U. S. DEPARTMENT OF COMMERCE
DANIEL C. ROPER, Secretary
NATIONAL BUREAU OF STANDARDS
LYMAN J. BRIGGS, Director

SUPPLEMENT

TO

CIRCULAR OF THE NATIONAL BUREAU OF STANDARDS C101 (ed. 2)

Physical Properties of Materials: I. Strengths and Related Properties of Metals and Wood

ANNOUNCEMENT

Circular 101 (2d edition) of April 23, 1924, entitled Physical Properties of Materials: I. Strength and Related Properties of Metals and Wood, has been out of print for some months.

The properties of materials are of the utmost value to technicians. They are working factors in design, construction, and use—they are the real objects purchased, sold, and used.

Since it does not seem probable that a revision can be made in the near future, and in view of the continuing persistent demand, it was decided to reprint the second edition of the Circular with no change and to issue this Supplement, containing certain corrections and giving some additional or substitute data.

The sources of the data are cited for each item. The sources include journals, specifications, Bureau work, and manufacturers' records.

LYMAN J. BRIGGS, *Director.*

February 12, 1937.

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TABLE 1.—*Tensile and thermal properties of metals*

[Table 1 (p. 16 to 21, incl.) and table 2 (p. 18) in Circular 101 are now out of date and are replaced by tables 1 and 2 in the Supplement]

Material and composition	Condition	Specific gravity	Tensile properties						Elongation in 50.8 mm or 2 in.	Reduction of area	Hardness number		Thermal properties				Reference
			Metric kg/mm²			English lb/in.²											
			Proportional limit	Yield point	Tensile strength	Proportional limit	Yield point	Tensile strength			Brinell	Scleroscope	Melting point	Linear coefficient of expansion×10⁶ (per 1° C)	Casting shrinkage		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Aluminum:[1]																	
Pure—									*Percent*	*Percent*			°C		mm/m	in./ft	
Al, 99.0 or better	Sand cast at 700° C (1,292° F).		2.11		8.4–9.1	3,000		12,000–13,000	30–35	35–40	21–24	6–9		[2] 23.0			(1)
	Sheet annealed; all gages ¼ in. (6.35 mm) or less.		2.11		8.4–9.8	3,000		12,000–14,000	20–35	50–75	22–26	4–6					(1)
	Sheet, full hard [9]				min 15.5			min [7] 22,000	min [8] 4–1								
	Bars and wire, full hard.[9]				min 15.5			min [7] 22,000									
	Cast, 1 in. (25.4 mm) diameter.			3.62	8.2		5,150	11,700	37								(110)
	Cast, chill shaped sand.			3.9	7.7		5,600	11,000	24								(110)
	Rolled, 1¾₁₆ in. (20.6 mm) diameter.			10.3	11.3		14,600	16,100	30.5								(110)
	Rolled hard (sheet)			14.2–15.8	15.8–17.3		20,200–22,400	22,400–24,600	5–6								(110)
	Sheet, 0.08 in. (2.03 mm) soft.			1.9–3.2	9.4–11.0		2,700–4,480	13,400–15,700	19.2								(110)
	Drawn, 1¾₁₆ in. (20.6 mm) diameter.			13.4	13.7		19,000	19,500	19.5								(110)

Aluminum:[3]																		
Pure—																		
Al, 99.3	Normalized, mechanically worked and annealed at 400° C (752° F).	2.70		5.6–6.3	8.8–10.6		8,000–9,000	12,500–15,000	10–40	20–30			659 (1,218° F)					(168)
	Cast, sand			6.0	7.7–9.1		8,500	11,000–13,000	15–25		[4] 23–28	[5] 4–6						(168)
	Cast, chill			6.3	8.4–9.8		9,000	12,000–14,000	15–25									(168)
	Sheet, annealed			5.6–6.3	8.4–10.6		8,000–9,000	12,000–15,000	12–35	20–30								(168)
	Sheet, half hard [9]			6.3–8.4	min 11.2		9,000–12,000	min 16,000	min 3–7	20–30		13–15						(168)
	Sheet, hard			8.4–17.6	15.5–24.6		12,000–25,000	22,000–35,000	1–7	20–30								(168)
	Bars, hard [9]			9.8–16.2	15.5–24.6		14,000–23,000	22,000–35,000		30–40								(168)
	Wire, hard			11.2–23.2	17.6–38.7		16,000–33,000	25,000–55,000		40–50								(168)
Aluminum [6]	Cast																	(63)
	Rolled																	(63)
Copper (Alloy A)— Cu, 7.0–8.5; imp., max 1.7; Al, remainder.[9]	Cast	2.89	7.3		12.7–16.9	10,000		18,000–24,000	1.0							13.0	0.156	(13)
Copper (Alloy B)— Cu, 8.5–11.0; imp., max 1.7; Al, remainder.[9]	do	2.95			12.7–16.9			18,000–24,000	Less than 1.0							13.0	0.156	(13)
Copper (Alloy C)— Cu, 11.0–14.0; imp., max 1.7; Al, remainder.[9]	do	3.00			14.1–19.7			20,000–28,000	Less than 1.0							13.0	0.156	(13)
Copper— Cu, 7.0–8.5; other elements not over 1.7.[9]	Sand cast	Not over 2.89			16.9–19.7			24,000–28,000	1.4									(168)
Copper (lynite)— Cu, 7.0–8.5; other elements not over 1.7; Al, balance.[9]	Cast, permanent mold.				14.8–19.7			21,000–28,000										(168)
Cu, 9.25–10.75; other elements not over 2.0; Al, balance.[9] [10]	do	Not over 2.95			14.8–19.7			21,000–28,000										(168)
Cu, 11.5–13.5; other elements not over 1.7; Al, balance.	Sand cast	Not over 2.97			13.4			19,000										(168)

See footnotes at end of table.

TABLE 1.—*Tensile and thermal properties of metals*—Continued

Material and composition	Condition	Specific gravity	Tensile properties						Elongation in 50.8 mm or 2 in.	Reduction of area	Hardness number		Thermal properties				Reference
			Metric kg/mm²			English lb/in.²											
			Proportional limit	Yield point	Tensile strength	Proportional limit	Yield point	Tensile strength			Brinell	Scleroscope	Melting point	Linear coefficient of expansion×10⁶ (per 1° C)	Casting shrinkage		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Aluminum—Contd.																	
Copper [11]—									*Percent*	*Percent*			°C		mm/m	in./ft	
Cu, 0.89; Fe, 0.52; Si, 0.33; Mn, 0.32; Al, balance.	Wire, for rivets, as received.			21.3	25.2		30,200	35,800	6.0								(133)
	Wire, for rivets, quenched and aged.			12.9	17.3		18,400	24,600	20.0								(133)
Copper, iron, zinc, nickel (major metal) [12 13]	Cast bars				21.1			30,000									(99)
Copper [9]— (Alloy no. 195)	Cast				19.7–26.7			28,000–38,000									
	Heat treated				25.3–35.1			36,000–50,000									
Cu, 2.15; Mn, 0.88; Al, balance.	Cast, sand			7.3	9.7		10,400	13,800	5								(168)
	Cast, chill			8.7	13.4		12,400	19,100	6								(168)
Cu, 2.15; Mn, 1.91; Al, balance.	Cast, sand			10.5	12.7		14,900	18,100	5								(168)
	Cast, chill			12.3	15.7		17,500	22,400	5								(168)
Cu, 4.13; Mn, 1.92; Al, balance.	Cast, sand																
	Cast, chill			10.1	13.1		14,300	18,600	3.5								(168)
Copper, manganese (Alloy no. 11)— Al, 96; Cu, 2.89; Mn, 0.94	Cast, sand			9.4	11.7		13,400	16,700	5.0								(168)
	Cast, chill			11.4	19.0		16,200	27,000	13.5								(168)
	Hot rolled to 1⅛ in. (28.6 mm).			13.9	24.8		19,700	35,300	20.0	32.8							(168)
	Hot rolled to 1 3/16 in. (20.6 mm).			20.1	26.0		28,600	37,000	15.0	38.0							(168)

Copper, manganese [14]—																		
Al, 97; Cu, 1.5; Mn, 1 [15]	Cast, sand	2.8			14.1			20,000	12.0									(169)
	Forged		13.7		19.5	19,500		27,800	12.0	47.0								(169)

[1] Average value for modulus of elasticity 7,030 kg/mm², or 10,000,000 lb/in². No values for heat treated Al are given, as pure Al is not improved by heat treatment.

[2] Smithsonian Physical Tables, 7th ed. (1920).

[3] The mean value of modulus of elasticity for bars and wire is given by Brislee at 17° C (62.6 °F), 6,900 kg/mm² (9,810,000 lb/in²). Landolt-Bornstein tables (1912) give for modulus of elasticity 6,300–7,500 kg/mm² (8,960,000–10,670,000 lb/in²). K. Koch and C. Danneker (see fig. 58) give for modulus of elasticity in shear at 20° C (68° F), 2,720 kg/mm² (3,870,000 lb/in²). According to Winkelman's Handbuch der Physik I, I, (1908); modulu of elasticity of cast aluminum 6,570 kg/mm² (9,340,000 lb/in²); modulus of elasticity of drawn aluminum 7,540 kg/mm² (10,725,000 lb/in²); modulus of elasticity in shear of cast aluminum 2,580 kg/mm² (3,670,000 lb/in²). Poisson's ratio (Cardani) is 0.363. Average ultimate compressive strength of cast aluminum (Elmendorf) 47.1 kg/mm² (67,000 lb/in²). Elmendorf gives the following formula for alternating stress of cast aluminum of tensile strength averaging 10.6 kg/mm² (15,000 lb/in²): $S = 48{,}000 \times R^{-.113}$, where S = fiber stress in lb/in² and R = number of reversals to rupture (White-Souther machine).

Erichsen values:

B. & S. gage.	28	24	20	16	12
Depth of cup, mm	5.5–7.5	7.0–8.0	7.5–9.0	9.0–10.5	10.5–12.0

[4] 500 kg (1,102 lb) load.

[5] Magnifying hammer.

[6] Shearing strength: Cast 8.4 kg/mm² (12,000 lb/in²); rolled 11.3 kg/mm² (16,000 lb/in²).

[7] Thinner gages may have higher strengths.

[8] Depending upon the gage.

[9] Aluminum Co. of Am., letter to NBS, July 15, 1926.

[10] For castings for use at high temperatures.

[11] Shearing strength: Wire as received avg, 13.9 kg/mm² (19,800 lb/in²); wire quenched and aged, 11.2 kg/mm² (15,900 lb/in²). It was concluded from this investigation that the use of very soft rivets, consisting of nearly pure aluminum, does not appear to be necessary, since perfectly satisfactory joints can be made, using cold-drawn and annealed wire of 3/20 alloy (Cu, 3; Zn, 20; Al, 77) or duralumin wire (see those materials), and since last two materials gave much higher shearing strength they are preferable.

[12] White metal can be cast, rolled in sheets, spun, and welded; can be easily machined. The castings have fine homogeneous structure and are very tough.

[13] National Bureau of Standards analysis showed: Cu, 2.90; Si, 0.37; Fe, 1.90; Zn, 0.43; Ni, 0.37; Mn, 0.10; Mg, 0.05; Al, balance.

[14] Specification values, aluminum castings, U. S. Navy, 49 Al, July 1, 1915: Aluminum, min, 94; Cu, max, 6; Mn, max, 3; Fe, max, 0.5; Si, max, 0.5; Minimum tensile strength, 12.7 kg/mm² (18,000 lb/in²), with 8.0-percent elongation in 2 inches (50.8 mm).

[15] Naval Gun Factory.

TABLE 2.—*Tensile requirements of sheet aluminum*

(Navy Department Specifications 47A2, Nov. 1, 1926)

Condition	Thickness	Tensile strength		Elongation in 2 inches
	in.	kg/mm²	lb/in.²	*Percent*
Soft	0.258 to 0.051	8.4	12,000	30
	.051 to .032	8.4	12,000	25
	.032 to .020	8.4	12,000	20
	.020 to .013	8.4	12,000	15
Medium hard	.162 to .051	11.2	16,000	7
	.051 to .032	11.2	16,000	5
	.032 to .020	11.2	16,000	4
	.020 to .013	11.2	16,000	3
Hard	.102 to .051	15.5	22,000	4
	.051 to .032	16.9	24,000	3
	.032 to .020	18.3	26,000	2
	.020 to .013	21.1	30,000	1

NOTE.—Bend test specimens cut from either soft or medium hard sheet, either parallel with or transversely to the direction of final rolling, shall withstand cold bending flat on themselves without cracking. The bend test is not required for the hard temper. From sheets of soft or hard temper, the specimens may be cut in any direction of the sheet; from sheets of medium hard temper, the specimens shall be cut with the major axis parallel to the direction of final rolling.

ADDITIONS AND CORRECTIONS TO CIRCULAR 101

(The citations below refer to the page numbers in Circular 101, 2d edition)

Page	Addition or correction
22	The materials "copper (duralumin, alloy H)" and "copper (duralumin, alloy D)" were heat treated and not soft as stated. National Bureau of Standards measurements in 1924 gave 22 to 24×10^{-6} (per 1° C) as the linear coefficient of expansion of "copper (duralumin)". The reference number given for this material should be deleted.
23	According to a letter from the Aluminum Co. of America, dated July 15, 1926, the most advantageous heat treatment for copper (duralumin) is water quenching at 504 to 516° C (940 to 960° F).
24	Delete the results for the aluminum-copper-tin alloys.
25	Delete footnotes 14 and 16.
26	The tensile strengths quoted for aluminum-silicon (Alpax) can be obtained by a special process according to a letter from the Aluminum Co. of America, dated July 15, 1926.
32	At bottom of column 18, delete reference number 170. The number 109 just above should read 169. Delete footnote references in columns 2 and 3.
33	Delete reference numbers 109 and 170. Substitute reference 169. Delete footnote references in first column. In footnote 40, "12,1500" should read "121,500". Delete footnotes 47 and 48.
34	Footnote 50, delete "modulus of elasticity of cast copper, 7,700 kg/mm² (11,000,000 lb/in²)". In column 18, delete reference 168.
41	Last column, substitute reference 92 for reference 169.
44	Column 18, substitute reference 169 for reference 42.
53	Delete the data for "Tin, zinc (Gov. bronze or USN gun bronze or admiralty gun metal)". Delete footnotes 63 and 64.
62	The third material should be Cu, 70; Zn, 27; Pb, 2; Sn, 1.
72	The specific gravity of glucinum, or beryllium, as it is now called, is 1.86, according to a determination at the National Bureau of Standards, in 1927. Substitute reference 174 for 51, in column 18.
85	Footnote "16" should read "10".
86	Delete footnote reference 4 in first column.
87	Delete footnote 4. In footnote 14, the centigrade equivalent of 1,700° F is 928° C.
89	Footnote 21, first line, substitute "pearlite" for "perlite".
123	Substitute the following for footnote 43: "General appearance of lead; may be cast, rolled, or extruded; specific gravity and melting point close to those of lead; has metallic ring of bell metal; not as brittle as antimonial lead; pronounced increase in hardness upon aging; aging accelerated by steam heat; excellent structure, free from blowholes, and has low coefficient of friction." Substitute "Frary Metal" for "Ulco Metal" as the designation of the table at the bottom of the page.
125	Delete footnote reference on pure cold-rolled nickel. Add on next line below, "Pure [61]".
130	Specific gravity of tantalum should read 16.6.

ADDITIONS AND CORRECTIONS TO CIRCULAR 101—Con.

Page 136

The following experimental relationships [1] were derived at the National Bureau of Standards for Brinell and Rockwell numbers and for tensile strength of steel:

$$Bn=\frac{7{,}300}{130-{}_{100}R_{B\,1/16}} \text{ for } {}_{100}R_{B\,1/16}>40 \text{ but } <100$$

$$Bn=\frac{3{,}710}{130-{}_{100}R_{B\,1/8}} \text{ for } {}_{100}R_{B\,1/8}>30 \text{ but } <100$$

$$Bn=\frac{1{,}520{,}000-4{,}500\,{}_{150}R_C}{(100-{}_{150}R_C)^2} \text{ for } {}_{150}R_C>10 \text{ but } <40$$

$$Bn=\frac{25{,}000-10(57-{}_{150}R_C)^2}{100-{}_{150}R_C} \text{ for } {}_{150}R_C>40 \text{ but } <70$$

$$\text{Tns. str. (lb/in.}^2)=\frac{4{,}750{,}000-12{,}000\,{}_{100}R_{B\,1/16}}{130-{}_{100}R_{B\,1/16}} \text{ for } {}_{100}R_{B\,1/16}>82 \text{ but } <100$$

$$\text{Tns. str. (lb/in.}^2)=\frac{10^5(7{,}000-10\,{}_{150}R_C)}{(100-{}_{150}R_C)^2} \text{ for } {}_{150}R_C>10 \text{ but } <40$$

in which:

${}_{100}R_{B\,1/16}$ = Rockwell *B* number, ball 1/16 in. diameter, load 100 kg.
${}_{100}R_{B\,1/8}$ = Rockwell *B* number, ball 1/8 in. diameter, load 100 kg.
${}_{150}R_C$ = Rockwell *C* number, brale, load 150 kg.

Page 139

In figure 60, these same steels are identified as nos. 1 to 8, corresponding to the serial order in the table.

Page 149

The tensile strength given for tin, annealed at 50° C (122° F) is 10 times too great. The corrected table should read:

Metal	Temperature		Tensile strength		Elongation	Reduction of area
	°C	°F	kg/mm²	lb/in.²	*Percent*	*Percent*
Tin, annealed at 50° C (122° F)	20	68	2.75	3,910	40	74
	53	127	1.75	2,490	45	72
	100	212	1.05	1,490	45	82
	153	307	0.65	925	41	97
	180	356	.45	640	10	12
	207	405	.25	355	0	0

Page 151 Table 30, fourth heading, delete "estimated."
Page 156 The values of the tensile strength of Sn, annealed at 50° C (122° F) should be divided by 10.
Page 199 2d column, "Aluminum, Ti." Delete entry.
Page 200 Substitute "Brazing metal" for "Brazin, metal."
Page 202 "Steel, Cr, effect of temperature", page number should read 158.
Page 203 "Steel, Cr, V, effect of drawing temperature", page number should read 110.

[1] National Bureau Standards Research Paper RP185.

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Additions and Corrections.

p. 17 two last lines. For ref. 11 read 63.
p. 19 line 1. For ref. 166 read 168.
pp 32 and 33 drop out footnotes 34, 47 and 48. For ref. 109, 170 read 169.
p. 34 line 7. For ref. 168, 170 read 170.
p. 34, footnote 50. Drop out "modulus of elasticity of cast copper 7,700 kg/mm^2 (11,000,000 lb./$in.^2$)"

p. 41 lines 1 and 2. For ref. 169 read 92.
p. 44 lines 1-5. For ref. 42 read 169.
p. 72 line 12. For fef. 51 read 174.
p. 85, Note. Insert "of" after "reduction."
p. 86 and 87 Drop out footnote 4.

p. 87 footnote 14. For 938 read 928.
p. 91 footnote 25. Insert(after "Upton".
p. 101, Carbon steel. Insert comma after "maximum."
p. 125 line 4. Drop out footnote 61 after "Pure"
p. 125 line 5, Column 1, Insert "Pure[61]"
p. 128 line 9. Drop out "Ni-67;Cu-29;Fe-3;Mn-1;Si, S, C, Co
p. 139, table 20. Insert numbers 1 to 8 opposite the names of steels.
p. 151, table 30, column 4. For "estimated time at load..." read "Time at load..."

p. 153, Fig. 46. For "...0.055; in." read "...0.055 in."
p. 199. Drop out "Aluminum - Ti....41"
p. 200 For "Brazin" read "Brazing."
p. 202 For "Stainless steel, effect of temperatures" read "Stainless steel, effect of temperature."
p. 202 Steel, Cr, effect of temperature. For 156 read 158.
p. 203 Steel, Cr, V, effect of drawing temperature. For 101 read 110.