
C-.24, Mo-.22, Mn-.85, Si-.19	plate, ⅝ in., rolled	—	—	42.5 (yld. pt.)	62.0	30 (2 in.)	—	194
C-.39, Cr-.86, Mo-.17, Mn-.56	oil-quenched from 1625°F, tempered at 500°F	—	—	116.5	149	6.5 (2 in.)	—	388

(continued)

TABLE 192.—MECHANICAL PROPERTIES OF IRON AND STEEL (continued)

Composition percent	Condition	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit kg/mm²	Hardness number
Nickel steels								
C–.43, Ni–3.47, Mn–.64, Si–.20	wrought, f.-c., from 1450°F	21,000	—	37.3	66.4	33(2 in.)	—	187
" " " "	wrought, o.-q., from 1450°F, tempered at 1100°F	19,800	—	57.8	82.2	34(2 in.)	—	226
C–.42, Ni–3.41, Mn–.66, Si–.21	bar, $\frac{3}{4}$ in. diam., wrought; ann. at 1550°F: 70°F	—	41.4	44.3 (yld. pt.)	70.0	26(2 in.)	—	195
	800°F	—	14.0	27.3 (yld. pt.)	55.0	30(2 in.)	—	
	1000°F	—	7.73	17.6 (yld. pt.)	32.7	39(2 in.)	—	
Nickel-chromium steels								
C–.37, Ni–1.28, Cr–.52, Mn–.55	bar, $1\frac{1}{8}$ in. diam., h.-t.	20,000	—	17.6 (.001% offset)	92	18(2 in.)	—	—
C–.37, Ni–1.33, Cr–.65, Mn–.75, Si–.18	hot-rolled	—	—	52.1 (yld. pt.)	81	25(2 in.)	31.0*	—
C–.36, Ni–1.33, Mn–.60, Cr–.56, Si–.26, (basic open-hearth, deoxidized with Si and Al)	bar, $\frac{3}{4}$ in. diam., wrought; 1 hr at 1550°F, o.-q. tempered at 1000°F, grain size 7-8 (ASTM std.), normal:							
	85°F	—	83.0	92.0 (.2% perm.)	99	19(2 in.)	—	285
	900°F	—	12.3	36.8 (.2% perm.)	62.5	22(2 in.)	—	
	1000°F	—	3.87	17.9 (.2% perm.)	43.6	20(2 in.)	—	
	1200°F	—	.70	5.27 (.2% perm.)	21.3	51(2 in.)	—	
Nickel-chromium-molybdenum steel								
C–.32, Ni–1.92, Cr–.86, Mo–.30, Mn–.60, Si–.16	wrought, f.-c., from 1450°F	20,200	—	34.9	67.6	37(2 in.)	—	202
C–.32, Ni–1.92, Cr–.86, Mo–.30, Mn–.60, Si–.16	wrought, o.-q. from 1530°F, tempered at 1100°F	20,000	—	73.8	98.5	32(2 in.)	—	229

(continued)

TABLE 192.—MECHANICAL PROPERTIES OF IRON AND STEEL (continued)

Composition percent	Condition	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit kg/mm²	Hardness number
Nickel-molybdenum steels								
C–.41, Ni–1.96, Mo–.31	oil-quenched from 1525°F, tempered at 1200°F	—	67.7	85.0 (yld. pt.)	91.5	23	47.2	252
" " "	quenched from 1525°F into lead at 840°F (austempered)	—	42.8	74.0 (yld. pt.)	90.0	19	—	—
Nickel-copper steels								
C–.08, Ni–2.00, Cu–1.00, Mn–.55, Si–<.3	plate, ½–¾ in., rolled	—	—	38.7 (yld. pt.)	52.8	25(8 in.)	28.1	—
Silicon steels								
C–.07, Si–1.17, Mn–.32	rolled	—	—	33.4	47.5	30(3 in.)	—	130
Silicon-manganese steels								
C–.52, Si–1.95, Mn–1.05, Cr–.05	oil-quenched from 1600°F, tempered at 970°F	—	—	102.5 (.1% perm.)	139	15(2 in.)	67.7	—
C–.53, Si–1.96, Mn–.83	¾ hr at 1600°F, quenched in oil at 130°F, tempered 1 hr at 860°F	20,500	—	92.8 (.01% perm.) 148 (.1% perm.)	166	12(2 in.)	78.7 97.0†	438–457
Stainless steel								
C–.17, Cr–18, Ni–8	water-quenched from 1100°F	—	21.1	—	65.4	68(2 in.)	26.7	170
C–.07, Cr–18.95, Ni–7.69	bar, ⅜ in. diam., cold-rolled	17,600	9.14	—	100.5	21(1.5 in.)	59.8	302
C–.13, Cr–24.5, Ni–20.3, Si–.85,	bar, 1 in. diam., rolled	—	—	28.1 (yld. pt.)	61.8	40(2 in.)	—	R_B 92
C–.11, Cr–16.2, Ni–11.5	water-quenched from 2010°F; room:	—	—	31.5 (yld. pt.)	65.8	48(2 in.)	—	—
	−85°F	—	—	—	—	—	—	—
	−292°	—	—	83.0 (yld. pt.)	155	55(2 in.)	—	—

(*continued*)

TABLE 192.—MECHANICAL PROPERTIES OF IRON AND STEEL (concluded)

Composition percent	Condition	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit kg/mm²	Hardness number
C-.08, Cr-18.58, Ni-9.68, Ti-.42	air-cooled from 1920°F	—	—	26.8	60.8	59(2 in.)	—	—
C-.07, Cr-18.2, Ni-9.42, Nb-.51	water-quenched from 2100°F	—	—	25.3	62.9	60(2 in.)	—	137
C-.40, Cr-15.21, Si-.59, Mn-.28, Ni-.18	bar, 1 in. diam., 1 hr at 1650°F, w.-q., tempered 1 hr at 1200°F	—	36.4	—	81.5	20(2 in.)	42.0 21.1*	—
C-.20, Cr-16.17, Mn-1.06, Si-.30	oil-quenched from 1740°F, tempered 3 hr at 840°F	23,100	35.7	62.5	133	10(2 in.)	—	357
C-.15, Cr-13.50, Si-.11	oil-quenched from 1740°F, tempered at 1110°F	22,000	57.8	77.3	92.8	21(2 in.)	—	285
" " "	oil-quenched from 1740°F, tempered at 1290°F	22,200	42.3	50.7	68.5	28(2 in.)	—	206
C-.09, Cr-16.53	sheet, .18 in., hot-rolled	—	—	73.0	93.5	4.5(8 in.)	—	R_B 103
" "	sheet, .18 in., ann.	—	—	34.5	49.2	20(8 in.)	—	R_B 82
C-.20, Cr-27.37, Mn-.32, Si-.28, Ni-.19	annealed	—	18.5	31.3	56.9	28(2 in.)	30.9	—
C-.08, Cr-5.81, Mo-.45	bar, ¾ in. diam., 4 hr at 1380°F, a.-c.	—	—	39.4 (yld. pt.)	60.4	29(2 in.)	—	149
Tungsten steels								
C-.71, W-17.30, Cr-3.86, V-.75	normalized at 1740°F; tempered at 1470°F	—	—	62 (yld. pt.)	92	19(2 in.)	—	—

S. A. E. carbon steel, No. 1050 or higher number specified (see carbon steels above). Steel used to be manufactured by acid open-hearth process, to be rolled, drawn, and then uniformly coated with pure tin to solder readily.

American or B. and S. wire gage	Diameter		Req'd twists in 203.2 mm or 8 in.	Weight		Req'd bends thru 90°	Spec. minimum tensile strength			
	mm	in.		kg/100 m	lb/100 ft		kg	lb	kg/mm²	lb/in.²
6	4.115	.162	16	10.44	7.01	5	2040	4500	154	219,000
7	3.665	.144	19	8.28	5.56	6	1680	3700	161	229,000
8	3.264	.129	21	6.55	4.40	8	1360	3000	164	233,000
9	2.906	.114	23	5.21	3.50	9	1135	2500	172	244,000
10	2.588	.102	26	4.12	2.77	11	910	2000	172	244,000
11	2.305	.091	30	3.28	2.20	14	735	1620	179	254,000
12	2.053	.081	33	2.60	1.74	17	590	1300	177	252,000
13	1.828	.072	37	2.06	1.38	21	470	1040	179	255,000
14	1.628	.064	42	1.64	1.10	25	375	830	181	258,000
15	1.450	.057	47	1.30	.87	29	300	660	182	259,000
16	1.291	.051	53	1.03	.69	34	245	540	186	264,000
17	1.150	.045	60	.81	.55	42	195	425	188	267,000
18	1.024	.040	67	.65	.43	52	155	340	190	270,000
19	.912	.036	75	.51	.34	70	125	280	193	275,000
20	.812	.032	85	.41	.27	85	100	225	197	280,000
21	.723	.028	96	.32	.22	105	80	175	200	284,000

NOTE.—Number of 90° bends specified above to be obtained by bending sample about 4.76 mm (.188 in.) radius, alternately, in opposite directions.

TABLE 194.—STEEL WIRE—EXPERIMENTAL VALUES

Data from tests at General Electric Co. laboratories. Commercial steel music wire (hardened).

Diameter		Ultimate strength tension		Diameter		Ultimate strength tension	
mm	in.	kg/mm²	lb/in.²	mm	in.	kg/mm²	lb/in.²
12.95	.051	226.0	321,500	6.35	.025	262.0	372,500
11.70	.046	249.0	354,000	4.55	.018	265.5	378,000
9.15	.036	253.0	360,000	2.55*	.010	386.5	550,000
7.60	.030	260.0	370,000	1.65*	.0065	527.0	750,000
				4.55†	.018	49.2	70,000

* For 4.55 mm wire drawn cold to indicated sizes. † For 4.55 mm (.018 in.) wire annealed in H_2 at 850°C.

TABLE 195.—PLOW-STEEL HOISTING ROPE (BRIGHT)

Wire rope to be of best plow-steel grade, and to be composed of 6 strands, 19 wires to the strand, with hemp center. Wires entering into construction of rope to have an elongation in 203.2 mm or 8 in. of about 2½ percent.

Diameter		Spec. minimum strength		Diameter		Spec. minimum strength	
mm	in.	kg	lb	mm	in.	kg	lb
9.5	⅜	5,215	11,500	38.1	1½	74,390	164,000
12.7	½	9,070	20,000	50.8	2	127,000	280,000
19.0	¾	20,860	46,000	63.5	2½	207,740	458,000
25.4	1	34,470	76,000	69.9	2¾	249,350	550,000

TABLE 196.—STEEL-WIRE ROPE—SPECIFICATION VALUES

Cast steel wire to be of hard crucible steel with minimum tensile strength of 155 kg/mm² or 220,000 lb/in.² and minimum elongation of 2 percent in 254 mm (10 in.).

Plow steel wire to be of hard crucible steel with minimum tensile strength of 183 kg/mm² or 260,000 lb/in.² and minimum elongation of 2 percent in 254 mm (10 in.).

Annealed steel wire to be of crucible cast steel, annealed, with minimum tensile strength of 77 kg/mm² or 110,000 lb/in.² and minimum elongation of 7 percent in 254 mm (10 in.).

Type A: 6 strands with hemp core and 19 wires to a strand (= 6 × 19), or 6 strands with hemp core and 18 wires to a strand with jute, cotton, or hemp center.

Type B: 6 strands with hemp core, and 12 wires to a strand with hemp center.

Type C: 6 strands with hemp core, and 14 wires to a strand with hemp or jute center.

Type AA: 6 strands with hemp core, and 37 wires to a strand (= 6 × 37) or 6 strands with hemp core and 36 wires to a strand with jute, cotton, or hemp center.

Description	Diameter		Approx. weight		Minimum strength	
	mm	in.	kg/m	lb/ft	kg	lb
Galv. cast steel, Type A	9.5	3/8	.31	.21	3,965	8,740
" " " " "	12.7	1/2	.55	.37	6,910	15,230
" " " " "	25.4	1	2.23	1.50	27,650	60,960
" " " " "	38.1	1 1/2	5.06	3.40	63,485	139,960
Galv. cast steel, Type AA	9.5	3/8	.35	.22	3,840	8,460
" " " " "	12.7	1/2	.58	.39	7,410	16,330
" " " " "	25.4	1	2.23	1.50	27,650	60,960
" " " " "	38.1	1 1/2	5.28	3.55	59,735	131,690
Galv. cast steel, Type B	9.5	3/8	.25	.17	2,995	6,600
" " " " "	12.7	1/2	.42	.28	5,210	11,500
" " " " "	25.4	1	1.68	1.13	20,890	46,060
" " " " "	38.1	1 1/2	3.94	2.65	47,965	105,740
Galv. cast steel, Type C	25.4	1	1.59	1.07	18,825	41,500
" " " " "	41.3	1 5/8	4.35	2.92	51,575	113,700
Galv. plow steel, Type A	9.5	3/8	.31	.21	4,690	10,340
" " " " "	12.7	1/2	.55	.37	8,165	18,000
" " " " "	25.4	1	2.23	1.50	32,675	72,040
" " " " "	36.5	1 7/16	4.66	3.13	69,140	152,430
Galv. plow steel, Type AA	9.5	3/8	.33	.22	4,540	10,000
" " " " "	12.7	1/2	.58	.39	8,750	19,300
" " " " "	25.4	1	2.35	1.58	32,250	71,100
" " " " "	41.3	1 5/8	6.18	4.15	83,010	183,000

TABLE 197.—STEEL-WIRE ROPE—EXPERIMENTAL VALUES

Wire rope purchased under Panama Canal Spec. 302 and tested by National Bureau of Standards, Washington, D. C.

Description and analysis	Diameter		Ultimate strength		Ultimate strength (net area)	
	mm	in.	kg	lb	kg/mm²	lb/in.²
Plow steel, 6 strands × 19 wires C .90, S .034, P .024, Mn .48, Si .172	50.8	2	137,900	304,000	129.5	184,200
Plow steel, 6 strands × 25 wires C .77, S .036, P .027, Mn .46, Si .152	69.9	2 3/4	314,800	694,000	151.2	214,900
Plow steel, 6 × 37 plus 6 × 19 C .58, S .032, P .033, Mn .41, Si .160	82.6	3 1/4	392,800	866,000	132.2	187,900
Monitor plow steel, 6 × 61 plus 6 × 19, C .82, S .025, P .019, Mn .23, Si .169	82.6	3 1/4	425,000	937,000	142.5	202,400

Recommended allowable load for wire rope running over sheave is one-fifth of specified minimum strength.

TABLE 198.—MECHANICAL PROPERTIES OF MISCELLANEOUS ALLOYS **

Composition percent	Condition	Density g/cm³	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit kg/mm²	Hardness number
Cadmium alloys									
Cu–1.5; Mg–.95	Cast	...	5,600	...	5.48 (.02% offset) 9.84 (.2% offset)	15.77	8.8(10 diam.)	3.8	42
Zn–5.0	Rod, 1 in. diam., chill-cast from 660°F; aged one month at r.-t.	8.55	...	...	...	9.2(rate of strain 6%/minute)	6.5(1.25 in.)	...	32
Cobalt alloys									
Fe–1.4; Ni–1.1; C–.24	Cast, ann. 2 hr at 1,650°F	...	20,800	...	...	...	...	...	...
Co–45–55; Cr–30–35; W–12–17	Cast	8.76	24,900	...	...	45.7	0(2 in.)	...	R_C 61
Gold alloys									
Cd–4.6; Cu–2.8; Zn–1.0	....	...	...	9.28	...	30.8	55(2 in.)	...	44
Cu–6.3; Ag–2.1	Strip, 3/8 in., ann. 1/3 hr at 1365°F	...	...	13.2	...	32.1	35	...	...
Cu–15.6; Ag–6.0; Pt–2.78; Zn–2.38; Ni–1.98	Rod, 1/8 in. diam., cast, w.-q. from 1290°F	...	9,140	37.6	...	48.5	4(3 in.)	...	...
Cu–17.95; Ni–17.60; Zn–6.0; Mn–.4	Sheet, .050 in., rolled (50% red) 1/2 hr at 1290°F, a.-c.	...	...	...	45.0 (yld. pt.)	72.4	44(2 in.)	...	...
Cu–34.9; Ni–12.14; Ag–11.11	Sheet, .045 in., rolled (50% red), ann. 1/3 hr at 1300°F, a.-c.	...	...	...	49.3 (yld. pt.)	63.5	19(1.25 in.)	...	R_B 94
Ni–17.0; Cu–16.0; Zn–8.65	Sheet, .05 in., rolled (50% red), 1/2 hr at 1380°F, a.-c.	...	...	...	45.3 (yld. pt.)	73.8	43(2 in.)	...	...

** For reference, see footnote 55, p. 187.

(continued)

TABLE 198.—MECHANICAL PROPERTIES OF MISCELLANEOUS ALLOYS (continued)

Composition percent	Condition	Density g/cm^3	Modulus of elasticity kg/mm^2	Proportional limit kg/mm^2	Yield strength kg/mm^2	Tensile strength kg/mm^2	Elongation percent	Endurance limit kg/mm^2	Hardness number
Pd-16.1; Pt-7.0; Ir-1.2; Zn-.07	Strip, .006 in., w.-q. from 1290°F	...	14,050	35.1	...	61.8	4.6(8 in.)	...	...
Pt-9.3; Ag-.1; Zn-.02; Ni-.01	Strip, .006 in., w.-q. from 1290°F	...	7,000	6.32	...	24.6	24(8 in.)	...	...
Ag-10.0; Pt-6.1; Cu-5.9; Ir-.1	Rod, $\frac{1}{8}$ in. diam., cast, w.-q. from 1290°F	...	7,700	15.8	...	33.7	18(3 in.)	...	...
Lead alloys									
Sb-.80	Cable sheath, 1 in. o.-d. × $\frac{1}{8}$ in. wall, extruded, aged 131 days at r.-t.	...	...	...	...	3.09(rate of strain) .1(in./in.)/min	32(2.5 in.)	.722(10^7)	V 10
Linotype: Sb-11.5; Sn-4.4; Cu-.08	Cast	...	...	...	...	8.22	9.0(2 in.)	...	21
Monotype: Sb-15.3; Sn-8.3	Cast	...	...	...	...	8.4	4.0(2 in.)	...	22
Bi-.065; Cu-.013; Sb-.0015	Cable sheath, 2.87 in. o.-d. × .159 in. wall (ring specimen)	...	...	...	...	1.34	47	...	3.9
Magnesium alloys									
Al-4.40; Mn-.26	Rod, extruded from $2\frac{15}{16}$ in. to $\frac{3}{4}$ in. diam. at 350-400°F	1.77	4,290	9.48	...	27.4	16(8 in.)	10.5(10^8)	58
Al-10; Mn>.1; Si<.5; Zn<.3	Cast, h.-t. and aged	...	4,570	...	13.4 (.2% offset)	25.3	2(2 in.)	6.3 (5×10^8)	69
Cu-13	Rod, 1 in. diam., hot-rolled	...	4,640	5.2	...	27.4	2.5($4\sqrt{area}$)	...	...
Manganese alloys									
Cu-18; Ni-10	....	...	12,240	...	...	77.0	6.5	...	...

(continued)

TABLE 198.—MECHANICAL PROPERTIES OF MISCELLANEOUS ALLOYS (concluded)

Composition percent	Condition	Density g/cm³	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit kg/mm²	Hardness number
Nickel alloys									
Al–4.78; Mn–.26; C–.17; Fe–.07; Si–.05	Rod, ⅞ in. diam., hot-rolled, ann. 2 hr at 1650°F, slowly cooled	. . .	21,500	9.4	18.75 (.01% offset)	61.6	43(4$\sqrt{\text{area}}$)	. . .	. . .
Ni–80; Cr–13; Fe–rem.	Sheet ann.	. . .	21,800	. . .	. . .	55.0	. . .	. . .	. . .
Cr–20	Wrought	8.4	21,800	. . .	44.5 (yld. pt.)	77.4	30(10 in.)	. . .	. . .
Cu–29; Fe–1.5; Si–1.25; Mn.9; C–.2; S<.015	Sand-cast	8.80	18,300	. . .	24.5 (.2% offset)	49.0	30(2 in.)	. . .	140
Ni–60; Cr–15; Mo–7; Be–.6–1.0; Fe–rem.	Quenched	8.3	15,500	. . .	41.8 (yld. pt.)	88.0	30(4 in.)	. . .	195
Mo–30; Fe–5	Cast	9.24	21,600	. . .	38.5–40.0 (yld. pt.)	53–58	6–9(2 in.)	. . .	190–230
Silver alloys									
Cu–5.75; Cd–1.75	Sand-cast	. . .	. . .	3.6	9.9	20.7	40(2 in.)	. . .	73
Tin alloys									
Sb–6.87; Cu–5.69; Pb–.19; Fe–.03; As–.02	Cast	. . .	6,120	. . .	5.76 (.2% offset)	8.4	5.2(10 diam.)	2.39	23
Sb–10.01; Cu–9.88; Pb–.19; Fe–.08	Cast	. . .	5,980	. . .	6.88 (.2% offset)	7.5	.6(10 diam.)	2.32	27

TABLE 199.—PHYSICAL PROPERTIES OF SOME SPECIAL-PURPOSE ALLOYS *

Composition percent	Density	Resistivity microhms-cm	Temperature coeff. of resistance	Thermal conductivity cgs	Thermal expansion per °C	Tensile strength kg/mm²	Yield strength kg/mm²	Young's modulus kg/mm²	Hardness number Rockwell	Elongation 2 in. percent
Alloys for strength with lightness										
Duralumin (A 17 S) Al 97, Cu 2.5, Mg .3..	2.74	4.3		.37		30		7200	70	
Super duralumin (24 S) Al 93, Cu 4.5, Mn .6 Mg 1.5	2.77	5.7		.29	20–200° 12.9×10^{-6}	50		7200	120	
Dow metal Mg 92, Al 8.........	1.81	13				23		4.6		
Beryllium alloys										
Beryllium †	1.83	4.3		.385	20–200° 12.4×10^{-6}	35	18.7	2.6×10^{4}	90–110	.0–2.5
Alloys †										
Be .45, Co 2.6, Bal Cu wrought	8.75	3.4		.50		81.	63.	1.26×10^{3}	C23–28	10–15
Be 2.60, Ni 1.10, Bal Cu	7.6	7.8		.18	20–200° 17×10^{-6}	112.	63.		C38	
Be 2.0, Co .5, Bal Cu cast	8.1	6.5		.30		115.	98.	1.33×10^{3}	C37–42	
Be 2.0, Co .3, Bal Cu wrought	8.21	12.7		.16		49.	21.	1.12×10^{3}	C85–95	.35–.50
Alloys for sealing to glass										
42% nickel iron § Fe 57, Ni 42, Mn 1...	8.1	7.0	...	03	0–200° 5.4×10^{-6}	70.3		14.7×10^{3}	(Specific heat cgs .12)	

* For reference, see footnote 55, p. 187. For low-melting-point alloys, see Table 201; for special magnetic alloys, see Tables 470-476.

† Annealed and heat treated. A number of alloys with beryllium are made by different manufacturers with about these same compositions and properties. These alloys are valuable due to their endurance and wear resistance, for a nonmagnetic mateial, and, in addition, good heat and electrical conductivity and corrosion resistance. Most of the data are taken from a special American Machinist report, McGraw-Hill.

(continued)

TABLE 199.—PHYSICAL PROPERTIES OF SOME SPECIAL-PURPOSE ALLOYS (continued)

Composition percent	Density	Resistivity microhms-cm	Temperature coeff. of resistance	Thermal conductivity, cgs	Thermal expansion per °C	Tensile strength kg/mm²	Yield strength kg/mm²	Young's modulus kg/mm²	Hardness number Rockwell	Elongation 2 in. percent
Chrom iron Fe 70–72, Cr 28–30, Mn .5–.8	7.8	...	...		20–600° 11.4×10^{-6}					
Fernico Fe 54, Ni 28, Co 18					100–500° $4.2\text{–}5.4\times10^{-6}$					
Sealmet	7.6	6.4	...	.06	20–100° 10.3×10^{-6}	53.0		20.3×10^{3}	(Specific heat cgs .15)	
Dumet core Ni 42, Fe 58, Cu 20–30 total weight	...	...	...	...	Radial 8.0–10×10^{-6} Axial 6.1–6.5×10^{-6}					
Miscellaneous										
Constantin § [a] Cu 53.3, Ni 45, Mn 1, Fe .6	8.4	49	8×10^{-6}	.23	15	70		25.000	100	
Manganin § [b] Cu 84, Mn 12, Ni 4	8.5	44	$<10^{-6}$ at 25°C		18			17.900		
Nichrome § [a] 59.9 Ni, 25 Fe, 15 Cr, .1 C	8.08	100	4×10^{-4}		12					
Invar [c] Fe 63.8, Ni 36, C .2	8.05	81	1.08×10^{-3}		1.6	80		21.000	160	(Specific heat cgs .12)

§ There are several alloys of about this same composition that are made by different manufacturers. They all have about the same characteristics.

Uses:
- [a] Heater and resistance.
- [b] Standard resistances.
- [c] Low thermal expansion.
- [d] Thermocouples.
- [e] Mirrors; is an exceedingly hard untarnishable metal.
- [f] Mirrors and reflecting gratings; takes good polish and does not tarnish easily.
- [g] An alloy sometimes used as a getter for clearing off last traces of gas in an evacuated vessel.
- [h] Used for making special casting and in art work.

(*continued*)

TABLE 199.—PHYSICAL PROPERTIES OF SOME SPECIAL-PURPOSE ALLOYS (continued)

Composition percent	Density	Tensile strength kg/mm²	Linear thermal expansion per °C	Specific heat cgs	Resistivity microhm-cm	Thermal conductivity cgs	Temperature coeff. of resistance
Chromel R ‡ [d] 90 Ni, 10 Cr, other elements	8.73	67	13.1×10^{-6} 20–100°C	.107	4.25	1.92 watts	3.2 20–100
Alumel ‡ [d] 94.1 Ni 3, Mn 2, Al and other elements	8.60	60	12×10^{-6} 20–100°C	.125	25.	.297 watts	24.5
Stellite § [e] Co 59.5, Mo 7.25, Cr 10.8, Fe 31, Mn 2, C .9, Si .8	8.3		Brinell hardness–512 at 3000 kg Spectral reflecting factor: λ .15, .20, .30, .50, .75, 1.00, 2.00, 3.00, 4.00, 5.00, 8.00 .32, .42, .50, .64, .67, .689, .747, .792, .825, .848, .880				
Speculum metal [f] Cu 67, Sn 33			Spectral reflecting factor: λ .188, .200, .251, .288, .305, .357, .385, .420, .450, .500 .23, .25, .299, .377, .417, .51, .531, .564, .600, .632 λ .550, .600, .650, .700, 1.00, 1.50, 2.00, 3.00, 4.00, 5.00 .64, .648, .654, .668, .705, .750, .804, .862, .885, .891 λ 7.00, 9.00, 11.00, 14.00 .901, .922, .929, 936				
Misch metal § [g] Ce 50–70, Fe 1-5, La, Nd Pr							
Pewter [h] 85 Sn, 6.8 Cu, 6 Bi, 1.7 Sb							

‡ Hoskins Thermocouple (see Table 51).

(continued)

TABLE 199.—PHYSICAL PROPERTIES OF SOME SPECIAL-PURPOSE ALLOYS (continued)

Soldering and brazing alloys

Soft solder—composition

Pb	Sn	Soldering temperature	Flux	Used for
30	70	170°C	resin	copper
40	60	175	zinc chloride	brass iron
50	50	190	zinc chloride + 25% HCl	zinc lead

Hard solder—composition

Cd	Cu	Zn	Ag	Sn	Al	Sb	Pb	Au	Soldering temperature	Flux	Used for
.5	52	38	10						820°C	borax	iron
	34	38	50						695	"	copper
	16	4	80						740	"	brass
	3	18		63	13	2	1			non-corrosive	aluminum
	20		30					50			gold

Brazing alloys—composition

Ni	Zn	Sn	Cu	Soldering temperature	Flux	Used for
	Rem		50–53	870°C	borax	steel
7–9	55–60		Rem	870	"	brass
	56–65	5–9	Rem	750	"	iron

(continued)

TABLE 199.—PHYSICAL PROPERTIES OF SOME SPECIAL-PURPOSE ALLOYS (concluded)

Carboloy cemented carbides

Grade designation	Composition WC	Co	TaC	TiC	Hardness Rockwell A 60 kg load	Density g/cm³	Traverse rupture strength psi	Young's modulus psi	Thermal expansion in.¹ in.⁻¹ °F⁻¹ 70°-1292°	Ultimate limit in compression psi	Torsion modulus psi
44A	94	6	...	...	91.0	14.95	240 [j]	84.5 [k]	2.8 [l]	700 [j]	36.0 [k]
55A	87	13	...	...	88.2	14.2	340	79.0	3.38	610	32.5
77B	57	16	27	...	85.0	13.55	285	88.0	4.03	610	...
78B	82	10	...	8	90.5	12.55	225	...	...	...	...
831	61	7	...	32	92.5	9.1	165	88.5	3.89	725	36.0

Heat-treated steel [i]

	Hardness	Density	Traverse rupture strength	Young's modulus	Thermal expansion	Ultimate limit in compression	Torsion modulus
SAE 1095—.9 C, .3 Mn, .04 P, .05 S	39R_c	7.8	...	30	8.2	172	11.5
H.S.S.—17 W, 4 Cr, 1 V	64R_c	8.6	...	32.5	7.1	600	5.0

Hardness versus temperature, °F ¶

Grade	80°F	200	400	600	800	1000	1100	1200°F
831	92.8	93.7	92.3	90.6	89.5	84.3	83.3	81.7
78B	91.0	90.1	90.4	89.0	86.0	82.5	80.8	79.8
77B	87.4	87.0	85.8	82.8	82.5	79.0	77.9	76.1
44A	90.9	90.5	90.0	88.0	86.5	85.5	84.1	81.8
55A	88.0	88.0	87.1	85.5	83.0	79.5	77.0	75.2

[i] For comparison. [j] $\times 10^3$. [k] $\times 10^6$. [l] $\times 10^{-6}$. ¶ Prepared by N. A. Waldrop, Carboloy Co.

Metal or alloy approx. comp. percent	Condition	Density or weight: gm per cm^3	Density or weight: lb per ft^3	Tension, kg/mm^2: P-limit	Tension, kg/mm^2: Ultimate strength	Tension, $lb/in.^2$: P-limit	Tension, $lb/in.^2$: Ultimate strength	Percent: Elong. in 50.8 mm (2 in.)	Percent: Reduct. of area	Hardness: Brinell @ 500 kg	Hardness: Sclero-scope
Tungsten, W 99.2*	Ingot sintered, D = 5.7 mm or .22 in.	18.0	1124	—	12.7	—	18,000	0.0	0.0	—	—
	Swaged rod, D = .7 mm or .03 in.	—	—	—	151.0	—	215,000	4.0	28.0	—	—
	Drawn hard, D = .029 mm or .00114 in.	—	—	—	415.0	—	590,000	—	65.0	—	—
	Swaged and drawn hot 97.5% reduction	—	—	—	164.0	—	233,500	3.2	14.0	—	—
	Same as above and equiaxed at 2000° C in H_2 †	—	—	—	118.0	—	168,000	0.0	0.0	—	—
Zinc,‡ Zn:	Cast	7.0	437	(Impurities Pb, Fe, and Cd)				—	—	—	—
	Coarse crystalline	—	—	—	2.8 to	—	4,000 to	—	—	42 to	8 to
	Fine crystalline	—	—	—	8.4	—	12,000	—	—	48	10
	Rolled (with grain or direction of rolling)	—	—	2.0	19.0	2,900	27,000	—	—	—	—
	Rolled (across grain or direction of rolling)	—	—	4.1	25.3	5,800	36,000	—	—	—	—
	Drawn hard	7.1	443	—	7.0	—	10,000	—	—	—	—

* Commercial composition for some incandescent electric lamp filaments containing thoria (ThO_2) approx. 0.75 percent.

† Ordinary annealing treatment makes W brittle, and severe working, below recrystallization or equiaxing temperature, produces ductility. W rods which have been worked and recrystallized are stronger than sintered rods. The equiaxing temperature of worked tungsten, with a 5-min exposure, varies from 2200°C for a work rod with 24 percent reduction, to 1350°C for a fine wire with 100 percent reduction. Tungsten wire, D = 0.635 mm or 0.025 in.

‡ Compression on cylinder 25.4 mm (1 in.) by 65.1 mm (2.6 in.), at 20 percent deformation:
For spelter (cast zinc) free from Cd, av. 17.2 kg/mm^2 or 24,500 $lb/in.^2$
For spelter with Cd 0.26, av. 27.4 kg/mm^2 or 39,000 $lb/in.^2$
Modulus of rupture averages twice the corresponding tensile strength.
Shearing strength: rolled, averages 13.6 kg/mm^2 or 194,000 $lb/in.^2$
Modulus of elasticity: cast, 7,750 kg/mm^2 or 11,025,000 $lb/in.^2$
Modulus of elasticity: rolled, 8450 kg/mm^2 or 12,000,000 $lb/in.^2$

TABLE 201.—LOW-MELTING ALLOYS *

Name	Composition, percent: Bi	Cd	Pb	Sn	Other	Melting point: °F	°C
Anatomical alloy	53.5	—	17	19	Hg 10.5	140	60
Wood's alloy	50	12.5	25	12.5	—	154.4	68
Quaternary eutectic alloy	49.5	10.10	27.27	13.13	—	158	70
Fusible alloy	38.4	15.4	30.8	15.4	—	159.8	71
Eutectic alloy (Bi-Cd-Pb)	51.6	8.1	40.2	—	—	196.7	91.5
Alloy for fine castings	50	—	32.2	17.8	—	212	100
Rose's alloy	50	—	28	22	—	212	100
Bismuth solder	40	—	40	20	—	235.4	113
Eutectic alloy (Bi-Sn)	57	—	—	43	—	280.4	138
Eutectic alloy (Bi-Cd)	60	40	—	—	—	291.2	144
Eutectic alloy (Bi-Pb-Sn)	13.7	—	44.8	41.5	—	320	160
Eutectic alloy (Cd-Sn)	—	32	—	68	—	350.6	177
Eutectic alloy (Pb-Sn)	—	—	38	62	—	361.4	183

* See also Table 123.

TABLE 202.—MECHANICAL PROPERTIES OF WHITE METAL BEARING ALLOYS (BABBITT METAL)

Experimental permanent deformation values from compression tests on cylinders 31.8 mm (1¼ in.) diam. by 63.5 mm (2½ in.) long, tested at 21°C (70°F). (Set readings after removing loads.)

Alloy No.	Formula, percent Sn	Sb	Cu	Pb	Pouring temp. °C	°F	Weight g/cm³	lb/ft³	Permanent deformation @ 21°C: @ 454 kg = 1000 lb mm	in.	@ 2268 kg = 5000 lb mm	in.	@ 4536 kg = 10,000 lb mm	in.	Hardness: Brinell @ 21°C	@ 500 kg @ 100°C
								Tin Base								
1	91.0	4.5	4.5	—	440	824	7.34	458	.000	.0000	.025	.0010	.380	.0150	28.6	12.8
2 *	89.0	7.5	3.5	—	432	808	7.39	461	.000	.0000	.038	.0015	.305	.0120	28.3	12.7
3	83.3	8.3	8.3	—	491	916	7.46	465	.025	.0010	.114	.0045	.180	.0070	34.4	15.7
4	75.0	12.0	3.0	10.0	360	680	7.52	469	.013	.0005	.064	.0025	.230	.0090	29.6	12.8
5	65.0	15.0	2.0	18.0	350	661	7.75	484	.025	.0010	.076	.0030	.230	.0090	29.6	11.8
								Lead Base								
6	20.0	15.0	1.5	63.5	337	638	9.33	582	.038	.0015	.127	.0050	.457	.0180	24.3	11.1
7	10.0	15.0	—	75.0	329	625	9.73	607	.025	.0010	.127	.0050	.583	.0230	24.1	11.7
8	5.0	15.0	—	80.0	329	625	10.04	627	.051	.0020	.229	.0090	1.575	.0620	20.9	10.3
9	5.0	10.0	—	85.0	319	616	10.24	640	.102	.0040	.305	.0120	2.130	.0840	19.5	8.6
10	2.0	15.0	—	83.0	325	625	10.07	629	.025	.0010	.254	.0100	3.910	.1540	17.0	8.9
11	—	15.0	—	85.0	325	625	10.28	642	.025	.0010	.254	.0100	3.020	.1190	17.0	9.9
12	—	10.0	—	90.0	334	634	10.67	666	.064	.0025	.432	.0170	7.240	.2850	14.3	6.4

* U. S. Navy Spec. 46M2b (Cu 3 to 4.5, Sn 88 to 89.5, Sb 7.0 to 8.0) covers manufacture of antifriction-metal castings. (Composition W.)

TABLE 203.—RIGIDITY MODULUS FOR A NUMBER OF MATERIALS

If to the four consecutive faces of a cube a tangential stress is applied, opposite in direction on adjacent sides, the modulus of rigidity is obtained by dividing the numerical value of the tangential stress per unit area (kg/mm²) by the number representing the change of angles on the nonstressed faces, measured in radians.

Substance	Rigidity modulus	Substance	Rigidity modulus	Substance	Rigidity modulus
Aluminum	3350	Iron, cast	6706	Steel cast	7458
" cast	2580	"	7975	" cast, coarse gr.	8070
Brass	3550	"	6940	" silver-	7872
"	3715	"	8108	Tin, cast	1730
" cast, 60 Cu+12 Sn	3700	"	7505	"	1543
Bismuth, slowly cooled	1240	Magnesium, cast	1710	Zinc	3880
Bronze, cast, 88 Cu+12 Sn	4060	Nickel	7820	"	3820
Cadmium, cast	2450	Phosphor bronze	4359	Platinum	6630
Copper, cast	4780	Quartz fiber	2888	"	6220
"	4213	" "	2380	Glass	2350
"	4450	Silver	2960	"	2730
"	4664	"	2650	Clay rock	1770
Gold	2850	"	2566	Granite	1280
"	3950	" hard-drawn	2816	Marble	1190
Iron, cast	5210	Steel	8290	Slate	2290

TABLE 204.—VARIATION OF THE RIGIDITY MODULUS WITH THE TEMPERATURE

$n_t = n_o (1 - \alpha t - \beta t^2 - \gamma t^3)$, where t = temperature Centigrade

Substance	n_0	$\alpha 10^6$	$\beta 10^8$	$\gamma 10^{10}$	Substance	n_0	$\alpha 10^6$	$\beta 10^8$	$\gamma 10^{10}$
Brass	2652	2158	48	32	Iron	8108	206	19	−11
"	3200	455	36	—	"	6940	483	12	—
Copper	3972	2716	−23	47	Platinum	6632	111	50	− 8
"	3900	572	28	—	Silver	2566	387	38	11
					Steel	8290	187	59	− 9

$n_t^* = n_{15} [1 - \alpha(t - 15)]$

Copper	4.37*	α=.00039	Platinum	6.46*	α=.00012	Tin	1.50*	α=.00416
Copper (commercial)	3.80	.00038	Gold	2.45	.00031	Lead	.80	.00164
Iron	8.26	.00029	Silver	2.67	.00048	Cadmium	2.31	.0058
Steel	8.45	.00026	Aluminum	2.55	.00148	Quartz	3.00	.00012

* Modulus of rigidity in 10^{11} dynes per cm².

TABLE 205.—INTERIOR FRICTION AT LOW TEMPERATURES

C is the damping coefficient for infinitely small oscillations; *T*, the period of oscillation in seconds; *N*, the modulus of rigidity dynes/cm².

Substance		Cu	Ni	Au	Pd	Pt	Ag	Quartz
Length of wire in cm		22.5	22.2	22.3	22.2	23.0	17.2	17.3
Diameter in mm		.643	.411	.609	.553	.812	.601	.612
100°C	C	24.1	1.34	27.5	1.67	2.98	55.8	—
	T	2.381	3.831	3.010	2.579	1.143	1.808	—
	$N \times 10^{-11}$	3.32	7.54	2.55	5.08	5.77	2.71	—
0°C	C	5.88	.417	4.82	1.25	4.60	7.19	4.69
	T	2.336	3.754	2.969	2.571	1.133	1.759	1.408
	$N \times 10^{-11}$	3.45	7.85	2.62	5.12	—	2.87	2.26
−195°C	C	3.64	.556	6.36	.744	3.02	1.64	1.02
	T	2.274	3.577	2.902	2.552	1.111	1.694	1.425
	$N \times 10^{-11}$	3.64	8.65	2.74	5.19	6.10	3.18	2.20

TABLE 206.—RATIO, ρ, OF TRANSVERSE CONTRACTION TO LONGITUDINAL EXTENSION UNDER TENSILE STRESS

(Poisson's Ratio)

Metal	Pb	Au	Pd	Pt	Ag	Cu	Al	Bi	Sn	Ni	Cd	Fe
ρ	.45	.42	.39	.39	.38	.35	.34	.33	.33	.31	.30	.28

ρ for: marbles, .27; granites, .24; basic-intrusives, .26; glass, .23.

TABLE 207.—A SCALE OF HARDNESS BASED UPON THE RELATIVE HARDNESS OF SELECTED MATERIALS

Each material will scratch the one following it in the table.

10 Diamond	8 Topaz	6 Feldspar	4 Fluorite	2 Rock salt or gypsum
9 Corundum	7 Quartz	5 Apatite	3 Calcite	1 Talc

TABLE 208.—RELATIVE HARDNESS

Agate	7.	Barite	3.3	Fluorite	4.	Marble	3–4.	Ross' metal	2.5–3.0
Alabaster	1.7	Bell-metal	4.	Galena	2.5	Meerschaum	2–3.	Serpentine	.3–4.
Alum	2–2.5	Beryl	7.8	Garnet	7.	Mica	2.8	Silver	2.5–3.
Aluminum	2.9	Bismuth	2.5	Glass	4.5–6.5	Opal	4–6.	Silver chloride	1.3
Amber	2–2.5	Boric acid	3.	Gold	2.5–3.	Orthoclase	6.	Steel	5–8.5
Andalusite	7.5	Brass	3–4.	Graphite	.5–1.	Palladium	4.8	Stibnite	2.
Anthracite	2.2	Calamine	5.	Gypsum	1.6–2.	Phosphor-bronze	4.	Sulfur	1.5–2.5
Antimony	3.3	Calcite	3.	Hematite	6.	Platin-iridium	6.5	Talc	1.
Apatite	5.	Copper	2.5–3.	Hornblende	5.5	Platinum	4.3	Tin	1.5
Aragonite	3.5	Corundum	9.	Iridium	6.5	Pyrite	6.3	Topaz	8.
Arsenic	3.5	Diamond	10.	Iridosmium	7.	Quartz	7.	Tourmaline	7.3
Asbestos	5.	Dolomite	3.5–4.	Iron	4–5.	Rock-salt	2.	Wax (0°)	.2
Asphalt	1–2.	Feldspar	6.	Kaolin	1.			Wood's metal	3.
Augite	6.	Flint	7.	Loess (0°)	.3				
				Magnetite	6.				

TABLE 209.—RELATIVE HARDNESS OF THE ELEMENTS (MEANS)

*C	10.	Ir	6.5	Zr	4.5	Al	2.9	Mg	2.0	In	1.2
B	9.5	Ge	6.2	Pt	4.3	Ag	2.7	Se	2.0	Tl	1.2
Cr	9.	Rh	6.	Ti	4.0	Zn	2.5	Cd	2.0	Li	.6
Ta	7.	Mo	6?	Fe	4.	Au	2,5	Sr	1.8	K	.5
Os	7.	Mn	5.	As	3.5	Ce	2.5	Sn	1.8	Na	.4
W	7.	Co	5.	Sb	3.	Bi	2.5	Pb	1.5	Rb	.3
Si	7.	Ni	5.	Be	3.	Te	2.3	Ga	1.5	Cs	.2
Ru	6.5	Pd	4.8	Cu	3.0	S	2.0	Hg	1.5		

* Diamond.