DEPARTMENT OF COMMERCE
BUREAU OF STANDARDS
George K. Burgess, Director

CIRCULAR OF THE BUREAU OF STANDARDS, No. 101

PHYSICAL PROPERTIES OF MATERIALS

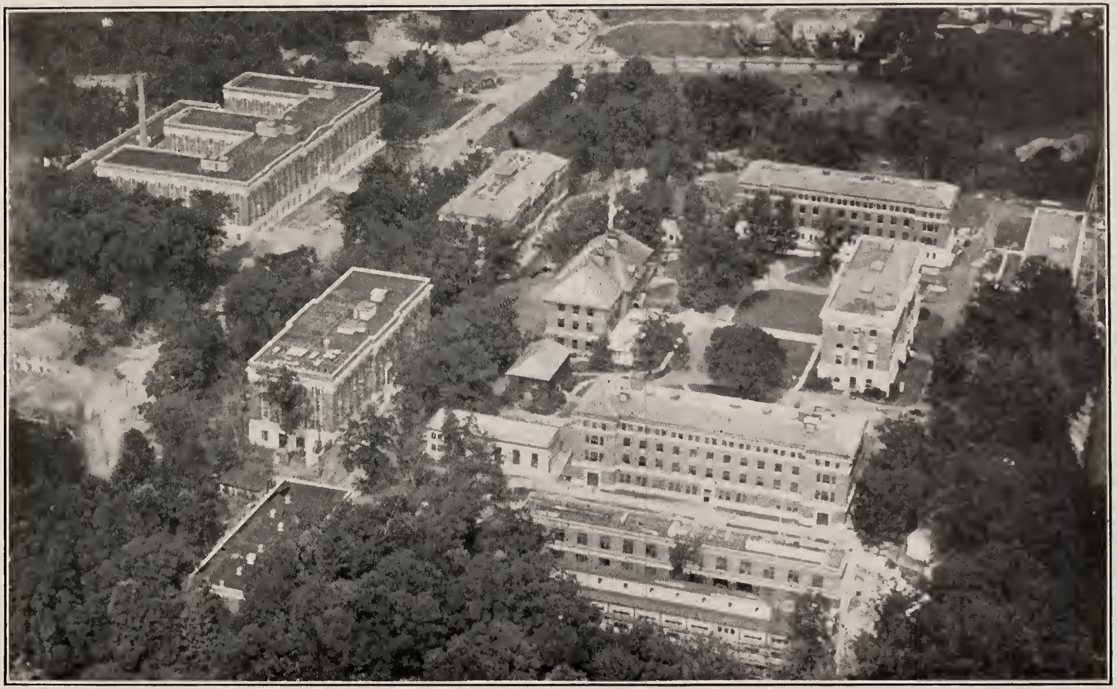
I. STRENGTHS AND RELATED PROPERTIES OF METALS AND WOOD

(Second Edition)

April 23, 1924

PRICE, 40 CENTS
Sold only by the Superintendent of Documents, Government Printing Office
Washington, D. C.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1924



Scientific and Technical Laboratories of the Bureau of Standards.

Investigations on the physical properties of metals and woods are made in the industrial laboratories shown in the upper left of this illustration.

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I. STRENGTH AND RELATED PROPERTIES OF METALS AND WOOD.

ABSTRACT.

This circular contains the values for tensile, compressive, and shearing strengths; ductility; modulus of elasticity; and other related properties of pure metals and their alloys and of wood. In addition to these the properties of metals at elevated temperatures, their fatigue and impact properties, and the effect of heat treatment and cold working are given.

Other properties and uses of less commonly used metals are described briefly. Graphical representation is used in many cases to show the change of the properties of a material with changing conditions. References to the sources are given for all values in this circular.

CONTENTS.

TABLES.

ILLUSTRATIONS.

LIST OF ABBREVIATIONS USED IN THIS CIRCULAR.

Tensile strength	tns. str.	Feet	ft.
Elastic limit	el. lim.	Inches	in.
Proportional limit	pro. lim.	Meter	m
Yield point	yld. pnt.	Centimeter	cm
Elongation	elong.	Millimeter	mm
Reduction	red.	Square inch	in.^{2}
Brinell hardness	Bhn.	Square centimeter	cm^2
Scleroscope hardness	scl.	Square millimeter	mm^2
Compression	comp.	Inch-pound	in.-lb.
Transverse	trv.	Kilogram meter	kgm
Torsion	tor.	Cubic inch	in.^{3}
Rupture	rupt.	Cubic centimeter	cm^3
Impact	imp.	Revolutions per minute	r. p. m.
Modulus of elasticity	mod. el.	Thousand	th.
Heat treatment	ht. tr.	Degrees (temperature)	°
Pounds	lb.	Centigrade	C.
Grains	gr	Fahrenheit	F.
Kilogram	kg	Average	avg.
Gram	g		

LIST OF CONVERSION FACTORS USED IN THIS CIRCULAR.

1 m=3.281 ft.
1 cm=0.3937 in.
1 kg=2.2046 lb.
1 kg/mm^2=1,422.3 lb./in.^{2}
1 kgm=7.233 ft.-lb.
1 kg/m^3=0.06243 lb./ft.^{3}
1 kgcm/cm^3=14.223 in. lb./in.^{3}

$$\eta^\circ \text{ C.}=\left(\frac{9}{5}\eta+32\right)^\circ \text{ F}$$

Chemical Symbols.

Smithsonian Physical Tables, 7th ed., 1920.]

Substance:	Symbol.
Aluminum	Al
Antimony	Sb
Argon	A
Arsenic	As
Barium	Ba
Bismuth	Bi
Boron	B
Bromine	Br
Cadmium	Cd
Caesium	Cs
Calcium	Ca
Carbon	C
Cerium	Ce
Chlorine	Cl
Chromium	Cr
Cobalt	Co
Columbium	Cb
Copper	Cu
Dysprosium	Dy
Erbium	Er
Europium	Eu
Fluorine	F
Gadolinium	Gd
Gallium	Ga
Germanium	Ge
Glucinum	Gl
Gold	Au
Hafnium	Hf
Helium	He
Holmium	Ho
Hydrogen	H
Indium	In
Iodine	I
Iridium	Ir
Iron	Fe
Krypton	Kr
Lanthanum	La
Lead	Pb
Lithium	Li
Lutecium	Lu
Magnesium	Mg

Substance—Continued.	Symbol.
Manganese	Mn
Mercury	Hg
Molybdenum	Mo
Neodymium	Nd
Neon	Ne
Nickel	Ni
Niton	Nt
Nitrogen	N
Osmium	Os
Oxygen	O
Palladium	Pd
Phosphorus	P
Platinum	Pt
Potassium	K
Praseodymium	Pr
Radium	Ra
Rhodium	Rh
Rubidium	Rb
Ruthenium	Ru
Samarium	Sa
Scandium	Sc
Selenium	Se
Silicon	Si
Silver	Ag
Sodium	Na
Strontium	Sr
Sulphur	S
Tantalum	Ta
Tellurium	Te
Terbium	Tb
Thallium	Tl
Thorium	Th
Thulium	Tm
Tin	Sn
Titanium	Ti
Tungsten	W
Uranium	U
Vanadium	V
Xenon	Xe
Ytterbium	Yb
Yttrium	Yt
Zinc	Zn
Zirconium	Zr

I. INTRODUCTION.

The compilation of the information contained in this circular was begun in response to a request in 1920 from the Smithsonian Institution for the assistance of the Bureau of Standards in the revision of the Smithsonian Physical Tables.

Due to the frequent requests for information on the physical properties of materials received at the Bureau of Standards, many of which could be answered by referring to the tables prepared for the Smithsonian Institution, they were published as Physical Properties of Materials, Circular No. 101, of the Bureau of Standards.

The first edition was compiled by H. A. Anderson, assistant engineer physicist. The unprecedented number of requests for the first edition, which soon exhausted the supply, led to the preparation of this edition.

In response to the request printed on the cover of the first edition of this circular for constructive criticism, many letters have been received from engineers in testing laboratories, manufacturing concerns, engineering offices, and technical societies and institutions. It was evident from these letters that the writers believed that a publication of this kind is greatly needed, as the data contained in it had not previously been easily accessible. In so far as possible all the suggested improvements have been made in this edition.

II. SCOPE OF THE WORK.

This edition, which has been enlarged to about four times the size of the first, includes the additional material which has appeared in the technical literature during the past few years, and, by enlarging its scope, it includes the properties of metals at elevated temperatures, their fatigue and impact resistance, as well as other useful data.

The physical properties of wood, obtained by the Forest Products Laboratory, have also been included.

In many cases graphical representation has been used to show the effect of heat treatment, temperature, and other factors on the property of a material. Often these graphs are reproduced with little alteration from the original source. Values may be read from these curves with an accuracy sufficient for the practical use of the curves. All values are given in both metric and English systems.

III. SOURCES OF INCLUDED DATA.

The data were gathered from three sources: (1) Experimental data published in the technical periodicals and engineering handbooks; (2) specifications prepared by the technical societies and Government departments; and (3) unpublished experimental data of the Bureau of Standards and those obtained from the manufacturers of the material.

The strengths and related properties of most engineering materials vary between wide limits; any value assigned to a material represents a materials engineer's opinion as the most probable value that can be obtained under given circumstances. These values should be looked upon as representative of material rather than as characterizing a single specimen.

The compiler has undertaken to select reliable sources of information; he has tried to conscientiously reproduce with accuracy the values given and the opinions expressed in the original source, reference to which is given in all cases in this circular.

IV. ACKNOWLEDGMENTS.

This edition was compiled and the charts drawn by S. N. Petrenko, associate mechanical engineer. Credit is due H. L. Whittemore, under whose supervision the work was done, and to all those who have assisted in putting the data in its present form.

V. TEST SPECIMENS AND CONDITIONS.

In general, test specimens used in the determination of the tabulated data were in conformity with the recommendations of the American Society for Testing Materials.[1] As a rule, tensile specimens were of 12.8 mm, or 0.505 inch diameter, and 50.8 mm, or 2 inches gauge length. The sizes of compressive and transverse specimens are usually shown accompanying the tables. Figure 1 shows the test specimens used and recommended by this bureau.

All data shown in these tables were determined at ordinary room temperature, averaging 20° C. (68° F.) unless otherwise stated.

VI. DEFINITIONS.

The following definitions represent the practice of the bureau in reporting data on physical properties of engineering materials and also govern the use of the terms in this circular. In tensile and compressive tests the stresses are computed on the basis of the original cross-sectional area of the specimen; in transverse and torsional tests the stress in the extreme fiber is computed from the flexural and torsional formulas.

Definitions of mechanical properties of materials and methods of testing in use at the bureau are in general conformity with the standard methods for testing of the American Society for Testing Materials.[2]

1. PROPORTIONAL LIMIT.

Stress at which the deformation ceases to be proportional to the load as determined by strainometer (extensometer for tension, compressometer for compression, and deflectometer for transverse tests, value being read from plotted results).

[1] A. S. T. M. Standards Handbook; 1921; and triennially thereafter, especially Standard methods for testing, p. 841.
[2] A. S. T. M. Standards, pp. 841–852; 1921.

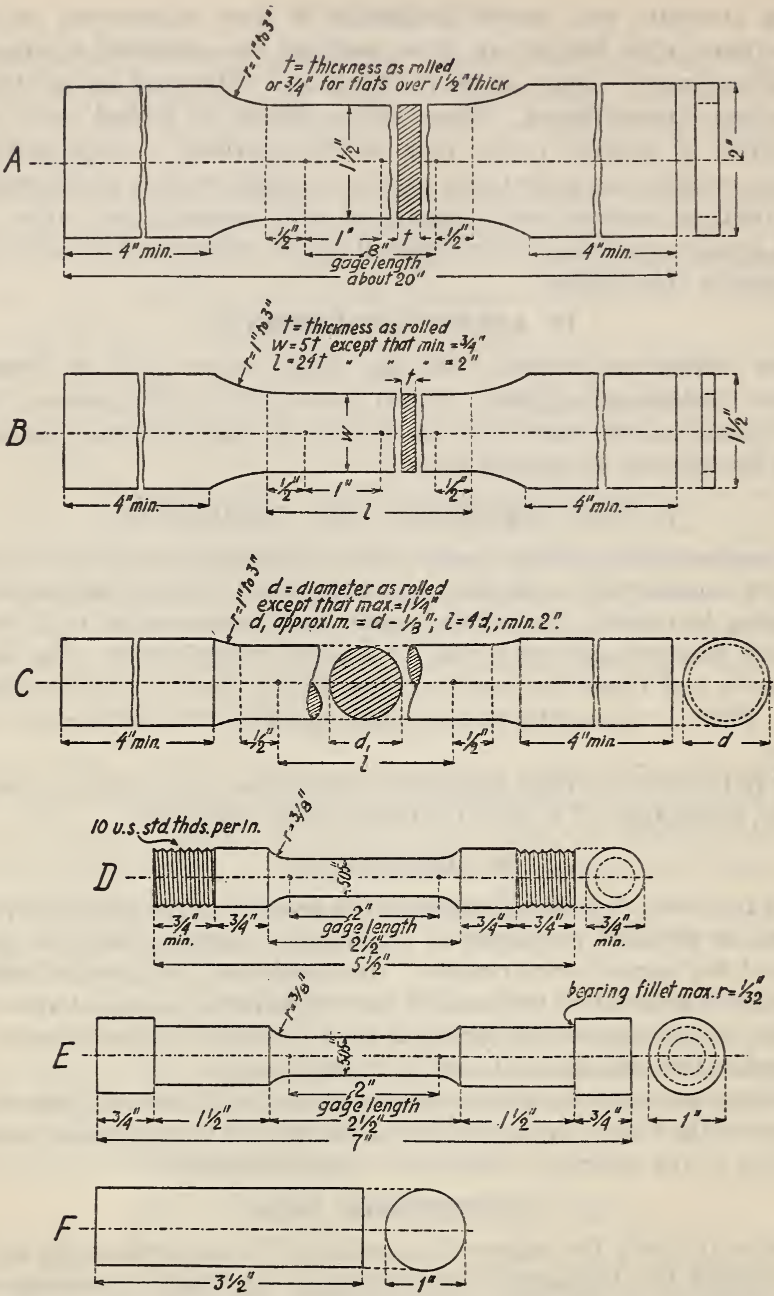

Fig. 1.—*Standard specimens used and recommended by structural and engineering mechanics section, Bureau of Standards.*

A, tension, flat, for wedge grips, for rolled plates over 1/4 in. (6.35 mm) thick; *B*, tension, flat, 1/4 in. (6.35 mm) thick or less; *C*, tension, round, for wedge grips, for rolled rods and bars; *D*, tension, round, for accurate tests, except determination of modulus of elasticity; *E*, tension, round (preferable form) for accurate tests, except determination of modulus of elasticity; *F*, compression, round, for all determinations except modulus of elasticity.

2. ELASTIC LIMIT.

In tensile and compressive tests: The stress at which the initial permanent elongation or shortening of the gauge length occurs, as shown by an instrument of high precision (determined from set readings with extensometer or compressometer). In transverse tests: The extreme fiber stress at which the initial appreciable permanent deflection occurs as determined with deflectometer.

Tests are rarely made to determine the elastic limit, since such tests involve repeated application and release of load and require considerable time. For practical purposes the elastic limit may be regarded as equal to the proportional limit.

3. YIELD POINT.

Stress at which marked increase in deformation of specimen occurs without increase in load as determined usually by drop of beam or with dividers for tensile, compressive, or transverse tests. (Reported for all tests of ductile materials.)

4. TENSILE, COMPRESSIVE, OR SHEARING STRENGTH.

Maximum stress developed in the material during test, load being referred to the original cross section.

5. MODULUS OF RUPTURE.

Maximum stress in the extreme fiber of a beam tested to rupture, as computed by the empirical application of the flexural formula to stresses above the transverse proportional limit. For simple rectangular beam with concentrated center load it equals

$$\frac{1.5 \times \text{load} \times \text{span}}{\text{area} \times \text{depth}}.$$

6. TORSIONAL STRENGTH (OR MODULUS OF RUPTURE IN TORSION).

Maximum stress in the extreme fiber of a specimen tested to rupture as computed by the empirical application of the torsional formula to stresses above the torsional proportional limit. For a round specimen it equals

$$S = \frac{5.1 \times \text{twisting moment}}{\text{diameter}^3}.$$

In ductile materials the stress at rupture may be considered uniformly distributed over the cross-sectional area and the above formula assumes the form

$$S = \frac{3.82 \times \text{twisting moment}}{\text{diameter}^3}.$$

7. ELONGATION.

The percentage of elongation is found by dividing the increase of length after rupture by the original gauge length. The percentage of elongation depends on the gauge length. The elongation indicates the ductility of the material.

8. REDUCTION.

The percentage of reduction is found as the ratio of the difference between the original and broken area of cross section to the original area. Reduction of area indicates generally the ductility of material.[3]

9. POISSON'S RATIO.

The ratio of lateral contraction per unit of diameter to longitudinal extension per unit of length of a bar under terminal tension within the elastic limit of material.

10. MODULUS OF ELASTICITY IN TENSION OR COMPRESSION.[4]

Ratio of stress within the proportional limit to the corresponding strain as determined with a precise extensometer. Accurate determinations of the modulus of elasticity are made with a gauge length at least 8 in. (203.2 mm) in length.

11. MODULUS OF ELASTICITY IN SHEAR.[5]

Ratio of stress within the proportional limit to the corresponding angular strain (in radians). The following theoretical relation exists between the modulus of elasticity in shear and the modulus of elasticity

$$G=\frac{E}{2\ (1+\lambda)},$$

where G is the modulus of elasticity in shear, E modulus of elasticity, and λ Poisson's ratio.

It is difficult to make a direct experimental determination of G on account of the presence of other stresses. It is usually determined by the torsion of a round bar.

12. BRINELL HARDNESS NUMBER.

Ratio of load on a sphere used to indent the material to be tested to the area of the spherical indentation produced. The standard sphere used is a 10 mm diameter hardened steel ball. The loads used are 3,000 kg (6,615 pounds) for steel and 500 kg (1,102 pounds) for softer metals, and the time of application of load is 30 seconds. Values shown in the tables are based

[3] Some authors consider the reduction of area as a measure of toughness.

[4] Generally known as Young's modulus (is called in this circular modulus of elasticity).

[5] Often called the modulus of rigidity.

on spherical areas computed in the main from measurements of the diameters of the spherical indentations, by the following formula:

$$\text{Bhn} = \frac{P}{\pi t D} = \frac{P}{\pi D\left(\frac{D}{2} - \sqrt{\frac{D^2}{4} - \frac{d^2}{4}}\right)}$$

P = load in kg, t = depth of indentation, D = diameter of ball, and d = diameter of indentation, all lengths being expressed in millimeters. Brinell hardness values have a certain relation to tensile strength, and hardness determinations may be used to determine tensile strengths approximately by employing the proper conversion factor for the material under consideration. See Table 16. (Data after Abbott.)

13. SHORE SCLEROSCOPE HARDNESS.

Height of rebound of a diamond-pointed hammer falling on the object from a fixed height through a tube under the acceleration due to its own weight. 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 properly determined, is considered an index of the tensile strength of the metal tested.

14. ERICHSEN VALUE.

Index of forming qualities 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 millimeters, required to obtain fracture is the Erichsen value for the metal. Erichsen standard values for trade qualities of soft metal sheets, corresponding to various sheet thicknesses, are furnished by the manufacturer of the machine.[6]

15. BEND TEST.

Angle through which the material can be bent without fracture or the number of bendings around a predetermined diameter is recorded. In some cases a minimum diameter around which the test piece can be bent through a certain angle is determined. Very valuable test indicating the ductility of malleable metals.

16. IMPACT VALUE.

Indicates the shock-resisting qualities of material. Is of particular value in ascertaining the influence of heat treatment. Impact value depends on the form of the specimen.[7] The data in this circular are given (unless

[6] Proc. A. S. T. M., 17 (2), p. 200; 1917.

[7] For the description of impact testing machines and specimens used by various investigators see H. L. Whittemore, Bibliography on impact testing, Proc. A. S. T. M.; 1922.

otherwise stated) for standard international Charpy specimen, 10 by 10 by 40 mm (0.394 by 0.394 by 1.575 inches, the last value being the distance between the supports).

17. FATIGUE RESISTANCE.

Resistance of material to a load, which is applied and removed in whole or in part many times and at short intervals. Fatigue resistance is a very valuable property of materials. Some engine parts are subjected to a very high number of reversals of stress during the life of the machine.

Numerical values for fatigue resistance may be given in two ways: (1) The "stress" at which a specimen endures a definite number of cycles of stress; (2) The "endurance limit," if such exists; that is, the maximum stress which the specimen will endure for any number of repetitions.[8]

18. RESILIENCE.

The potential energy of deformation of a body. The resilient materials are those which are capable of absorbing elastically a large amount of work done by the applied load. The resilience depends upon the elastic limit of material and upon its modulus of elasticity (in tension or in shear).

19. DUCTILE MATERIALS.

Ductile materials are those which are capable of undergoing considerable permanent deformation while subjected to tensile stresses.

20. PLASTIC MATERIALS.

Plastic materials are those which are capable of undergoing considerable permanent deformation under compressive stresses.

21. MALLEABLE MATERIALS.

Malleable materials are those which can be hammered into thin sheets without rupture.

22. BRITTLE MATERIALS.

Brittle materials are those which show little permanent deformation when stressed to rupture.

23. STIFF MATERIALS.

Stiff materials are those which have a high modulus of elasticity or a high modulus of elasticity in shear. They deform little, if subjected to stresses not exceeding the elastic limit.

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[8] Description of fatigue testing machines may be found in the following publications: (1) McAdam, jr., Alternating torsion machine, Iron Age, 100; 1917; (2) McAdam, jr., Impact endurance testing machine, Jour. Am. Soc. Nav. Eng., November, 1917; (3) Arnold, Alternating testing machine, Proc. Inst. Mech. Eng., pt. 3; 1904; (4) Farmer, Rotating beam testing machine, Proc. A. S. T. M.; 1919; (5) Landgraf Turner, Alternating stress machine, Am. Mach. Apr. 22, 1919; (6) Upton Lewis, Am. Mach., October, 1912; (7) Stanton, Alternating stress machine, Proc. Inst. Civ. Eng., 166; (8) Stromeyer, Alternating torsion machine, Proc. Roy. Soc. A., 90; 1914; (9) Kommers, Wisconsin rotating beam machine, Univ. Ill., Eng. Exp. Sta. Bul. No. 120; (10) Smith, Alternating tension and compression machine, Engineering, 88, p. 105; (11) Olsen-Foster, Reversed torsion testing machine, Univ. Ill. Eng. Exp. Sta. Bul. No. 120; (12) White-Souther, Chem. and Met. Eng., December, 1921; (13) Haigh, Alternating testing machine, Engineering, November, 1912; and (14) Olsen, Vibrating testing machine, Electr. Rev., April, 1908.

24. FLEXIBLE MATERIALS.

Flexible materials are those which have a low modulus of elasticity or a low modulus of elasticity in shear. They can be deformed considerably by bending, twisting, etc., within the elastic limit of material.

25. TOUGH MATERIALS.

Tough materials are those which will withstand heavy shocks or will absorb a large amount of energy.

26. SOFT MATERIALS.[9]

Soft materials are those which offer little resistance to indenting or scratching.

27. HARD MATERIALS.[9]

Hard materials are those which offer great resistance to indenting or scratching.

VII. TEXTS ON STRENGTH OF MATERIALS.

For an interpretation of the physical significance of the elastic limit, proportional limit, yield point, and other properties, reference may be made to any good text on mechanics of materials, including the following:

Andrews, The strength of materials; 1916. Van Nostrand & Co., New York.
Boyd, Strength of materials; 1917. McGraw-Hill Book Co., New York.
Burr, The elasticity and resistance of the materials of engineering; 1915. John Wiley & Sons, New York.
Ewing, Strength of materials; 1906. Putnam Co., London.
Goodman, Mechanics applied to engineering; 1899. Longmans, Green & Co., London.
Johnson, Materials of construction; 1918. John Wiley & Sons, New York.
Lanza, Applied mechanics; 1910. John Wiley & Sons, New York.
Merriman, Mechanics of materials; 1915. John Wiley & Sons, New York
Mills, Materials of construction; 1922. John Wiley & Sons, New York.
Moore, Materials of engineering; 1917. McGraw-Hill Book Co., New York
Morley, Strength of materials; 1920. Longmans, Green & Co., London.
Murdock, Strength of materials; 1911. John Wiley & Sons, New York.
Slocum, Resistance of materials; 1914. Ginn & Co., Boston.
Unwin, The testing of materials of construction; 1910. Longmans, Green & Co., London.
Love, A treatise on the mathematical theory of elasticity; 1906. Cambridge, University Press.
Fuller and Johnston, Strength of materials; 1919. J. Wiley & Sons, New York.
Martens, Handbook of testing materials; 1899. J. Wiley & Sons, New York.
Bach, Elasticität und festigkeit; 1922. Berlin.
Lorenz, Technische elasticitätslehre; 1913. München.
Föppl, Forlesungen über technischen mechanik; 1900–1912. Leipzig.
Record, Mechanical properties of wood; 1914. New York.
Bulletin No. 556, Forest Service, U. S. Department of Agriculture; 1917.

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[9] "Soft" and "hard" are indefinite terms which acquire a definite relative meaning when a definite hardness test is specified.

VIII. PHYSICAL PROPERTIES OF METALS.

TABLE 1.—Tensile and Thermal Properties of Metals.

Material and composition.	Condition.	Specific gravity.	Tensile properties						Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number.		Thermal properties.				Reference.
			Metric kg/mm.^{2}			English lb./in.^{2}											
			Proportional limit.	Yield point.	Tensile strength.	Proportional limit.	Yield point.	Tensile strength.			Brinell.	Scleroscope.	Melting point.	Linear coefficient of expansion $\times 10^6$ (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—									Per ct.	Per ct.			°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 gauges 1/4 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. Bars and wire, full hard.	(Properties vary with the gauge.)															(1)
	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, 13/16 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, 13/16 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	...	...	6.3–8.4	12.7–15.5	...	9,000–12,000	18,000–22,000	5–12	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	...	...	9.8–16.2	19.7–24.6	...	14,000–23,000	28,000–35,000	...	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	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	(11)
	Rolled	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	(11)

[1] Average value for modulus of elasticity 7,030 kg/mm², or 10,000,000 lb./in.² No values for heat treated Al are given, as pure Al is not improved by heat treatment.

[2] Smithsonian Physical Tables, 7th edition; 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./in.²) Landolt-Bornstein tables (1912) give for modulus of elasticity 6,300–7,500 kg/mm² (8,960,000–10,670,000 lb./in.²) 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./in.²) According to Winkelman's Handbuch der Physik, 1, 1, 1908; modulus of elasticity of cast aluminum 6,570 kg/mm² (9,340,000 lb./in.²); modulus of elasticity of drawn aluminum 7,540 kg/mm² (10,725,000 lb./in.²); modulus of elasticity in shear of cast aluminum 2,580 kg/mm² (3,670,000 lb./in.²). Poisson's ratio (Cardani) is 0.363. Average ultimate compressive strength of cast aluminum (Elmendorf) 47.1 kg/mm² (67,000 lb. /in.²) Elmendorf gives the following formula for alternating stress of cast aluminum of tensile strength averaging 10.6 kg/mm² (15,000 lb./in.²): $S=48{,}000 \times R^{-0.118}$, where S=fiber stress in lb./in.² and R=number of reversals to rupture (White-Souther machine).

Erichsen values:

B. & S. gauge.	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./in.²); rolled 11.3 kg/mm² (16,000 lb./in.²),

TABLE 2.—Tensile Requirements of Sheet Aluminum—Specification Values.

[Sheet: A. S. T. M., B25–19 T. Al min., 99.0; minimum strengths and elongation.]

Gauge (B. & S.).	Thickness.		Temper number.	Hardness.	Tensile strength.		Elongation in 50.8 mm (2 in.).
	mm	in.			kg/mm²	lb./in.²	Per cent.
12–16, inclusive	2.052–1.290	0.0808–0.0508	[1] 1	Soft, annealed	8.8	12,500	30.0
			[2] 2	Half hard	12.7	18,000	7.0
			3	Hard	15.5	22,000	4.0
17–22, inclusive	1.152– .643	.0453– .0253	[1] 1	Soft, annealed	8.8	12,500	20.0
			[2] 2	Half hard	12.7	18,000	5.0
			3	Hard	17.6	25,000	2.0
23–26, inclusive	.574– .404	.0226– .0159	[1] 1	Soft, annealed	8.8	12,500	10.0
			[2] 2	Half hard	12.7	18,000	5.0
			3	Hard	21.1	30,000	2.0

[1] Sheets of temper No. 1 to withstand being bent double in any direction and hammered flat.
[2] Sheets of temper No. 2 to bend 180° about radius equal to thickness without cracking.

NOTE.—Tensile test specimen to be taken parallel to the direction of cold-rolling of the sheet.

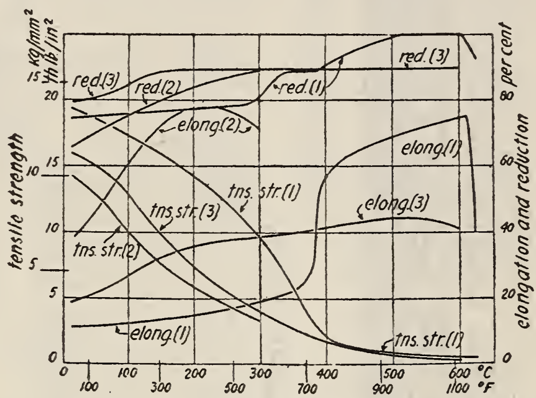

FIG. 2.—*Effect of temperature on the tensile properties of aluminum.*

Curves (1) for rolled unannealed sample of 99.56 per cent aluminum 6.3 mm (1/4 in.) round bars; G. D. Bengough, J. Inst. Met., 7, p. 123; 1912.

Curves (2) for annealed sample sheet, 8 mm (0.315 in.) thick; R. Baumann, Mitteilungen uber Forschungsarbeiten auf dem Gebiete des Ingenieurwesen, No. 112, p. 23; 1911.

Curves (3) for a sample annealed at 350° C. (662° F.) 8 mm (0.315 in.) round bars. P. Ludwik, Zeitschrift des Vereines Deutscher Ingenieure, August 14, p. 657; 1915.

TABLE 3.—Ductility and Hardness of Sheet Aluminum—Experimental Results.

[Aluminum sheet, Grade A (Al min., 99.0). From tests on No. 18 B. & S. gauge, sheet rolled from 6.3 mm, or 0.25 in., slab, Iron Age, vol. 101, p. 950; 1918.]

Heat treatment, annealed.	Thickness.		Erichsen value, depth of cup.	Scleroscope hardness.
	mm	in.	mm	
None (as rolled)	1.08	0.0425	6.83	14.0
At 200° C. (392° F.), 2 hours	1.09	.0429	8.39	10.0
At 300° C. (572° F.), 2 hours	1.07	.0422	10.17	4.5
At 400° C. (752° F.), 2 hours	1.08	.0425	10.10	4.5
At 200° C. (392° F.), 30 min	1.07	.0422	7.97	11.8
At 400° C. (752° F.), 30 min	1.08	.0425	9.83	4.5

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm[2] Proportional limit.	Tensile properties. Metric kg/mm[2] Yield point.	Tensile properties. Metric kg/mm[2] Tensile strength.	Tensile properties. English lb./in.[2] Proportional limit.	Tensile properties. English lb./in.[2] Yield point.	Tensile properties. English lb./in.[2] Tensile strength.	Tensile properties. Elongation in 50.8 mm or 2 inches.	Tensile properties. Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Thermal properties. Linear coefficient of expansion $\times 10^6$ per 1°C.).	Thermal properties. Casting shrinkage.	Thermal properties. Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Aluminum: Copper—									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Al and Cu, various proportions (See Figs. 3 and 4).																	(166)
Al, 99.0; Cu, 1.0	Rolled and annealed.				14.8			21,000	26.0		[1] 41						(39)
Al, 94.9; Cu, 5.1.	do				17.8			25,300	21.0		[1] 49						(39)
Al, 89.0; Cu, 11.0.	do				19.5			27,700	16.0								(39)
Al, 98; Cu, 1; imp., max. 1.	Cast, chill		5.3		10.5	7,500		15,000	24.0	34.0							(43)
	Plates, 0.05 in. (1.27 mm) thick.		19.0		21.4	27,000		30,500	4.0								(43)
Al, 96; Cu, 3; imp., max. 1.	Cast, chill		8.1		13.7	11,500		19,500	12.0	21.0							(43)
	Plates 0.05 in. (1.27mm) thick.		24.6		28.8	35,000		41,000	5.0								(43)
Al, 96.24; Cu, 3.76.	Cast, chill			8.5	14.4		12,100	20,500	10.5	21.5							(40)
	1.25 in. (31.8 mm) diam. rolled bar.			13.5	26.5		19,160	37,700	20.0	38.2							(40)
	0.8125 in. (20.7 mm) diam. rolled bar.			18.3	26.8		26,000	38,100	21.0	49.8							(40)
	0.8125 in. (20.7 mm) diam. bar drawn with annealing.			24.4	26.6		34,700	37,900	8.0	21.8							(40)
	0.9063 in. (23.0 mm) bar drawn without annealing.			29.1	31.5		41,400	44,800	7.5	20.8							(40)
Al, 94; Cu, 5; imp., max. 1.	Cast, chill		10.2		15.1	14,500		21,500	7.0	14.0							(43)
	Rolled, 70 per cent reduction.		23.2		26.7	33,000		38,000	5.5								(43)
Copper (Alloy No. 12)— Al, 92; Cu, 8.	Cast, sand	2.83	3.5	10.8	13.9	5,000	15,400	19,800	.8	4.9	50			24.0	14.6	0.175	(40)
	Cast, chill				15.5			22,000									(111)

[1] 2.5 mm ball, 62.5 kg (138 lb.) load.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm.[2] Proportional limit.	Metric Yield point.	Metric Tensile strength.	English lb./in.[2] Proportional limit.	English Yield point.	English Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Scleroscope.	Thermal properties. Melting point.	Linear coefficient of expansion ×10^6 (per 1°C.)	Casting shrinkage.		Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Aluminum—Con. Copper (Alloy A)— Cu, 7.0–8.5; imp., max. 1.7; Al, remainder.	Cast	2.89	7.3	....	12.7	10,000	....	18,000	Per ct. 1.0	Per ct.	....	....	....	....	mm/m 13.0	in./ft. 0.156	(13)
Copper (Alloy B)— Cu, 8.5–11.0; imp. max. 1.7; Al, remainder.	do	2.95	....	....	12.7	....	....	18,000	Less than 1.0	....	....	....	....	....	13.0	.156	(13)
Copper (Alloy C)— Cu, 11.0–14.0; imp., max. 1.7; Al, remainder.	do	3.00	....	....	13.4	....	....	19,000	Less than 1.0	....	....	....	....	....	13.0	.156	(13)
Copper— Cu, 7.0–8.5; other elements not over 1.7.[2]	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.	Die cast	....	....	....	19.7	....	....	28,000	....	....	....	....	....	....	....	....	(168)
Cu, 9.25–10.75; other elements not over 2.0; Al, balance.[3]	do	Not over 2.95.	....	....	19.7	....	....	28,000	....	....	....	....	....	....	....	....	(168)
Cu, 11.5–13.5; other elements not over 1.7; Al, balance.[4]	Sand cast	Not over 2.97.	....	....	13.4	....	....	19,000	....	....	....	....	....	....	....	....	(168)

Copper, iron[5]— 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).[6,7]	Cast bars				21.1			30,000									(99)
Copper, magnesium— Al, 95.2; Cu, 4.2; Mg, 0.6.	Cast at 700° C. (1,292° F.).		3.2–4.6		9.6–13.3	4,500–6,500		13,600–18,900	2–0	0.5–0	74	17–18					(169)
	Annealed, 500° C. (932° F.).		4.6		17.5	6,500		24,900	3	1	80	21					(169)
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			2.3	2.3		3,200	3,200	2.5								(168)
	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 13/16 in. (20.6 mm).			20.1	26.0		28,600	37,000	15.0	38.0							(168)
Copper, manganese[8]— Al, 97; Cu, 1.5; Mn, 1.[9]	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)

[2] Used for general castings.
[3] For castings for use at high temperatures.
[4] For pressure castings.
[5] Shearing strength: Wire as received avg., 13.9 kg/mm² (19,800 lb./in.²); wire quenched and aged, 11.2 kg/mm² (15,900 lb./in.²).
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.
[6] 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. Heat treatment increases tensile strength of cast bars to 38.7 kg/mm² (55,000 lb./in.²). The metal does not corrode nor tarnish and takes high polish. The only acid which shows an ill effect is hydrochloric acid.
[7] 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.
[8] 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./in.²), with 8.0 per cent elongation in 2 inches (50.8 mm).
[9] Naval Gun Factory.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Tensile properties. Metric kg/mm² Yield point.	Tensile properties. Metric kg/mm² Tensile strength	Tensile properties. English lb./in.² Proportional limit.	Tensile properties. English lb./in.² Yield point.	Tensile properties. English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Thermal properties. Linear coefficient of expansion ×10⁶ (per 1°C.)	Thermal properties. Casting shrinkage.	Thermal properties. Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Aluminum—Con. Copper, manganese (alloy No. 10)—									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Al, 96.0; Cu, 2.06; Mn, 1.94.	Cast, sand	...	...	9.1	13.4	...	13,000	19,000	4.0	...	...	...	...	...	...	...	(168)
	Cast, chill	...	...	10.1	14.3	...	14,300	20,300	5.0	...	...	...	...	...	...	...	(168)
	Hot rolled to 1⅛ in. (28.6 mm).	...	...	15.5	25.8	...	22,000	36,700	18.5	39.5	...	...	...	...	...	...	(168)
	Hot rolled to $\frac{13}{16}$ in. (20.6 mm).	...	...	19.1	26.9	...	27,100	38,200	16.0	37.6	...	...	...	...	...	...	(168)
	Drawn with annealing to $\frac{13}{16}$ in. (20.6 mm).	...	...	17.7	28.8	...	25,200	41,000	6.0	11.2	...	...	...	...	...	...	(168)
Copper (duralumin, alloy H).[10]	Soft, 7 mm (0.275 in.).	...	...	19.0	36.0	...	27,000	51,200	25.0	34	...	...	650 (1,202° F.)	...	...	...	(168)
	Rolled to 5 mm (0.197 in.).	...	...	...	42.0	...	...	59,800	6.3	18	...	...	...	...	...	...	(168)
	Rolled to 3 mm (0.118 in.).	...	...	...	45.6	...	...	64,800	5.0	14	...	...	...	...	...	...	(168)
Copper (duralumin, alloy D).	Soft, 7 mm (0.275 in.).	2.83	...	25.9	45.9	...	36,900	65,300	17.5	21.0	...	...	...	...	...	...	(168)
	Rolled to 5 mm (0.197 in.).	...	...	45.1	55.2	...	64,200	78,500	6.6	15.0	...	...	...	...	...	...	(168)
	Rolled to 3 mm (0.118 in.).	...	...	53.0	59.1	...	75,400	84,000	4.6	11.0	...	...	...	...	...	...	(168)
Copper (duralumin).[11]	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	(104)
Copper, manganese (duralumin)[12]—																	
Cu, 3.92; Mn, 0.51; Si, 0.41; Fe, 0.36; Mg, 0.37; Al, balance.	Wire for rivets heat treated, diam. 0.125 in. (3.2 mm).	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	(133)
Copper, manganese (duralumin) (or 17-S alloy)—																	

Cu, 3.5-4.5; Mn, 0.4-1.0; Mg, 0.2-0.75; Al and imp., balance.	Annealed	...	8.4-10.5	...	19.7-24.6	12,000-15,000	...	28,000-35,000	15-18	25-30	53-58	18-28	...	...	...	...	(1)
	Rolled, 70 per cent reduction.	...	21.1-24.6	...	31.6-33.0	30,000-35,000	...	45,000-47,000	2.0-2.5	5-8	85-90	35-40	...	...	...	...	(1)
	Rolled and heat treated.	...	12.7-15.5	...	36.9-40.4	18,000-22,000	...	52,500-57,500	16-20	20-25	85-100	30-40	...	...	...	...	(1)
	Rolled after heat treatment.	...	21.1-31.6	...	42.2-52.7	30,000-45,000	...	60,000-75,000	1-15	15-20	110-150	35-50	...	...	...	...	(1)
Copper, nickel, magnesium alloy("Y")[13]— Cu, 4; Ni, 2; Mg, 1.5; Al, balance.	Cast, chill.	2.8	...	...	18.9	...	...	26,900	6.5	...	...	...	...	...	...	...	(134)
	7/8 in. (22.3 mm) diam. rod hot rolled.	...	...	18.9	27.7	...	26,900	39,400	20.0	30.0	...	...	...	...	...	...	(134)
	7/8 in. (22.3 mm) diam. rod cold rolled from 1 1/4 in. (31.7 mm) quenched 530° C. (986° F.) aged.	...	12.1	24.0	38.1	17,200	34,100	54,200	25.0	34.0	...	...	...	...	...	...	(134)
	0.05 in. (1.27 mm) sheet hot rolled quenched 530° C. (986° F.) aged.	...	...	27.1	41.0	...	38,500	58,200	19.0	...	...	...	...	...	...	...	(134)
	0.018 in. (0.46 mm) sheet quenched 530° C. (986° F.) aged.	...	15.5	33.0	44.1	22,000	47,000	62,700	17.0	...	...	...	...	...	...	...	(134)

[10] Most remarkable light alloy of Al. Discovered by Wilm in 1903-1911. Chemical composition Cu, 3.5-5.5; Mn, 0.5-0.8; Mg, 0.5; Al, balance. Can be readily rolled and forged. Quenching from 400-520° C. (752-968° F.) increases hardness very little, but upon aging for several days both hardness and ductility are increased from 15 to 50 per cent. Duralumin is remarkably resistant to corrosion in hardened state. Can be welded, but the joint is weaker than original material. The density of duralumin varies from 2.75 to 2.84. Modulus of elasticity, 7,030 kg/mm² (10,000,000 lb./in.²). (P. Merica Chem. and Met. Eng., Sept. 15, 1918.)

[11] Most advantageous heat treatment: Water quenching at 475° C. (887° F.). The following results were obtained by Dr. Sauveur:

Treatment.	When tested.	Elastic limit.		Tensile strength.		Elongation in 4 inches (101.6 mm).	Reduction of area.
		kg/mm²	lb./in.²	kg/mm²	lb./in.²	Per cent.	Per cent.
None	...	30.2	43,000	38.4	54,600	17	21
Heated to 475° C. (887° F.) in salt bath and quenched in water.	Immediately	18.7	26,600	29.0	41,300	22.2	24
	After 24 hours	21.7	30,800	37.5	53,200	23.4	25
	After 48 hours	23.6	33,600	39.1	55,600	21.6	27
	After 1 week	23.6	33,600	39.9	56,700	22.5	27
	After 1 month	25.2	35,800	39.1	55,600	23	25

[12] Shearing strength, 25.9 kg/mm² (36,800 lb./in.²). Riveted joints showed no tendency to cracking or deterioration in the course of many months. Owing to their higher strength compare favorably with rivets made of softer alloys.

[13] Tensile strength at 250° C. (482° F.), 17.3 kg/mm² or 24,600 lb./in.²; tensile strength at 350° C. (662° F.), 7.9 kg/mm² or 11,200 lb./in.²; elongation in 2 inches (50.8 mm), at 350° C. (662° F.), 15 per cent. Alloy "Y" though weaker than other alloys at ordinary temperatures has superior tensile strength at elevated temperatures as well as higher resistance to alternating stress. It is immune from "season cracking" and possesses remarkable resistance to corrosion.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Metric kg/mm² Yield point.	Metric kg/mm² Tensile strength.	English lb./in.² Proportional limit.	English lb./in.² Yield point.	English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Linear coefficient of expansion ×10⁶ (per 1°C.)	Casting shrinkage.	Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Aluminum—Con.									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Copper, nickel, magnesium, manganese—Al, 93.5; Cu, 3.5; Ni, 1.5; Mg, 1.0; Mn, 0.5.	Cast at 700° C. (1,292° F.)	....	3.5–9.8	....	17.9–23.2	5,000–14,000	....	25,500–33,000	6–1.5	8.5–1	54–86	9–25	....	....	....	....	(169)
Copper, nickel, manganese—Al, 94.2; Cu, 3; Ni, 2; Mn, 0.8.	....do....	....	....	....	14.5–21.4	....	....	20,600–30,500	6–1	11–2	50–91	9–27	....	....	....	....	(169)
Copper, tin[14]—Al, 90.0; Cu, 7.0–8.5; Zn, max., 0.2; Si, Fe, Zn, Mn, Sn, max., 1.7; other imp., none.	Cast, sand[15]....	2.83	....	....	12.7–14.1	....	....	18,000–20,000	1–2	....	....	....	....	....	13.0	0.156	(142)
Copper, tin[16]—Al, 85.5; Cu, 11.0–13.5; Zn, max., 0.2; Si, Fe, Zn, Mn, Sn, max., 1.7; other imp., none.	....do.[15]....	2.95	....	....	13.4–16.2	....	....	19,000–23,000	Practically none.	....	....	....	....	....	13.0	.156	(143)
Copper, zinc, iron—Al, 88.0–92.0; Cu, 6.0–8.0; Zn, max., 2.5; Fe, max., 1.5; Si, Mn, Sn, max., 0.75; other imp., none.	....do.[15]....	2.83–2.86	....	....	13.4–14.8	....	....	19,000–21,000	1–2	....	....	....	....	....	13.0	.156	(144)

Magnesium (magnalium)—																	
Al, 95; Mg, 5	....do	2.5			12.0–21.1			17,000–30,000									(169
Al, 77–98; Mg, 23–2.	Cast, chill	2.4–2.56			29.5–45.0			42,000–64,000									(169)
Mg, 2.0; Al, balance.[17]	Cast	2.50–2.57			12.6			17,900	3								(98)
	Cast, chill				20.1			28,600	2								(98)
	Cast, water chilled.				28.1			40,000	1								(98)
Mg, 10.0; Al, balance.	Cast				15.1			21,400	2.4								(98)
	Cast, chill				23.6			33,600	3.4								(98)
	Cast, water chilled.				43.0			61,100	4.2								(98)
Mg, 5; Al, balance.[18]	Cast	2.63			[19] 14.1			[19] 20,000	0.5 to 2								(168)
Nickel—																	
Ni, 1.11; Al, balance.	Cast, chill			4.1	10.5		5,800	14,900	20.8	36.2							(168)
Ni, 5.52; Al, balance.	....do			6.3	15.3		9,000	21,700	9.0	11.1							(168)
Ni, 1.87; Al, balance.	Cold-drawn rods			13.9	16.0		19,700	22,700	12.6	36.9							(168)
Ni, 4.31; Al, balance.	....do			16.1	19.6		22,900	27,900	8.5	24.0							(168)
Ni, 1.87; Al, balance.	Annealed rods			3.9	11.5		5,600	16,300	34.1	55.8							(168)
Ni, 4.31; Al, balance.	....do			7.0	14.2		9,900	20,200	26.2	42.1							(168)
Ni, 1.87; Al, balance.	Hot-rolled rods			8.4	12.8		11,900	18,200	28.4	52.5							(168)
Ni, 4.31; Al, balance.	....do			9.5	15.7		13,500	22,300	22.0	36.4							(168)
Nickel, copper—																	
Ni, 1.10; Cu, 1.01; Al, balance.	Chill cast			4.4	12.8		6,200	18,200	19.1	29.2							(168)
Ni, 5.51; Cu, 1.02; Al, balance.	....do			7.5	17.4		10,700	24,800	6.1	8.5							(168)
Ni, 1.12; Cu, 2.00; Al, balance.	Cold-drawn rods			18.4	22.6		26,200	32,200	16.0	47.7							(168)
Ni, 5.33; Cu, 2.10; Al, balance.	....do			22.3	26.6		31,700	37,800	7.5	15.3							(168)
Ni, 1.12; Cu, 2.00; Al, balance.	Annealed rods			5.8	16.4		8,300	23,400	30.5	56.6							(168)

[14] This alloy is used more extensively in the automotive industry than all other light-casting alloys combined.
[15] About 0.5 inch (12.7 mm) diameter; tested without machining off the skin.
[16] Used for parts which should be free from leaks and where the brittleness of the alloy is not objectionable.
[17] Magnalium can be cast, rolled, forged, and drawn. Magnalium castings are not as porous as those of other aluminum alloys. The metal is much tougher than aluminum. Thermal conductivity is high and this simplifies the cooling problem. Takes high polish. Used for airplane and automobile engines.
[18] Magnalium is an alloy of aluminum and magnesium (the latter from 5 to 30 per cent). It contains small quantities of copper and nickel.
[19] With care, tensile strength up to 17.6 kg/mm² (25,000 lb./in.²) and elongation of 5 per cent may be obtained.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Tensile properties. Metric kg/mm² Yield point.	Tensile properties. Metric kg/mm² Tensile strength.	Tensile properties. English lb./in.² Proportional limit.	Tensile properties. English lb./in.² Yield point.	Tensile properties. English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Thermal properties. Linear coefficient of expansion ×10⁶ (per 1°C.)	Thermal properties. Casting shrinkage.	Thermal properties. Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Aluminum—Con. Nickel, copper—Cotinued.									Per ct.	Per ct.		°C.			mm/m	in./ft.	
Ni, 5.33; Cu, 2.10; Al, balance.	Annealed rods			7.0	18.6		9,900	26,500	25.0	36.3							(168)
Ni, 1.12; Cu, 2.00; Al, balance.	Hot-rolled rods			10.1	17.9		14,300	25,400	27.8	52.0							(168)
Ni, 5.33; Cu, 2,10; Al, balance.	do			12.8	22.1		18,160	31,500	16.0	23.6							(168
Ni, 1.08; Cu, 3.94; Al, balance.	Chill cast			6.3	17.0		9,000	24,100	7.5	11.7							(168)
Ni, 4.36; Cu, 4.04; Al, balance.	do			7.0	17.7		9,900	25,200	4.4	5.0							(168)
Ni, 1.12; Cu, 4.07; Al, balance.	Cold-drawn rods			22.1	26.3		31,400	37,400	12.1	28.8							(168)
Ni, 4.30; Cu, 4.08; Al, balance.	do			20.8	25.9		29,600	36,800	3.8	6.2							(168)
Ni, 1.12; Cu; 4.07; Al, balance.	Annealed rods			5.2	20.4		7,400	29,000	28.7	44.3							(168)
Ni, 4.30; Cu, 4.08; Al, balance.	do			5.1	17.8		7,200	25,300	23.5	29.7							(168)
Ni, 1.12; Cu, 4.07; Al, balance.	Hot-rolled rods			12.9	22.5		18,400	32,000	20.7	36.9							(168)
Ni, 4.30; Cu, 4.08; Al, balance.	do			12.0	20.7		17,000	29,500	13.5	18.6							(168)
Silicon (alpax)—																	
Al, Si	Cast				18.0–22.0			{25,600 31,300}	5–10								(67)

Silicon (silumin)[20]—																	
Si, 11–14; Al, balance.	....do....	2.5–2.65	....	....	20.0	....	....	28,400	5–10	....	60	....	....	....	....	....	(211)
Silver (argental)[21] —																	
Al, Ag....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	(112)
Tungsten (partinium)[22] —																	
Al, W....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	(44)
Zinc—																	
Al, Zn; various proportions (see fig. 10.)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	(168)
Zinc (alzene)[23]..	Cast, sand....	3.8	....	....	16.9	....	....	24,000	0	....	....	....	....	....	....	....	(98)
Zinc, copper[24]—																	
Al, 89; Zn, 10; Cu, 1.	Cast....	2.88	....	....	17.4	....	....	24,700	6.2	....	....	....	....	....	....	....	(105)
Al, 88; Zn, 10; Cu, 2.	....do....	2.91	....	....	17.8	....	....	25,380	4.0	....	....	....	....	....	....	....	(105)
Al, 92; Zn, 5; Cu, 3.	....do....	2.85	....	....	14.7	....	....	20,860	5.7	....	....	....	....	....	....	....	(105)
Al, 88.6; Zn, 8.4; Cu, 3.	Cast at 700° C. (1,292° F.).	....	4.7	....	18.5	6,700	....	26,300	8.0	7.5	50	10	....	....	....	....	(169)
	Annealed 500° C. (932° F.).	....	4.4	....	20.2	6,200	....	28,800	8.0	7.5	50	10	....	....	....	....	(169)
Al, 81.1; Zn, 15.9; Cu, 3.	Cast at 700° C. (1,292° F.).	3.09	9.8	....	24.7	14,000	....	35,100	2.0	2.0	74	15	....	....	....	....	(169)
	Annealed 500° C. (932° F.).	....	9.8	....	29.0	14,000	....	41,200	4.0	4.0	70	15	....	....	....	....	(169)
Al, 81.0; Zn, 12.5–14.5; Cu, 2.25–3.25; Si, Fe, Mn, Sn, max. 1.7; other imp., none.	Cast sand; 0.5 in. (12.7 mm) diam.[25]	3.0	....	....	17.6–21.1	....	....	25,000–30,000	More than 1.0	....	....	....	....	....	13.0	0.156	(145)
Zinc, copper (alloy L 5)[26]—																	
Zn, 12.5–14.5; Cu, 2.5–3; Al, balance.	Cast, chill....	3.0	....	....	[27] 17.3	....	....	[27] 24,600	[27] 4	....	....	....	....	....	....	....	(134)

[20] Has advantage over other aluminum alloys at high temperature. Brinell hardness 60 at 500 kg (1,102 lb.), load, 10 mm ball at room temperature and 20–25 at 350° C. (662° F.) Wet steam does not appreciably attack silumin. Somewhat less resistant than pure aluminum to attack by dilute nitric acid (25 per cent) or other strong acids. Conducts heat better than other known alloys of aluminum.

[21] Alloy of aluminum and silver. Fine white color; good casting properties; rolls and machines well, and takes good polish.

[22] Alloy of aluminum and tungsten. Used in France in automobile construction because of its lightness and strength.

[23] Good for casting; resists corrosion well; takes good polish; used in automobile industry.

[24] Alloys containing 5 per cent and over of zinc are subject to an "aging" phenomenon which results in an increase in tensile strength and a decrease in elongation. Alloys of 5 per cent or more of zinc are not adapted for parts subjected to high temperature.

[25] Tested without machining off the skin.

[26] Tensile strength of "L 5" increases considerably on aging. Tensile strength of chill bar 1 inch (25.4 mm) diameter increases 30 per cent in 10 months. Tensile strength falls off rapidly as the temperature increases. Tensile strength at normal temperature = 22.0 kg/mm^2 (31,200 lb./in.^{2}). Tensile strength at 250° C. (482° F.) = 6.3 kg/mm^2 (9,000 lb./in.^{2}). Tensile strength at 350° C. (662° F) = 2.4 kg/mm^2 (3,400 lb./in.^{2}).

[27] Specification values.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Metric kg/mm² Yield point.	Metric kg/mm² Tensile strength.	English lb./in.² Proportional limit.	English lb./in.² Yield point.	English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Linear coefficient of expansion ×10⁶ (per 1°C.)	Casting shrinkage.		Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Aluminum—Con.																	
									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Zinc, copper, Manganese (alloy "E")[28]—Zn, 20.0; Cu, 2.5; Mn, 0.5; Mg, 0.5; Fe, not over 0.2; Si, not over 0.2; Al, balance.	7/8 in. (22.2 mm) diam. rod, hot rolled.	3.1	......	37.3	46.7	......	53,000	66,500	15	......	......	......	......	......	......	......	(134)
	7/8 in. (22.2 mm) diam. rod, quenched, 350° C. (662° F.), aged 5 days.	......	34.8	51.8	59.5	49,500	73,700	84,600	12	13.4	......	......	......	......	......	......	(134)
	0.05 in. (1.27 mm) sheet hot rolled.	......	......	38.5	51.1	......	54,800	72,600	18	......	......	......	......	......	......	......	(134)
	0.05 in. (1.27 mm) sheet quenched 400° C. (752° F.), aged.	......	......	46.1	60.1	......	65,600	85,500	15	......	......	......	......	......	......	......	(134)
	0.05 in. (1.27 mm) sheet hot rolled, annealed 250° C. (483° F.).	......	......	22.9	39.9	......	32,500	56,700	20	......	......	......	......	......	......	......	(134)
Zinc, copper (alloy 3/20)[29]—Al, 77; Zn, 20; Cu, 3.	Wire for rivets, cold drawn and annealed at 250° C. (482° F.), diam. 0.063 in. (1.6 mm).	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	(133)
Zn, 20; Cu, 3; Al, balance.[30]	Hot rolled, 1 5/8 in. (41.2 mm) diam. rod.	......	18.6–20.5	27.7	41.6	26,400–29,100	39,400	59,200	17	29.8	......	......	......	......	......	......	(134)
	1 5/8 in. (41.2 mm) diam. rod annealed at 200° C. 392° (F.).	......	......	23.8	39.0	......	33,800	55,500	21	......	......	......	......	......	......	......	(134)
	Hot rolled 0.10 in. (2.54 mm) sheet.	......	......	26.6	42.8	......	37,800	60,900	19	......	......	......	......	......	......	......	(134)

	0.10 in. (2.54 mm) sheet hot rolled, annealed at 200° C. (392° F.).	....	....	19.3	35.0	....	27,550	49,700	24–28	....	....	....	....	....	....	....	(134)
	0.063 in. (1.6 mm) diam. wire as received.	....	....	....	43.8	....	....	62,200	[31] 8	....	....	....	....	....	....	....	(134)
	0.063 in. (1.6 mm) diam. wire annealed at 250° C. (482° F.).	....	....	....	32.6	....	....	46,300	[31] 14	....	....	....	....	....	....	....	(134)
Antimony [32]	....	([33])	....	....	....	....	....	....	....	....	....	....	630 (1,166° F.)	[34] 11.5	....	....	(98)
Antimony: [35] Sb, 99.45; As, Fe.	Wire, 0.36 mm (0.0091 in.) diam.	....	....	....	1.08	....	....	1,540	....	....	....	....	....	....	....	....	(130)
Bismuth: [36] Bi	....	9.8	....	....	....	....	....	....	....	....	....	....	[34] 271 (520° F.)	[34] 13.46	....	....	(74)
Boron: [37] B	....	....	....	....	....	....	....	....	....	....	....	....	2,000–2,500 (3,632–4,532° F.)	....	....	....	(2)
Cadmium: [38] Cd	....	[34]8.64	....	....	....	....	....	....	....	....	....	....	321 (610° F.)	[34] 30.7	....	....	(138)

[28] Corroded strongly even by a weak saline solution and ultimately undergoes a complete disintegration.

[29] Shearing strength, 26.8 kg/mm² (38,100 lb./in.²). Riveted joints showed no tendency to cracking or deterioration in the course of many months. Owing to their higher strength they compare favorably with rivets made of softer alloys.

[30] Shearing strength, 35.4 kg./mm.² (50,400 lb./in.²). Notched bar tests at 80 and 185° below 0° C. (112 and 301° below 0° F.) showed no embrittling action of the intense cold.

[31] In 4 in. (101.6 mm).

[32] Silver white crystalline brittle metal. Used in bearing metals and as type metal (expands on solidification).

[33] Vacuo distilled, 6.62; ditto-compressed, 6.69; amorphous, 6.22 (Smithsonian Physical Tables, 1920).

[34] Smithsonian Physical Tables, 7th edition, 1920.

[35] Modulus of elasticity, 7,950 kg/mm² (11,300,000 lb./in.²); modulus of elasticity in shear, 2,020 kg/mm² (2,870,000 lb./in.²). These results were obtained from bending tests and due to the anisotropic nature of wire can be used for calculation of bending stresses only.

[36] Has lustrous appearance like antimony; is very brittle; not altered in cold air, but on heating forms oxide; forms easily fusible alloys suitable for reproduction of woodcuts, for fusible valves and wires.

Melting Points of Some Bismuth Alloys.

Name of alloy.	Chemical composition, parts—				Melting point.	
	Bi	Pb	Sn	Cd	°C.	°F.
Wood's metal	5	8	4	3	68	154
Rose's metal	9	8	3	....	79	174
Newton's alloy	8	5	3	....	94.5	202
Lipowitz's alloy	15	8	8	3	70	158

Landolt Börnstein tables (1912) give for the modulus of elasticity of cast Bi 3,200 kg/mm² (4,550,000 lb./in.²) and for the modulus of elasticity in shear 1,200 to 1,400 kg/mm² (1,710,000 to 1,990,000 lb./in.²). Poisson's ratio of Bismuth 0.33. Poisson's ratio of Wood's metal, 0.49. Winkelman's Handbuch der Physik, 1908, **1** (1), gives for modulus of elasticity in shear of Wood's metal, 840 kg/mm² (1,190,000 lb./in.²). Poisson's ratio of Rose's metal, 0.47 and that of Lipowitz's alloy, 0.45.

[37] Hardness of fused boron inferior only to diamond. Most interesting property; enormous (2,000,000 times) increase of electrical conductivity at red heat.

[38] 1 per cent of Cd in brasses with 60–70 per cent copper has no appreciable effect. Cd content more than 1 per cent has a detrimental effect, especially on resilience. Landolt Börnstein tables (1912) give for modulus of elasticity 5,000 to 7,000 kg/mm² (7,100,000 to 9,950,000 lb./in.²) and the modulus of elasticity in shear 1,000 to 2,500 kg/mm² (1,420,000 to 3,550,000 lb./in.²). Poisson's ratio, 0.30. According to Winkelman's Handbuch der Physik, 1908, **1** (1), modulus of elasticity of cast Cd, 7,070 kg/mm² (10,050,000 lb./in.²) and modulus of elasticity in shear, 2,450 kg/mm² (3,480,000 lb./in.²).

[39] Landolt Börnstein tables, 1912.

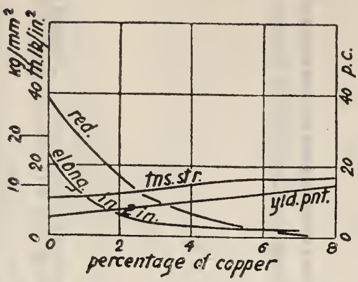

Fig. 3.—*Tensile properties of aluminum-copper sand-cast alloys.*

H. C. Carpenter and C. A. Edwards, 8th report to the alloys research committee of the Inst. Mech. Eng.; 1907.

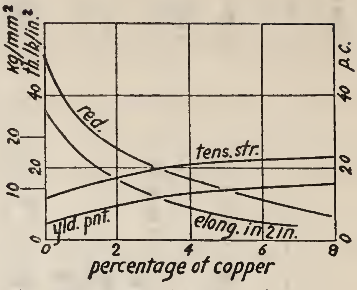

Fig. 4.—*The tensile properties of aluminum-copper chill-cast alloys.*

H. C. Carpenter and C. A. Edwards, 8th report to the alloys research committee of the Inst. Mech. Eng.; 1907.

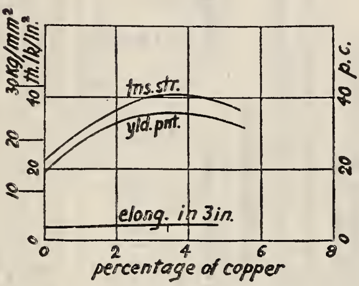

Fig. 5.—*The tensile properties of aluminum-copper alloys in the form of sheet 0.05 in. (1.27 mm) thick.*

The ingots were cast ⅝ in. (15.9 mm) thick, hot rolled to ⅜ in. (9.52 mm), cold rolled to ¼ in. (6.35 mm), annealed, cold rolled to 0.1 in. (2.54 mm), annealed, cold rolled to 0.05 in. (1.27 mm). H. C. Carpenter and C. A. Edwards, 8th report to the alloys research committee of the Inst. Mech. Eng.; 1907.

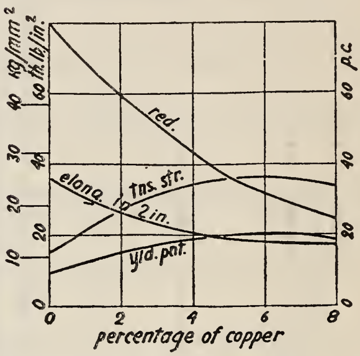

Fig. 6.—*The tensile properties of aluminum-copper alloys 1¼ in. (31.7 mm) diameter bars hot rolled from 3 in. (76.2 mm) ingots.*

H. C. Carpenter and C. A. Edwards, 8th report to the alloys research committee of the Inst. Mech. Eng.; 1907.

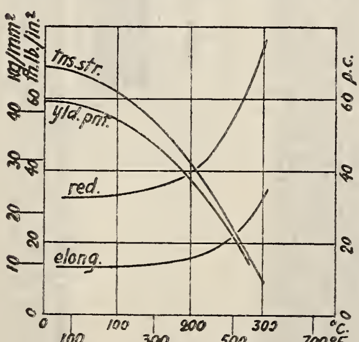

Fig. 7.—*Variation of the tensile properties of duralumin with temperature.*

L. M. Cohn, Elektrotechnik und Machinenbau, 30, pp. 809, 829; 1912; and Duralumin, Ver. z. Ford. d. Gewerbefleisses, 89, p. 643; 1910.

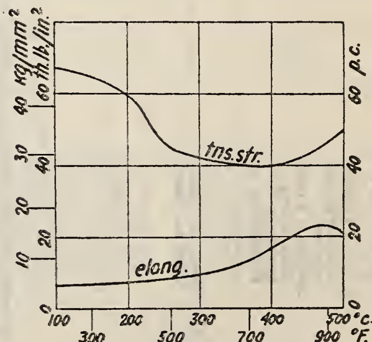

Fig. 8.—*Effect of annealing on the tensile properties of duralumin.*

L. M. Cohn, Duralumin, Elektrotechnik und Machinenbau, 30, pp. 809, 829; 1912; and Duralumin, Ver. z. Ford. d. Gewerbefleisses, 89, p. 643; 1910.

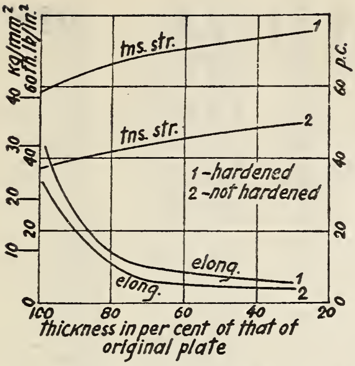

FIG. 9.—*Effect of cold working on the tensile properties of duralumin.*

Samples cold rolled from a thickness of 7 mm (0.276 in.). L. M. Cohn, Duralumin, Elektrotechnik und Machinenbau, 80, pp. 809, 829; 1912; and Duralumin, Ver. z. Ford. d. Gewerbefleisses, 89, p. 643; 1910.

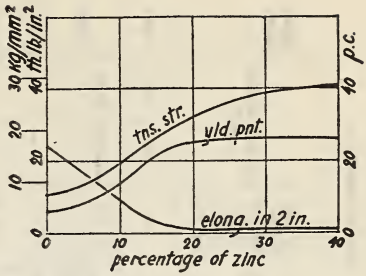

FIG. 10.—*The tensile properties of aluminum-zinc sand-cast alloys.*

W. Rosenhain and L. Archbutt, 10th report to the alloys research committee, Inst. Mech. Eng.; 1912.

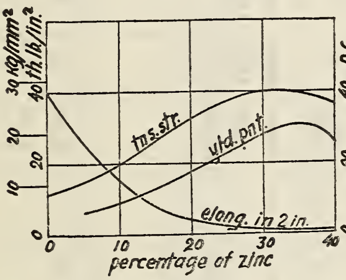

FIG. 11.—*The tensile properties of aluminum-zinc chill-cast alloys.*

W. Rosenhain and L. Archbutt, 10th report to the alloys research committee, Inst. Mech. Eng.; 1912.

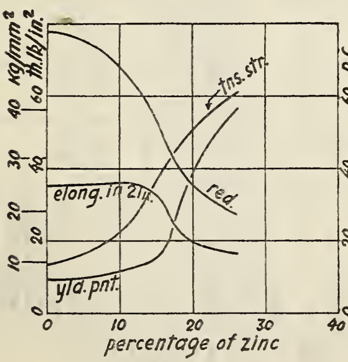

FIG. 12.—*The tensile properties of aluminum-zinc alloys; 1¼ in. (31.7 mm), diameter bars hot rolled from 3 in. (76.2 mm) ingots.*

W. Rosenhain and L. Archbutt, 10th report to the alloys research committee, Inst. Mech. Eng.; 1912.

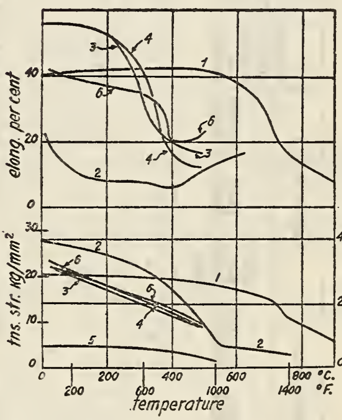

FIG. 13.—*Effect of high temperatures on the tensile properties of copper.*

1. Annealed electrolytic copper; rate of loading 1,120 lb./in.² (0.79 kg/mm²) per minute, tested in air. (G. D. Bengough and D. Hanson, Jour. Inst. Met., 12, p. 56; 1914.)

2. Rolled arsenical copper; rate of loading 1,120 lb./in.² (0.79 kg/mm²) per minute, tested in CO². (G. D. Bengough and D. Hanson, Jour. Inst. Met., 12, p. 56; 1914.)

3. Annealed electrolytic copper, tested in air. (A. K. Huntington, Jour. Inst. Met., 8, p. 126; 1912.)

4. Arsenical copper, tested in air. (A. K. Huntington, Jour. Inst. Met., 12, p. 234; 1914.)

5. Yield point for electrolytic copper. (B. S. Circular No. 73, p. 41; 1918.)

6. "Pure" copper, Le Chatelier, Congrès des Méthodés d' Essais, Paris; 1912.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties.								Hardness number.		Thermal properties.				Reference.
			Metric kg/mm²			English lb./in.²			Elongation in 50.8mm or 2 inches.	Reduction of area.	Brinell.	Scleroscope.	Melting point.	Linear coefficient of expansion ×10⁶ (per 1°C.)	Casting shrinkage.		
			Proportional limit.	Yield point.	Tensile strength	Proportional limit.	Yield point.	Tensile strength.									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Cerium:									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Ce		7.02											640 (1,184° F.)				(138)
Chromium:																	
Cr		[84] 6.52–6.73											[84] 1,615 (2,939° F.)				(138)
Cobalt, (pure): [40]																	
Co	Cast	8.79		([41])	24.2		([41])	34,400	Less than 1.0	Less than 1.0	[42] 124		1,478 (2,692° F.)	[43] 12.36			(91)
	Annealed	8.81		([41])	26.0		([41])	36,980	Less than 1.0	Less than 1.0							(91)
	Wire	8.93			63.3			About 90,000	4.7	5.1							(91)
(Commercial) (Imp. Fe, Si, C) [44]—																	
Co, 97–99; C, 0.062.	Cast				42.0			59,700	About 8.0	About 7.0							(91)
C, 0.25	do				43.5			61,900	About 25.0	About 29.0							(91)
Chromium (stellite).[45]	do		59.8		77.3	85,000		110,000									(5)
Co, 59.5; Cr, 22.5; Mo, 10.8; Fe, 3.1; Mn, 2.0; C, 0.9; Si, 0.8.											512						(169)
Copper:[46]																	
Electrolytic—																	
Cu, 99.9	Wire																(113)
	Annealed at 500° C. (932° F.).	8.89	6.0		26.7	8,500		38,000	50	50	40	7					(109, 170)
	Not annealed (96 per cent reduction).[47]				47.4			67,400	0.8	64.5							(109, 170)

Annealed at 750° C. (1,382° F.) after drawing cold.[47]				21.9			31,200	24.5	76.0							(109, 170)
Drawn hot (64 per cent reduction).[48]				32.9			46,800	4.3	70.5							(109, 170)

[34] See foot note 34, p. 29.

[40] Compressive strength; Cast 85.3 kg/mm ^{2} (12,1500 lb./in.^{2}); annealed, 82.3 kg/mm ^{2} (117,200 lb./in.^{2}). Compressive yield point: Cast 29.6 kg/mm ^{2} (42,200 lb./in.^{2}); annealed 39.5 kg/mm ^{2} (56,100 lb./in.^{2}). Cobalt is readily machined but brittle. Special treatment is necessary to render pure cast cobalt amenable to working.

[41] Very close to the tensile strength.

[42] Under load of 1,590 kg (3,500 lb.).

[43] Smithsonian Physical Tables, 7th edition, 1920.

[44] Compressive strength—C, about 0.18: Cast, 125.1 kg/mm ^{2} (178,000 lb./in.^{2}); annealed 104.1 kg/mm ^{2} (148,000 lb./in.^{2}). Compressive yield point—C, about 0.18: Cast, 36.6 kg/mm ^{2} (52,100 lb./in.^{2}); annealed, 42.9 kg/mm ^{2} (61,000 lb./in.^{2}). Commercial Co containing C may be readily swaged down from cast bars to wire. Addition of C gives toughness.

[45] Produced in 1899. Considerable hardness and toughness. Most important property, ability to maintain a cutting edge at a high speed, even at a full, red heat. Can not be forged and can only be reduced to the desired form by casting in the form of bars, which are afterwards ground.

[46] Tests made under working conditions on stranded cables of hard-drawn wire gave: Modulus of elasticity of 7-strand cable 14,100 kg/mm^2 (20,000,000 lb./in.^{2}); modulus of elasticity of 19-strand cable 12,300 kg/mm^2 (17,500,000 lb./in.^{2}); modulus of elasticity of 37-strand cable 10,900 kg/mm^2 (15,500,000 lb./in.^{2}); 14,050 kg/mm^2 (20,000,000 lb./in.^{2}) was suggested as suitable working value for solid wire.

Properties of Bare Copper Cables.

[Results of Tests Made at the Massachusetts Institute of Technology in 1912; Pender, Handbook for Electrical Engineers, 1914, p. 1880. The cables Were Given Preliminary Stretch Before Readings Were Taken.]

Cables designation.	Number of wires in cables.	Pitch of layers.				Elastic limit.		Tensile strength.		Modulus of elasticity.	
		First layer.		Second layer.							
		mm	in.	mm	in.	kg/mm^2	lb./in.^{2}	kg/mm^2	lb./in.^{2}	kg/mm^2	lb./in.^{2}
A	7	114.3	4.5			15.5	22,000	37.6	53,500	11,680	16,600,000
B	19	177.8	7	127.0	5	15.0	21,300	42.0	59,800	11,540	16,400,000
C	19	228.6	9	114.3	4.5	17.6	25,000	39.4	56,000	11,470	16,300,000
D	19	228.6	9	228.6	9	16.9	24,000	37.0	52,600	11,600	16,500,000
E	19	114.3	4.5	76.2	3	17.8	25,300	37.8	53,800	9,570	13,600,000

Properties of Component Wires of Above Cables.

Wires from cables.	Diameter of wires.		Elastic limit.		Tensile strength.		Modulus of elasticity.	
	mm	in.	kg/mm^2	lb./in.^{2}	kg/mm^2	lb./in.^{2}	kg/mm^2	lb./in.^{2}
B	3.17	0.125	19.0	27,000	44.2	62,800	11,890	16,900,000
C	3.17	.125	19.0	27,000	43.5	61,900	13,300	18,900,000
D	3.17	.125	18.3	26,000	43.4	61,800	11,680	16,600,000
E	3.17	.125	18.3	26,000	41.7	59,300	12,320	17,500,000

[47] Wire drawn cold from 0.125 to 0.025 inch (3.18 to 0.64 mm).

[48] Wire drawn at 150° C. (302° F.) from 0.031 to 0.025 inch (0.79 to 0.64 mm).

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm.[2] Proportional limit.	Metric kg/mm.[2] Yield point.	Metric kg/mm.[2] Tensile strength.	English lb./in.[2] Proportional limit.	English lb./in.[2] Yield point.	English lb./in.[2] Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Linear coefficient of expansion ×10⁶ (per 1°C.)	Casting shrinkage.	Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Copper (pure) [49]																	
Pure— Cu, min. 99.5	Soft, sheet 0.005–0.031 in. (0.13–0.79 mm).				26.0			max. 37,000	min. 20.0								(146)
	Soft, sheet, 0.032–0.375 in. (0.81–9.51 mm).				25.3			max. 36,000	min. 25.0								(146)
	Hard, sheet, 0.072–0.375 in. (1.83–9.51 mm).				28.1			min. 40,000	min. 8.0								(146)
	Hard, sheet, over 0.375 in. (9.51 mm).				26.4			min. 37,500	min. 15.0								(146)
Cu, 99.9 [50]	Normalized [51]	8.89	([52])		21.1–28.1			30,000–40,000	40–60	40–60	([53])		1,083 (1,982° F.)	([54])			(170)
Commercial— Cu, 99.6	Cast	8.85	7.0		17.6	10,000		25,000	20	60	80	8					(168, 170)
	Rolled, hard (40 per cent reduction).	8.89	14.1		35.2	20,000		50,000	5	8	94						(170)
	Annealed at 500° C. (932° F.).	8.90			24.6			35,000	50	60	42	6					(170)
	Drawn, cold (50 per cent reduction).		26.0		35.2	37,000		50,000	9			18					(170)

[49] According to Winkelman's Handbuch der Physik, 1908, 1, 1.—: Modulus of elasticity of cast copper, 10,800 kg/mm² (15,350,000 lb./in.²); modulus of elasticity of annealed copper, 10,520 kg/mm² (14,950,000 lb./in.²); modulus of elasticity of drawn copper, 12,140 kg/mm² (17,250,000 lb./in.²); modulus of elasticity in shear of cast copper, 4,780 kg/mm² (6,790,000 lb./in.²); modulus of elasticity in shear of drawn copper, 4,200 kg/mm² (5,950,000 lb./in.²).

[50] Modulus of elasticity of copper (electrolytic), 12,200 kg/mm² (17,350,000 lb./in.²): modulus of elasticity of drawn copper, 12,400 kg/mm² (17,600,000 lb./in.²); modulus of elasticity of annealed copper, 12,900 kg/mm² (18,300,000 lb./in.²); modulus of elasticity of cast copper, 7,700 kg/mm² (11,000,000 lb./in.²). According to American Steel & Wire Co. (1923) modulus of elasticity of hard-drawn copper is 9,800 kg/mm² (14,000,000 lb./in.²). Modulus of elasticity in shear, 4,240 kg/mm² (6,030,000 lb./in.²) Poisson's ratio, 0.33. Shearing strength=tensile strength and varies in annealed or cast condition from 15.5 to 25.3 kg/mm² (22,000 to 36,000 lb./in.²). Compression—copper of good quality does not fail in compression test by fracture; it merely yields indefinitely. Cast-copper annealed cylinders 0.625-inch (15.8 mm) diameter and 2 inches (50.8 mm) long: shortened 5 per cent at 22.0 kg/mm² (31,300 lb./in.²); shortened 10 per cent at 28.9 kg/mm² (41,200 lb./in.²); shortened 20 per cent at 39.0 kg/mm² (55,400 lb./in.²)

[51] Pure copper may best be normalized by casting, rolling, and drawing, followed by annealing at 500° C. (932° F.).

[52] Not determinable.

[53] Bhn. of annealed or cast copper is 30–40 (500 kg (1,102 lb.) 10 mm ball). When hardened by cold work, Bhn. may become as high as 100.

[54] Coefficient of expansion $(16.4t+0.004t^2)10^{-6}$ where t=degrees Centigrade.

TABLE 4.—Tensile Requirements of Soft or Annealed Copper Wire.

[A. S. T. M. specification B 3–15.]

Diameter.		Tensile strength.		Elongation (minimum) in 254 mm (10 in.).
mm	in.	kg/mm²	lb./in.²	Per cent.
11.70–7.37	0.460–0.290	25.3	36,000	35
7.34–2.62	.289–.103	26.0	37,000	30
2.59–.53	.102–.021	27.1	38,500	25
.51–.08	.020–.003	28.2	40,000	20

TABLE 5.—Tensile Requirements of Medium Hard-Drawn Copper Wire.

[A. S. T. M. specification B 2–15.]

Diameter.		A. W. G. (No.).	Tensile strength.				Elongation (minimum).
			Minimum.		Maximum.		
mm	in.		kg/mm²	lb./in.²	kg/mm²	lb./in.²	Per cent in 254 mm (10 in.).
11.68	0.460	0000	29.5	42,000	34.4	49,000	3.75
10.40	.410	000	30.2	43,000	35.1	50,000	3.6
9.27	.365	00	30.9	44,000	35.8	51,000	3.25
8.25	.325	0	31.6	45,000	36.5	52,000	3.0
7.35	.289	1	32.3	46,000	37.2	53,000	2.75
6.54	.258	2	33.0	47,000	37.9	54,000	2.5
5.83	.229	3	33.7	48,000	38.7	55,000	2.25
							Per cent in 1,524 mm (60 in.).
5.19	.204	4	34.0	48,330	38.9	55,330	1.25
4.62	.182	5	34.2	48,660	39.1	55,660	1.20
4.12	.162	6	34.4	49,000	39.4	56,000	1.15
3.66	.144	7	34.7	49,330	39.6	56,330	1.11
3.26	.128	8	34.9	49,660	39.8	56,660	1.08
2.91	.114	9	35.1	50,000	40.1	57,000	1.06
2.59	.102	10	35.4	50,330	40.3	57,330	1.04
2.31	.091	11	35.6	50,660	40.5	57,660	1.02
2.05	.081	12	35.8	51,000	40.8	58,000	1.00
1.83	.072	13	36.0	51,330	41.0	58,330	.98
1.63	.064	14	36.3	51,660	41.2	58,660	.96
1.45	.057	15	36.5	52,000	41.5	59,000	.94
1.29	.051	16	36.8	52,330	41.7	59,330	.92
1.15	.045	17	37.0	52,660	41.9	59,660	.90
1.02	.040	18	37.2	53,000	42.2	60,000	.88

Proportional limit of medium hard-drawn copper wire averages 50 per cent of tensile strength required in these specifications.

TABLE 6.—Tensile Requirements of Hard-Drawn and Hard-Rolled Copper Wire—Specification Values.

[Specific gravity, 8.89 at 20° C. (68° F.). For copper wire and for hard-drawn and hard-rolled flat copper of thicknesses corresponding to diameters of wire. (A. S. T. M., B 1-15.)]

Diameter.		A. W. G. No.	Minimum tensile strength.		Minimum elongation.
mm	in.		kg/mm²	lb./in.²	Per cent in 254 mm (10 in.).
11.68	0.460	0000	34.5	49,000	3.75
10.40	.410	000	35.9	51,000	3.25
9.27	.365	00	37.1	52,800	2.80
8.25	.325	0	38.3	54,500	2.40
7.35	.289	1	39.4	56,100	2.17
6.54	.258	2	40.5	57,600	1.98
5.83	.229	3	41.5	59,000	1.79
					Per cent in 1,524 mm (60 in.).
5.19	.204	4	42.2	60,100	1.24
4.62	.182	5	43.0	61,200	1.18
4.12	.162	6	43.7	62,100	1.14
3.66	.144	7	44.3	63,000	1.09
3.26	.128	8	44.8	63,700	1.06
2.91	.114	9	45.2	64,300	1.02
2.59	.102	10	45.9	64,900	1.00
2.31	.091	11	46.0	65,400	.97
2.05	.081	12	46.2	65,700	.95
1.83	.072	13	46.3	65,900	.92
1.63	.064	14	46.5	66,200	.90
1.45	.057	15	46.7	66,400	.89
1.29	.051	16	46.8	66,600	.87
1.15	.045	17	47.0	66,800	.86
1.02	.040	18	47.1	67,000	.85

Proportional limit of hard-drawn copper wire averages 55 per cent of tensile strength required in these specifications for four largest-sized wires in table, and 60 per cent of tensile strength for smaller sizes.

TABLE 7.—Tensile Requirements of Copper Plates.

[A. S. T. M. specification B 11-18.]

Analysis.	Tensile strength.		Elongation in 203.2 mm (8 in.).
	kg/mm²	lb./in.²	Per cent.
Copper, arsenical, As, 0.25-0.50; impurities, max, 0.12	21.8	31,000	35
Copper, nonarsenical, impurities, max., 0.12	21.1	30,000	30

TABLE 8.—Tensile Requirements of Rolled Copper—Specification Values.

[U. S. Navy Department, 47C2b, minimums for rolled copper, Cu, min. 99.5.]

Description.	Temper.	Thickness.	Tensile strength.		Elongation in 50.8 mm (2 in.).
			kg/mm²	lb./in.²	Per cent.
Rods, bars, and shapes [1]	Soft		21.1	30,000	25
	Hard	To 9.5 mm (3/8 in.), inclusive	35.2	50,000	10
	...do	9.5 to 25.4 mm (1 in.)	31.6	45,000	12
	...do	25.4 to 50.8 mm (2 in.)	28.1	40,000	15
	...do	Over 50.8 mm (2 in.)	24.6	35,000	20
Sheets and plates	Soft		21.1-28.1	30,000-40,000	25
	Hard		24.6	35,000	18

[1] Hammer test: Bars shall stand hammering hot to a fine point. Bending test: Bars shall stand bending cold through 120° to radius equal to diameter or thickness of test bar.

IX. NOMENCLATURE OF COPPER ALLOYS.

The general system of nomenclature employed has been to denominate (*a*) all simple copper-zinc alloys as *brasses;* (*b*) all simple copper-tin alloys as *bronzes;* and (*c*) three or more metal alloys composed primarily of either of these two combinations as *alloy brasses* or *bronzes*, as, for example, "Zinc bronze" for U. S. Government composition "G," Cu, 88 per cent; Sn, 10 per cent; Zn, 2 per cent. Alloys of the third type noted above, together with other alloys composed mainly of copper, have been called *copper alloys*, with the alloying elements other than minor impurities listed as modifying copper in the order of their relative percentages. In some instances the scientific name used to denote an alloy is based upon the deoxidizer used in its preparation, which may appear either as a minor element of its composition or not at all, as, for example, phosphor bronze. Commercial names are shown below the scientific names. In some cases a commercial name is used for alloys of widely varying composition.

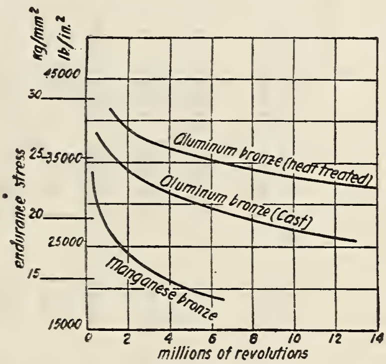

FIG. 14.—*Fatigue properties of aluminum and manganese bronzes.*

W. M. Corse and G. F. Comstock, Proc. A. S. T. M., 162, p. 117; 1916.
The tests were made in White-Souther machine. For chemical composition and other physical properties of tested metals see Table 21.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Tensile properties. Metric kg/mm² Yield point.	Tensile properties. Metric kg/mm² Tensile strength.	Tensile properties. English lb./in.² Proportional limit.	Tensile properties. English lb./in.² Yield point.	Tensile properties. English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell	Hardness number. Scleroscope.	Thermal properties. Melting point.	Thermal properties. Linear coefficient of expansion $\times 10^6$ (per 1° C.)	Thermal properties. Casting shrinkage.		Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Copper:									Per ct.	Per ct.			°C.		mm/m	In./ft.	
Aluminum (aluminum bronze)[1]	Cast																(109)
Cu, 92.5; Al, 7.2.	Rolled, annealed		6.7		37.6	9,600		53,500	9.0	72.9	81	19					(164)
Cu, 90.1; Al, 9.9.	Cast, sand			17.8	50.0		25,300	71,000	21.7								(40)
	Cast, sand slowly cooled from 800° C. (1,472° F.)			21.0			29,800										(40)
	Cast, sand quenched from 800° C. (1,472° F.)			35.3	78.7		50,200	112,000	3.0								(40)
	Cast, chill			19.5	58.2		27,800	82,700	30.5								(40)
	Cast, chill, slowly cooled from 800° C. (1,472° F.)			26.0	41.6		37,000	59,100	5.0								(40)
	Cast, chill, quenched from 800° C. (1,472° F.)			27.8	60.8		39,600	86,400	22.0								(40)
	1.25 in. (31.8 mm) diam. rolled bar.			21.5	55.2		30,500	78,500	31.5	30.5							(40)
	0.8125 in. (20.6 mm) diam. rolled bar.			23.3	60.0		33,200	85,300	28.8	30.8							(40)
	0.8125 in. (20.6 mm) rolled bar slowly cooled from 800° C. (1,472° F.).			24.8	45.0		35,200	63,900	6.5	10.2							(40)
	0.8125 in. (20.6 mm) rolled bar quenched from 800° C. (1,472° F.)			41.3	71.7		58,700	101,900	11.0	16.8							(40)
	Cold-drawn 0.8125 in. (20.6 mm) bar.			63.7	69.2		90,500	98,400	13.4	22.2							(40)
Cu, 90; Al, 10[2]		7.5		16.9	49.3		24,000	70,100	20.5	20	90–100				18.3	0.22	(114)
Cu, 90; Al, 10[3]	Cast, sand	7.5–7.45	13.9–23.3		51.1–60.0	19,800–33,200		72,700–85,500	28.8–21.7	30.0–22.4	102–106	25–26					(169)

Aluminum, iron (aluminum bronze)[4]—																	
Cu, 85–87; Al, 7–9; Fe, 2.5–4.5; Sn, max. 0.5; Pb, Zn, etc., 0.1.	Rods and bars up to 0.5 in. (12.7 mm)[5].	....	....	28.1	56.2	....	40,000	80,000	30.0	....	....	....	....	....	....	....	(189)
	Rods and bars 0.5 to 1.0 in. (12.7 to 25.4 mm)[5].	....	....	26.4	52.7	....	37,500	75,000	30.0	....	....	....	....	....	....	....	(189)
	Rods and bars over 1 in. (25.4 mm).[5]	....	....	24.6	50.6	....	35,000	72,000	30.0	....	....	....	....	....	....	....	(189)
	Shapes, all thicknesses,[5]	....	....	26.4	52.7	....	37,500	75,000	30.0	....	....	....	....	....	....	....	(189)
	Sheets and plates up to 0.5 in. (12.7 mm) over 30 in. width (76.2 mm).[5]	....	....	27.4	54.8	....	[6] 39,000	[6] 78,000	30.0	....	....	....	....	....	....	....	(189)
	Shapes and plates over 0.5 in. (12.7 mm).[5]	....	....	26.4	52.7	....	37,500	75,000	30.0	....	....	....	....	....	....	....	(189)
Cu, 85–87; Al, 7–9; Fe, 2.5–4.5; Sn (none desired), max. 0.5; other imp., max. 0.25[7].	Cast..........	....	....	14.1	45.7	....	min. 20,000	min. 65,000	min. 20	....	....	....	....	....	....	....	(147)
	Wrought bars annealed or hot rolled, diameter or thickness up to 0.5 in. (12.7 mm).	....	....	28.1	56.2	....	min. 40,000	min. 80,000	min. 30	....	....	....	....	....	....	....	(147)
	Wrought bars annealed or hot rolled, diameter or thickness 0.5 to 1.0 in. (12.7 to 25.4 mm)	....	....	26.4	52.7	....	min. 37,500	min. 75,000	min. 28	....	....	....	....	....	....	....	(147)
	Wrought bars annealed or hot rolled, diameter or thickness over 1.0 in. (25.4 mm).	....	....	24.6	50.6	....	min. 35,000	min. 72,000	min. 25	....	....	....	....	....	....	....	(147)
Aluminum, iron[8]—																	
Cu, 89; Al, 10; Fe, 1; Ti, ?.	Cast..........	7.58	14.1–17.6	....	45.7–56.2	20,000–25,000	....	65,000–80,000	30–20	30–20	93–100	25	....	....	....	....	(169)

[1] Modulus of elasticity, 11,800 kg/mm² (16,800,000 lb./in.²).
[2] Load giving compression of 0.1 per cent 13.7 kg/mm² (19,500 lb./in.²); compression at load of 70.3 kg/mm² (100,000 lb./in.²) is 12 per cent.
[3] Compressive proportional limit 13.5 kg/mm² (19,200 lb./in.²) with 13.5 per cent set for 70.3 kg/mm² (100,000 lb./in.²) load.
[4] Specifications minimums for the hot-rolled aluminum bronze.
[5] Required to bend cold through 120° about radius equal to thickness.
[6] 2.6 per cent increase in strength for sheets and plates up to 30 in. (762 mm) width.
[7] Noncorrodible alloy of great strength with a hardness equal to that of a manganese bronze and good bearing qualities. It is suitable for use in gears and worm wheels.
[8] Compressive proportional limit, cast, 12.7 to 14.1 kg/mm² (18,000 to 20,000 lb./in.²) with 13 to 15 per cent set at 70.3 kg/mm² (100,000 lb./in.²) load.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Metric kg/mm² Yield point.	Metric kg/mm² Tensile strength.	English lb./in.² Proportional limit.	English lb./in.² Yield point.	English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Linear coefficient of expansion ×10⁶ (per 1°C.)	Casting shrinkage.		Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Copper—Contd. Aluminum, iron (aluminum bronze)—									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Cu, 88.5; Al, 10.5; Fe, 1.0.	Cast, sand	...	14.1	...	54.1	20,000	...	77,000	24.5	25.0	100	...	...	...	...	...	(169)
	Quenched, 850° C. (1,562° F.); drawn, 700° C. (1,292° F.)	...	28.1	...	64.7	40,000	...	92,000	14.0	18.5	140	...	...	...	...	...	(169)
Cu, 89; Al, 10; Fe, 1.[9]	...	7.5	...	16.2–19.7	45.7–56.3	...	23,000–28,000	65,000–80,000	20–30	21–29	[10] 92–100	...	...	...	18.3	0.22	(45)
Cu, 89; Al, 10; Fe, 1.[11]	...	7.5	...	16.9	54.2	...	24,000	77,000	24	25	95–105	25	...	...	18.3	.22	(114)
Cu, 87.0; Al, 9.8; Fe, 3.14.[12]	...	7.71	...	...	52.6	...	...	74,800	21.0	19.0	...	...	...	...	...	...	(46)
Cu, 85.6; Al, 10.81; Fe, 3.57.	...	7.58	...	...	46.8	...	...	66,600	11.5	13.0	...	...	...	...	...	...	(46)
Aluminum, iron (Silliman bronze)—																	
Cu, 86.4; Al, 9.7; Fe, 3.9.	Wrought	...	9.84	...	59.3	14,000	...	84,400	11.5	...	...	...	...	...	...	...	(175)
	Cast	...	8.1	...	55.4	11,500	...	78,850	14.5	...	...	...	...	...	...	...	(175)
Aluminum, tin, iron (aluminum bronze)[13]—																	
Cu, 90.4; Al, 8.9; Sn, 0.4; Fe, 0.2; Pb, 0.1.	...	...	8.9	...	43.5	12,700	...	61,900	27.0	29.2	...	...	...	...	...	...	(177)
Cu, 90.4; Al, 8.8; Sn, 0.1; Fe, 0.4; Pb, 0.2.[14]	...	...	10.2	...	39.0	14,500	...	55,500	27.5	34.7	...	...	...	...	...	...	(177)
Aluminum, tin—																	
Cu, 88.5; Al, 10.4; Sn, 1.2.	Cast, chill	...	25.8	...	47.8	36,700	...	68,000	4.4	5.6	189	32	...	...	...	...	(83)

Aluminum, titanium, (aluminum titanium bronze)—																	
Cu, 90; Al, 10; Ti, —.	Cast		9.6		51.8	13,650		73,600	19.5	33.7	100						(169)
	Quenched		19.5		73.6	27,700		104,500	1.0	0.8	262						(169)
Cu, 90; Al, 10; Ti, —[15]	Cast	7.5			49.3			70,000	20.0		95				18.3	.22	(72)
Aluminum, titanium (aluminum titanium bronze), alloy No. 5[16]—																	
Cu, 90; Al, 10; Ti, —.	do		13.9		52.0	19,800		74,000	19.5	23.7	100						(6)
	Quenched		28.5		74.0	40,500		105,200	1.0	0.8	262						(6)
	Heat treated		27.4–39.4		64.0–68.2	39,000–56,000		91,000–97,000	14.0–5.5	18.5–9.1	140–158						(6)
Cerium[17]—																	
Ce, 0.22; balance, commercial copper.	Cast		11.9		18.8	16,900		26,700	33.5	47.2							(4)

[9] Modulus of elasticity, 10,550–12,670 kg/mm² (15,000,000–18,000,000 lb./in.²). Compressive elastic limit 13.4 kg/mm² (19,000 lb./in.²). Low coefficient of friction. Resistance to impact (Fremont notched bar test, cross section 7 by 10 mm) 7–10 kgm (50–70 ft.-lb.). Endurance to alternating impact (Landgraf-Turner, or Arnold test) alternations 3,500–5,500. Resistance to shear by impact (McAdam machine) 750–850 ft.-lb. (104–117 kgm). Cu, Al bronzes have practically double the tensile strength of Sn bronzes. Their resistance to shock and their resistance to wear is superior to that of Cu, Sn bronzes. Aluminum bronze is cast with great difficulty, but it is perfectly possible to make as good castings as from any nonferrous alloy. It absorbs gases readily while in molten condition. Alloys research committee of the Institute of Mechanical Engineers of Great Britain points out that cast-aluminum bronze possesses properties equal to those of rolled-aluminum bronze. Important property—resistance to alternating stresses, which is greater than that of some steels.

[10] 500 kg (1,102 lb.) load.

[11] Load giving compression of 0.1 per cent 13.4 kg/mm² (19,000 lb./in.²). Compression at load of 70.3 kg/mm² (100,000 lb./in.²) is 15 per cent.

[12] In tensile strength and ductility it ranks with mild steel, can be easily machined to nice finish; it can be forged while hot, also rolled into sheets. Sound castings can be made free from shrinkage holes or blowholes. It is resistant to several acids, particularly to sulphuric, lactic, phosphoric, tartaric, and acetic. Nitric acid, hydrochloric acid, and aqua ammonia attack readily.

Corrosion in 35 per cent sulphuric acid.

[Cumulative loss at 72° F. (22° C.).]

Days.	Forged.		Rolled.		Cast.	
	g/cm²	lb./in.²	g/cm²	lb./in.²	g/cm²	lb./in.²
7	0.00022	0.0000031	0.00053	0.0000075	0.00051	0.0000073
14	.00043	.0000062	.00102	.0000145	.00105	.0000150
21	.00064	.0000090	.00175	.0000249	.00172	.0000245
28	.00085	.0000121	.00211	.0000300	.00223	.0000318

[13] Bronze N (Bureau of Construction and Repair, Navy Department), modulus of elasticity 12,300 kg/mm² (17,500,000 lb./in.²).

[14] Bronze RM (Bureau of Construction and Repair, Navy Department), modulus of elasticity 12,000 kg/mm² (17,000,000 lb./in.²).

[15] Not readily corrodible by sea water.

[16] Valuable property—ability to withstand alternating stresses.

[17] Addition of small amount of cerium improves mechanical properties of ordinary copper.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Tensile properties. Metric kg/mm² Yield point.	Tensile properties. Metric kg/mm² Tensile strength.	Tensile properties. English lb./in.² Proportional limit.	Tensile properties. English lb./in.² Yield point.	Tensile properties. English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Thermal properties. Linear coefficient of expansion ×10⁶ (per 1°C.)	Thermal properties. Casting shrinkage.	Thermal properties. Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Copper—Contd.																	
Iron, aluminum, (lynux bronze)[18]																	
Cu, 89.01; Al, 3.76; Fe, 7.23	....	7.37	14.1	....	55.1	20,000	....	78,300	Per ct. 28.0	Per ct. 34.6	....	30	°C.	....	mm/m	in./ft.	(106)
Lead (roman metal)[19]	....	....	1.8	....	7.3	2,550	....	10,400	6.0	8.0	34	7	....	....	....	....	(178)
Lead, tin—																	
Cu, 71.9; Pb, 27.5; Sn, 0.5	Cast	....	....	....	4.2–4.6	....	....	6,000–6,600	3–3.2	4.2–6.7	....	....	....	....	....	....	(169)
Lead, tin, nickel (ceco bearing metal)[20]—																	
Cu, 62.5; Pb, 31.9; Sn, 4.6; Ni, 0.9; Fe, less than 0.03	....	....	3.3	....	13.5	4,700	....	19,200	9.7	8.0	40	10	....	....	....	....	(179)
Manganese, nickel (manganin)[21, 22, 23]	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	(3)
Nickel (constantan)—[24]																	
Cu, 55; Ni, 45	0.25 in. (6.35 mm) hot rolled rod.	....	....	....	45.7–59.8	....	....	65,000–85,000	25–40	....	....	....	....	....	....	....	(115)
	Annealed wire	....	....	....	42.2–45.7	....	....	60,000–65,000	....	....	....	....	....	....	....	....	(115)
	Hard drawn wire.	....	....	....	77.4–98.4	....	....	110,000–140,000	....	....	....	....	....	....	....	....	(115)
Nickel[25]—																	
Cu, 89.94; Ni, 0; Al, 10.06.	....	....	....	22.6	40.5	....	32,200	57,500	9.0	10.4	....	....	....	....	....	....	(115)
Cu, 87.66; Ni, 2.46; Al, 9.88.	....	....	....	28.5	50.3	....	40,500	71,500	12.3	13.0	....	....	....	....	....	....	(115)
Cu, 85.11; Ni, 4.95; Al, 9.94.	....	....	....	28.5	54.4	....	40,400	77,400	16.2	17.4	....	....	....	....	....	....	(115)
Cu, 82.82; Ni, 7.48; Al, 9.70.	....	....	....	29.6	61.2	....	42,100	87,000	13.1	15.1	....	....	....	....	....	....	(115)

Cu, 94.98; Ni, 0; Al, 5.02.	...	...	...	8.2	34.9	...	11,600	49,600	82.5	78.9	...	...	...	...	...	...	(115)
Cu, 93.96; Ni, 0.94; Al, 5.10.	...	...	...	8.3	35.9	...	11,800	51,000	94.6	76.1	...	...	...	...	...	...	(115)
Cu, 92.68; Ni, 2.38; Al, 4.94.	...	...	...	8.7	36.2	...	12,300	51,400	90.2	71.0	...	...	...	...	...	...	(115)
Cu, 89.84; Ni, 4.84; Al, 5.32.	...	...	...	14.8	40.2	...	21,100	57,200	70.0	60.2	...	...	...	...	...	...	(115)
Cu, 87.48; Ni, 7.31; Al, 5.21.	...	...	...	37.8	61.4	...	53,700	87,400	25.6	26.8	...	...	...	...	...	...	(115)
Nickel (Benedict nickel)[26]—																	
Cu, 84–86; Ni, remainder.	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	(190)
Nickel, aluminum [27]—																	
Cu, 82.1; Ni, 14.6; Al, 2.5; Zn, 0.7.	Forged...	...	48.0	...	90.0	68,400	...	128,000	10.0	12.0	...	...	...	...	...	...	(84)

[18] Modulus of elasticity, 10,720 kg/mm² (15,250,000 lb./in.²).
[19] Compressive proportional limit, 1.9 kg/mm² (2,750 lb./in.²); compressive strength, 19.7 kg/mm² (28,000 lb./in.²); compression, per cent of original length, 25.
[20] Compressive proportional limit, 5.1 kg/mm² (7,200 lb./in.²); compressive strength, 32.8 kg/mm² (46,700 lb./in.²); modulus of elasticity: in tension, 5,620 kg/mm² (8,000,000 lb./in.²); in compression, 4,360 kg/mm² (6,200,000 lb./in.²).
[21] Valuable property—an extremely low temperature coefficient of electrical resistance.
[22] Chemical composition according to various authors:

	Cu	Mn	Ni	Fe
Fuessner and Linden	84	12	4	...
Liddell	82.12	15.02	2.29	0.57
Analysis of manganin bar made from old German stock	82.62	12.82	3.78	.72

[23] Landolt Börnstein Physical Tables (1912) give for modulus of elasticity, 12,600 kg/mm² (17,900,000 lb./in.²); modulus of elasticity in shear 4,700 kg/mm² (6,680,000 lb./in.²) and Poisson's ratio 0.33.
[24] Landolt Börnstein Physical Tables (1912) give for modulus of elasticity 16,600 kg/mm² (23,600,000 lb./in.²); modulus of elasticity in shear, 6,200 kg/mm² (8,820,000 lb./in.²) and Poisson's ratio 0.33.
[25] Nickel alloys are often used for the construction of turbine blading (resistance to heat and steam action). The following compositions are in commerical use in Great Britain:

Components.	Alloy A.	Alloy B.	Alloy C.
Cu	82.07	79.63	79.0
Al	2.54	9.77	11.5
Ni	14.64	4.13	5.0
Mn	Nil.	.94	Nil.
Zn	.68	Nil.	Nil.
Fe	Trace.	4.80	4.5
Si	.04	.14	...

[26] Suitable for tubes for condenser distillers and feed-water heaters.
[27] Modulus of elasticity, 14,900 kg/mm² (21,150,000 lb./in.²).

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Metric kg/mm² Yield point.	Metric kg/mm² Tensile strength	English lb./in.² Proportional limit.	English lb./in.² Yield point.	English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Linear coefficient of expansion ×10⁶ (per 1°C.)	Casting shrinkage.	Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Copper—Contd.																	
Tin [28]—									Per ct.	Per ct.			°C.		mm/m.	in/ft.	
Cu, 97.7; Sn, 2.3.	Cast		5.98		19.7	8,500		28,000	20								(42)
	Rolled		7.6		33.7	10,800		48,000	55	75							(42)
Cu, 90; Sn, 10 (gun bronze or bell metal).[29]		8.78	7.24		23.2	10 300		33,000	10								(42)
Cu, 80; Sn, 20	Cast	8.81	7.10		22.5	10,100		32,000	1.5								(42)
Cu, 70; Sn, 30	do	8.84	1.41		4.9	2,000		7,000									(42)
Tin, lead [30]—																	
Cu, 89; Sn, 10; Pb, 1.	do				15.5			22,000									(164)
Tin, lead [31]—																	
Cu, 88; Sn, 10; Pb, 2.	do		13.4–16.2		21.1–24.6	19,000–23,000		30,000–35,000	20–15	26–18	65–70						(164)
Tin, lead (leaded gun metal) [32]—																	
Cu, 86.0–89.0; Sn, 9.0–11.0; Pb, 1.0–2.5; P, max. 0.25; Zn and other imp., max. 0.5.	do			8.4	21.1		min. 12,000	min. 30,000	min. 10								(148)
Tin, lead (semi-plastic bronze)[33]—																	
Cu, 75.5–78.5; Sn, 7.25–8.75; Pb, 13.5–16.5; Zn, max. 0.5; P, max. 0.25; Fe, max. 0.25; Sb,	do				14.1			20,000	min. 10								(149)

max. 0.5; Al, none; other imp., max. 0.75.																	
Tin, lead [34]—																	
Cu, 83.0–86.0; Sn, 4.5–6.0; Pb, 8.0–10.0; Zn, max. 2.0; imp., max. 0.25.	.....do........	......	......	8.4	17.6	......	12,000	25,000	Min. 8	......	......	......	......	......	......	......	(150)
Tin, lead (bronze bearing metal) [35]—																	
Cu, 85; Sn, 10; Pb, 5.	Cast, sand	......	......	......	19.7	......	......	28,000	12.5	......	[36] 60	......	......	......	20.8	.25	(14)
Cu, 80; Sn, 10; Pb, 10.	.....do........	......	......	......	17.6	......	......	25,000	8.0	......	[36] 55	......	......	......	20.8	.25	(14)
Cu, 77; Sn, 8; Pb, 15.	.....do........	......	......	......	14.1	......	......	20,000	10.0	......	[36] 48	......	......	......	20.8	.25	(14)
Cu, 73; Sn, 7; Pb, 20.	.....do........	......	......	......	12.7	......	......	18,000	7.0	......	[36] 45	......	......	......	20.8	.25	(14)
Cu, 70; Sn, 5; Pb, 25.	.....do........	......	......	......	10.5	......	......	15,000	5.0	......	[36] 40	......	......	......	20.8	.25	(14)
Tin, lead, phosphorus—																	
Cu, 80; Sn, 10; Pb, 10; P, tr.	Cast........	9.1	11.3	......	21.1	16,000	......	30,000	6.0	3.5	65	12	......	......	......	......	(169)

[28] Compressive strengths: Cu, 97.7; Sn, 2.3, 23.9 kg/mm^2 (34,000 $lb./in.^2$); Cu, 90; Sn, 10. 39.5 kg/mm^2 (56,000 $lb./in.^2$): Cu, 80; Sn, 20, 83.0 kg/mm^2 (118,000 $lb./in.^2$); Cu, 70; Sn, 30, 105.5 kg/mm^2 (150,000 $lb./in.^2$). Minimum compressive elastic limit (specification value, A. S. T. M. B. 22–18 T.) for cylinders 1 $in.^2$ (645 mm^2) area and 1 in. (25.4 mm) long, of Cu, 80; Sn, 20 is 16.9 kg/mm^2 24,000 $lb./in.^2$ and equals to load required to produce 0.01 per cent set). Average modulus of elasticity of bronzes varies from 7,030 kg/mm^2 (10,000,000 $lb./in.^2$ to 10,900 kg/mm^2 (15,500,000 $lb./in.^2$).

[29] According to Winkelman's Handbuch der Physik, 1908, **1**, 1, modulus of elasticity of cast bronze (Cu, 88; Sn, 12) 10,600 kg/mm^2 (15,070,000 $lb./in.^2$); and modulus of elasticity in shear (Cu, 88; Sn, 12) 4,060 kg/mm^2 (5,770,000 $lb./in.^2$).

[30] Compressive proportional limit, 15.5 kg/mm^2 (22,000 $lb./in.^2$).

[31] Compressive proportional limit, 10.5 kg/mm^2 (15,000 $lb./in.^2$) and 28 per cent set for 70.3 kg/mm^2 (100,000 $lb./in.^2$).

[32] Combines strength with fair machining qualities. Good for bushings subjected to severe working conditions.

[33] This metal has good antifriction qualities.

[34] Suitable alloy for bronze-backed bearings.

[35] Compressive elastic limit was taken as the load producing a compression of 0.001 in. (0.025 mm) in the specimen of 1 $in.^2$ (646 mm^2) sectional area and 1 in. (25.4 mm) high.

Composition.			Compressive elastic limit.	
Cu	Sn	Pb	kg/mm^2	$lb/in.^2$
85	10	5	12.7	18,000
80	10	10	10.5	15,000
77	8	15	8.4	12,000
73	7	20	7.7	11,000
70	5	25	7.0	10,000

[36] 500 kg (1,102 lb.) load.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Metric kg/mm² Yield point.	Metric kg/mm² Tensile strength.	English lb./in.² Proportional limit.	English lb./in.² Yield point.	English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Linear coefficient of expansion ×10⁶ (per 1°C.)	Casting shrinkage.	Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Copper—Contd.																	
Tin, lead, phosphorus (phosphor bronze)[37]—									Per ct.	Per ct.			C.		mm/m	in./ft.	
Cu, 78.5–81.5; Sn, 9.0–11.0; Pb, 9.0–11.0; P, 0.05–0.25; Zn, max. 0.75; other imp., max. 0.25.	Cast			8.4	17.6		min. 12,000	min. 25,000	min. 8.0								(151)
Tin, lead, zinc (red brass)[38]—																	
Cu, 76; Sn, 7; Pb, 13; Zn, 4.	do		13.8		18.8	19,600		26,800	11.0	11.5		8					(169)
Tin, lead, zinc[39]—																	
Cu, 81; Sn, 7; Pb, 9; Zn, 3.	do		13.4–14.1		21.1–24.6	19,000–20,000		30,000–35,000	18–15	24–22	50–55						(164)
Cu, 88; Sn, 8; Pb, 2; Zn, 2.	do				21.8–26.0			31,000–37,000	20–16		57–59						(164)
Tin, lead, zinc, phosphorus[40]—																	
Cu, 73.2; Sn, 11.3; Pb, 12.0; Zn, 2.5; P, 1.	do		10.5		21.4	15,000		30,400	4.0	3.3		11					(169)
Tin, lead, zinc (red brass)[41]—																	
Cu, 83.0–86.0; Sn, 4.5–5.5; Pb, 4.5–5.5; Zn, 4.5–5.5; Fe, max. 0.35; Sb, max. 0.25; Al, none.	do			8.4	19.0		12,000	27,000	min. 16								(152)
Tin, lead, zinc (car journal bearings)[42]—																	
Cu, 95; Sn, 5	do				29.4			41,800	34.5			23					(7)
Cu, 90; Sn, 5; Pb, 5.	do				28.5			40,500	34.5			15					(7)

Cu, 90; Sn, 10.	....do........	....	....	....	27.4	....	....	39,000	15	....	....	23	....	....	....	....	(7)
Cu, 85; Sn, 5; Pb, 5; Zn, 5.	....do........	....	....	....	26.8	....	....	38,100	36	....	....	14	....	....	....	....	(7)

[37] This metal is an excellent composition for use where antifriction qualities are desired, standing up exceedingly well under heavy loads and severe usage.
[38] Compressive strength, 54.2 kg/mm² (77,100 lb./in.²).
[39] Compressive proportional limit, 8.8 to 9.1 kg/mm² (12,500 to 13,000 lb./in.²) and 34 to 35 per cent set for 70.3 kg/mm² (100,000 lb./in.²).
[40] Compressive strength, 49.5 kg/mm² (70,500 lb./in.²).
[41] Free-cutting brass with good casting and finishing properties.
[42] Conclusions reached: (1) The lowest per cent of copper to be used, 65; (2) it is desirable to have not more than 5 per cent of tin; (3) it is desirable to increase the percentage of lead rather than zinc; and (4) alloys having 5 per cent of tin, up to 20 per cent of lead and up to 5 per cent of zinc may be satisfactory for car journal bearings.

Compressive strength of bearing alloys.

Chemical composition (per cent).				Compressive proportional limit.		Compression under load of 100,000 lb./in.² (70.3 kg/mm²).	Chemical composition (per cent).				Compressive proportional limit.		Compression under load of 100,000 lb./in.² (70.3 kg/mm²).
Cu	Sn	Pb	Zn	kg/mm²	lb./in.²	Per cent.	Cu	Sn	Pb	Zn	kg/mm²	lb./in.²	Per cent.
95	5	0	0	12.7	18,000	31	75	5	10	10	13.4	19,000	32
90	5	5	0	13.4	19,000	32	75	5	20	0	10.5	15,000	....
90	10	0	0	17.6	25,000	26	75	10	5	10	19.0	27,000	19.5
85	5	5	5	12.7	18,000	33	75	10	10	5	20.0	28,500	22
85	5	10	0	12.7	18,000	36	75	10	15	0	16.2	23,000	32
85	10	5	0	15.5	22,000	26	70	5	25	0	11.6	16,500	....
80	5	5	10	12.7	18,000	32	70	5	10	15	13.0	18,500	30
80	5	10	5	11.3	16,000	34	70	5	20	5	12.3	17,500	....
80	5	15	0	11.3	16,000	39	70	10	20	0	14.8	21,000	....
80	10	5	5	19.0	27,000	21	70	10	5	15	28.1	40,000	17
80	10	10	0	16.2	23,000	29	70	10	15	5	18.3	26,000	....
75	5	5	15	12.0	17,000	28	70	10	10	10	20.4	29,000	17
75	5	15	5	13.0	18,500	....	65	5	30	0	10.5	15,000	....

Wearing test of some bearing alloys.

[Total number of revolutions 100,000 (525 r. p. m.). Pressure 1,000 lb./in.² (0.70 kg/mm²)].

Chemical composition (per cent).				Temperature above room.		Wear.	
Cu	Sn	Pb	Zn	°C.	°F.	gr	g
85.76	14.90	....	....	28	82	0.2800	0.0181
95.01	4.95	....	....	29	84	.0766	.0049
90.82	4.62	4.82	....	29	84	.0542	.0035
81.27	5.17	14.14	....	32	90	.0327	.0021
68.71	5.24	26.67	....	32	90	.0204	.0013
85.12	4.65	10.64	....	31	88	.0380	.0025
79.84	4.71	10.30	5.44	37	99	.0466	.0030
74.28	4.68	10.51	11.04	38	100	.0846	.0055

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties.								Hardness number.		Thermal properties.				Reference.
			Metric kg/mm²			English lb./in.²											
			Proportional limit.	Yield point.	Tensile strength.	Proportional limit.	Yield point.	Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Brinell.	Scleroscope.	Melting point.	Linear coefficient of expansion $\times 10^6$ (per 1°C.).	Casting shrinkage.		
1	2	3	4	5	6	7	8	9	10	11	12	18	14	15	16	17	18
Copper—Contd. Tin, lead, zinc (car journal bearings)—Continued.									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Cu, 85; Sn, 5; Pb, 10.	Cast				22.0			31,200	19.5			14					(7)
Cu, 85; Sn, 10; Pb, 5.	do				23.0			32,700	9.5			19					(7)
Cu, 80; Sn, 5; Pb, 5; Zn, 10.	do				19.8			28,100	15			16					(7)
Cu, 80; Sn, 5; Pb, 10; Zn, 5.	do				24.4			34,700	23			18					(7)
Cu, 80; Sn, 5; Pb, 15.	do				16.4			23,300	15.5			14					(7)
Cu, 80; Sn, 10; Pb, 5; Zn, 5.	do				23.6			33,500	3.5			21					(7)
Cu, 80; Sn, 10; Pb, 10.	do				22.4			31,800	8.5			21					(7)
Cu, 75; Sn, 5; Pb, 5; Zn, 15.	do				19.0			27,000	10			18					(7)
Cu, 75; Sn, 5; Pb, 15; Zn, 5.	do				22.0			31,300	19			19					(7)
Cu, 75; Sn, 5; Pb, 10; Zn, 10.	do				21.0			29,800	13			18					(7)
Cu, 75; Sn, 5; Pb, 20.	do				16.4			23,300	15.5			12					(7)
Cu, 75; Sn, 10; Pb, 5; Zn, 10.	do				17.2			24,400	1.0			25					(7)
Cu, 75; Sn, 10; Pb, 10; Zn, 5.	do				22.0			31,300	2.5			21					(7)
Cu, 75; Sn, 10; Pb, 15.	do				19.0			27,000	6			15					(7)
Cu, 70; Sn, 5; Pb, 25.	do				17.4			24,700	14			12					(7)
Cu, 70; Sn, 5; Pb, 10; Zn, 15.	do				20.0			28,400	10			20					(7)

Cu, 70; Sn, 5; Pb, 20; Zn, 5.	do				19.8			28,100	20			15					(7)
Cu, 70; Sn, 10; Pb, 20.	do				19.0			27,000	6			19					(7)
Cu, 70; Sn, 10; Pb, 5; Zn, 15.	do				19.3			27,500	1.5			28					(7)
Cu, 70; Sn, 10; Pb, 10; Zn, 10.	do				19.8			28,100	1.5			23					(7)
Cu, 70; Sn, 10; Pb, 15; Zn, 5.	do				21.1			30,000	4.7			22					(7)
Cu, 65; Sn, 5; Pb, 30.	do				13.9			19,800	12			10					(7)
Tin, nickel, zinc (nickel bronze)[43]—																	
Cu, 88; Sn, 5; Ni, 5; Zn, 2.				9.1	28.6		13,000	40,700	31.8	28.0							(180)
Cu, 89; Sn, 4; Ni, 4; Zn, 3.[44]				8.1	27.9		11,500	39,700	31.2	31.2							(180)
Tin, phosphorus (phosphor bronze)[45]—																	
Sn, 4.0–6.0; P, 0.03–0.4; Zn, max. 0.2; Fe, max. 0.1; Pb, max. 0.1; Cu, remainder.	Spring wire up to 0.0625 in. (1.59 mm).				91.4			min. 130,000									(153)
	Spring wire 0.0625–0.125 in. (1.59–3.17 mm).				84.3			min. 120,000									(153)
	Spring wire 0.125–0.250 in. (3.17–6.34 mm).				77.3			min. 110,000									(153)
	Spring wire 0.250–0.375 in. (6.34–9.51 mm).				70.3			min. 100,000									(153)
Tin, phosphorus (phosphor bronze)[46]—																	
Cu, 95; Sn, 4.9; P, 0.1.	Rolled	8.6	28.2		45.7	40,000		65,000	30.0			37					(169)
Tin, phosphorus—																	
Cu, 89; Sn, 10.5; P. 0.5.	Cast				21.8–24.6			31,000–35,000	6–10		72–77						(164)
Tin, phosphorus (phosphor gear bronze)[47]—																	
Cu, 88.0–90.0; Sn, 10.0–12.0; P, 0.1–0.3; Pb, Zn, and other imp., max. 0.5.	do			14.1	24.6		min. 20,000	min. 35,000	min. 10								(154)

[43] Modulus of elasticity, 12,200 kg/mm² (17,300,000 lb./in.²).
[44] Modulus of elasticity, 10,500 kg/mm² (14,900,000 lb./in.²).
[45] The wire shall be capable of being bent through an angle of 180° flat back on itself without fracture on the outside of the bent portion.
[46] Cu, 80; Sn, 20; P max, 1; cast, Compressive proportional limit, 17.6 to 28.1, kg/mm² or 25,000 to 40,000 lb./in.² and 6 to 10 per cent set for 70.3 kg/mm² (100,000 lb./in.²) load.
[47] Very hard bronze; may be used for gears and worm wheels.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm.² Proportional limit.	Metric kg/mm.² Yield point.	Metric kg/mm.² Tensile strength.	English lb./in.² Proportional limit.	English lb./in.² Yield point.	English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Linear coefficient of expansion ×10⁶ (per 1°C.)	Casting shrinkage.	Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Copper—Contd. Tin, phosphorus Stone's English gear bronze)[48]—									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Cu, 89; Sn, 11; P, 0.3.	....	8.5	......	15.8–17.3	24.6–28.4	......	22,400–24,600	34,900–40,300	6–10	7–9	80	......	......	......	10.4	0.125	(73)
Tin, phosphorus (phosphor bronze)[49]—																	
Cu, min. 94; Sn, min. 3.5; Zn, max. 0.30; Fe, max. 0.10; Pb, max. 0.20; P, 0.05–0.50.	Rods and bars up to 0.5 in. (12.7 mm).[50]	......	......	42.2	56.2	......	60,000	80,000	12.0	......	......	......	......	......	......	......	(191)
	Rods and bars 0.5–1 in. (12.7–25.4 mm).[50]	......	......	28.1	42.2	......	40,000	60,000	20.0	......	......	......	......	......	......	......	(191)
	Rods and bars over 1 in. (25.4 mm).[50]	......	......	21.1	38.7	......	30,000	55,000	25.0	......	......	......	......	......	......	......	(191)
	Sheets and plates spring temper, narrow.	......	......	......	63.2	......	......	90,000	......	......	......	......	......	......	......	......	(191)
	Sheets and plates, spring temper, wide.	......	......	......	56.2	......	......	80,000	......	......	......	......	......	......	......	......	(191)
	Sheets and plates, medium temper.[50]	......	......	17.6	35.1	......	25,000	50,000	25.0	......	......	......	......	......	......	......	(191)
Cu, 94; Sn, 4.5 min.; Zn, 0.3 max.; Fe, 0.1 max.; Pb, 0.2 max.; P, 0.05–0.5 max.	Spring wire, hard drawn or hard rolled up to 0.0625 in. (1.59 mm) diameter.	......	......	......	95.0	......	......	135,000	[51] 4	......	......	......	......	......	......	......	(192)
	Spring wire, hard drawn or hard rolled, 0.0625–0.125 in. (1.59–3.18 mm) diameter.	......	......	......	88.0	......	......	125,000	......	......	......	......	......	......	......	......	(192)

	Spring wire, hard drawn or hard rolled, 0.125–0.250 in. (3.18–6.35 mm) diameter.	...	...	...	77.3	...	...	110,000	...	...	...	...	...	...	...	...	(192)
	Spring wire, hard drawn or hard rolled, 0.250–0.375 in. (6.35–9.51 mm) diameter.	...	...	...	73.9	...	...	105,000	...	...	...	...	...	...	...	...	(192)
(Phosphor bronze).[52]	Wire, 0.072 in. (1.83 mm) diameter.	...	...	41.5	95.6	...	59,000	136,000	1.0	...	...	...	...	...	...	...	(181)
Tin, silicon— Cu, 70; Sn, 29.5; Si, 0.5.	Cast	...	...	...	45.7	...	...	65,000	...	...	...	...	...	...	...	...	(169)
	Drawn, hard	...	...	...	73.8	...	...	105,000	0	...	...	...	...	...	...	...	(169)
Tin, zinc— Cu, 85; Sn, 13; Zn, 2.	Cast	8.5	16.2–17.6	...	26.0–27.4	23,000–25,000	...	37,000–39,000	2–3	1–4	...	25	...	...	...	...	(164)
Tin, zinc (Government bronze); composition "G"[53, 54]— Cu, 88; Sn, 10; Zn, 2.	Cast, sand	8.6	8.4	...	27.3	12,000	...	38,900	25.0	21.0	64	13	...	...	...	...	(182)
Tin, zinc[55]— Cu, 88; Sn, 8; Zn, 4.	Cast	8.5	7.74	...	27.5	11,000	...	39,200	30.5	24.0	58	11	...	...	...	...	(182)
Tin, zinc[56]— Cu, 80; Sn, 10; Zn, 10.	Cast, sand	8.85	11.2	14.8	22.1	16,000	21,000	31,400	13.6	12.0	63	...	872	18.7	10.3	.124	(114)
	Cast, chill	...	...	18.3	24.6	...	26,000	35,000	4.5	3.5	85	...	...	...	...	...	(114)

[48] Proportional limit in compression, 11.0 kg/mm² (15,700 lb./in.²).
[49] Rolled or drawn.
[50] Required to bend cold through 120° about radius equal to thickness.
[51] In 8 in. (203.2 mm).
[52] Number of twists before fracture (length 10 in. or 254 mm), 3.
[53] Values shown are averages for 30 specimens from 5 foundries, tested at the Bureau of Standards.
[54] Specification values, cast (minimums), (A. S. T. M., B 10–18) Cu, 86 to 89; Sn, 8 to 11; Zn, 1 to 3. Ultimate strength, 21.1 kg/mm² (30,000 lb./in.²), with 14 per cent elongation in 2 in. (50.8 mm).
[55] Averages for 26 specimens from 5 foundries, tested at Bureau of Standards.
[56] Data collected from various sources.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm.² Proportional limit.	Tensile properties. Metric kg/mm.² Yield point.	Tensile properties. Metric kg/mm.² Tensile strength.	Tensile properties. English lb./in.² Proportional limit.	Tensile properties. English lb./in.² Yield point.	Tensile properties. English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Thermal properties. Linear coefficient of expansion ×10⁶ (per 1 °C.).	Thermal properties. Casting shrinkage.		Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Copper—Contd.																	
Tin, zinc, arsenic, lead (admiralty gun metal)[57], [58]—									Per ct.	Per ct.			°C.		mm/m.	in./ft.	
Cu, 87.72; Sn, 9.97; Zn, 1.54; As, 0.48; Pb, 0.17; Fe, 0.08.	Cast, sand			16.4	23.3		23,300	33,100	11.5		74	8.5					(68)
	Cast, chill			16.7	26.9		23,700	38,300	5.0		91	9.0					(68)
Cu, 87.30; Sn, 10.05; Zn, 1.16; Pb, 0.86; As, 0.50; Fe, 0.07.	Cast, sand			15.2	24.8		21,600	35,200	12.5		70	7.0					(68)
	Cast, chill			18.0	24.8		25,600	35,200	4.5		88	8.0					(68)
Cu, 86.58; Sn, 10.04; Zn, 1.33; Pb, 1.46; As, 0.48; Fe, 0.06.	Cast, sand			15.4	25.1		21,900	35,600	15.0		66	6.0					(68)
	Cast, chill			16.1	22.5		22,800	32,000	3.5		83	7.0					(68)
Cu, 86.23; Sn, 10.12; Zn, 1.42; Pb, 1.68; As, 0.47; Fe, 0.06.	Cast, sand			14.8	24.9		21,000	35,400	10.5		69	7.0					(68)
	Cast, chill			17.2	22.5		24,400	32,000	2.5		89	7.5					(68)
Tin zinc (hard cast bronze)[59]—																	
Cu, 86.0–89.0; Sn, 9.0–11.0; Zn, 1.0–3.0; Pb, max. 0.2; Fe, max. 0.06.	Cast			10.5	21.1		15,000	30,000	14								(155)
Tin, zinc, phosphorus ("non-gram")—																	
Cu, 86; Sn, 11; Zn, 3; P, tr.	do		13.4		24.6	19,000		35,000	9.0								(169)

Tin, zinc, lead— Cu, 83; Sn, 14; Zn, 2; Pb, 1.	do	...	10.5–13.4	...	16.2–19.0	15,000–19,000	...	23,000–27,000	4–0.5	4–0.5	...	20–24	...	...	...	...	(164)
Tin, zinc, lead (U.S.N. valve bronze)[60]— Cu, 87; Sn, 7; Zn, 5; Pb, 1.	do	...	13.2	...	24.8	18,700	...	35,300	23.2	24.9	...	...	...	...	...	...	(169)
Tin, zinc, lead[61]— Cu, 90; Sn, 6.5; Zn, 2; Pb, 1.5.	do	...	12.7–15.5	...	23.9–28.1	18,000–22,000	...	34,000–40,000	33–25	34–26	50–60	...	...	...	...	...	(164)
Cu, 85; Sn, 5; Zn, 5; Pb, 5.[62]	do	...	10.5–13.4	...	19.0–23.2	15,000–19,000	...	27,000–33,000	20–16	20–15	50–63	...	...	...	...	...	(164)
Cu, 88; Sn, 8; Zn, 2; Pb, 2.	do	...	...	...	21.8–26.0	...	...	31,000–37,000	20–16	...	57–59	...	...	...	...	...	(164)
Tin, zinc (Gov. bronze or U. S. N. gun bronze or admiralty gun metal)[63]— Cu, 88; Sn, 10; Zn, 2.	Cast, sand	8.7	...	12.7	33.8	...	18,000	48,000	50	...	[64] 70	12–15	995	...	10.8	0.13	(116)
Tin, zinc (gun metal)— Cu, 87–89; Sn, 9–11; Zn, 1–3; Fe, max. 0.06; Pb, max. 0.20.	Cast	...	...	10.5	21.1	...	15,000	30,000	min. 15.0	...	...	...	...	...	...	...	(193)

[57] The opinion of various investigators regarding the effect of lead varies: F. Johnson (small chill casting), "Pb does not affect seriously mechanical properties, except shock resistance." H. Primrose (chill casting), "It has even been claimed that 0.5 per cent Pb improves alloy, but it is very doubtful." W. Ramsay, "Even 0.5 per cent Pb reduces tensile strength materially." A. Seaton, "Pb is really a good friend and not an enemy." R. Rolfe, conclusion derived from this investigation, "The proportion of lead may be with advantage increased up to 1 per cent."

[58] Stanton impact test; energy to fracture.

Lead content.	Sand cast.		Chill cast.	
Per cent.	kgm	ft. lb.	kgm	ft. lb.
0.17	16.7	121	4.2	30
.86	30.0	217	2.4	17
1.46	14.2	103	4.3	31
1.68	8.2	59	3.5	25

[59] This alloy is suitable wherever a strong, general utility bronze is required. It may be used for severe working conditions where heavy pressures obtain, as in gears and bearings.
[60] U. S. Navy specification 46B8b, June 1, 1922: Cu, min. 87; Sn, min. 7; Pb, max. 1.0; Fe, max. 0.06; Zn, remainder.
[61] Compressive proportional limit 9.1 kg/mm² (13,000 lb./in.²) with 34 per cent set for 70.3 kg/mm² (100,000 lb./in.²) load.
[62] Compressive proportional limit 8.4 kg/mm² (12,000 lb./in.²) with 36 per cent set for 70.3 kg/mm² (100,000 lb./in.²) load.
[63] Impurities present in the alloy: Fe, not exceeding 0.10 per cent; S, not exceeding 0.05 per cent; Pb, not exceeding 0.50 per cent (improves machining qualities). Al and Sb are not allowed even in small quantities.
[64] 500 kg (1,102 lb.) load, 10 mm ball.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Tensile properties. Metric kg/mm² Yield point.	Tensile properties. Metric kg/mm² Tensile strength.	Tensile properties. English lb./in.² Proportional limit.	Tensile properties. English lb./in.² Yield point.	Tensile properties. English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell	Hardness number. Scleroscope.	Thermal properties. Melting point.	Thermal properties. Linear coefficient of expansion $\times 10^6$ (per 1 °C.)	Thermal properties. Casting shrinkage.		Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Copper—Contd. Tin, zinc, phosphorus (phosphor bronze)[65]—									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Cu, 85–90; Sn, 6–11; Fe, max. 0.06; Pb, max. 0.2; P, max. 0.5; Zn, max. 4.0.	Cast, grade 1				31.6			min. 45,000	min. 20.0								(194)
Cu, 85–90; Sn, 6–11; Fe, max. 0.1; Pb, max. 1.0; P, max. 0.5; Zn, remainder.	Cast, grade 2				21.1			min. 30,000	min. 15.0								(194)
(Other alloying elements?) Bronze trolley wire	40 per cent conductivity wire, 0.460 in. (11.7 mm).				48.6			69,200	[66] 3.0								(15)
	40 per cent conductivity wire, 0.410 in. (10.4 mm).				49.0			69,700	[66] 3.0								(15)
	40 per cent conductivity wire, 0.365 in. (9.27 mm).				50.4			71,700	[66] 2.5								(15)
	40 per cent conductivity wire, 0.325 in. (8.25 mm).				54.2			77,100	[66] 2.25								(15)
	60 per cent conductivity wire, 0.460 in. (11.7 mm).				41.7			59,300	[66] 3.0								(15)
	60 per cent conductivity wire,				42.0			59,800	[66] 3.0								(15)

	0.410 in. (10.4 mm).																
	60 per cent conductivity wire, 0.365 in. (9.27 mm).				43.3			61,600	[66] 2.5								(15)
	60 per cent conductivity wire, 0.325 in. (8.25 mm).				46.6			66,300	[66] 2.25								(15)
Zinc (brass)[67], [68]																	
Zinc[69]—																	
Grade A: Cu, 70.0–74.0; Pb, max. 0.1; Fe, max. 0.06; Zn, remainder.[70]	Spring wire				70.3			min. 100,000									(156)
Grade B: Cu, 64.0–68.0; Pb, max. 0.1; Fe, max. 0.07; Zn, remainder.	do				70.3			min. 100,000									(156)
Zinc (low brass)— Cu, 80; Zn, 20	Cast, sand				24.6			35,000	31	32							(169)
	Rolled, hard				52.7			75,000	5		75	28					(169)
	Rolled, soft	8.6			29.5			42,000	50	85	46	12					(169)
Zinc (brass)— Cu, 70; Zn, 30	Cast, sand	8.4			28.1			40,000	35		37						(169)
Cu, 66; Zn, 34 (standard sheet).	Rolled, hard	8.5			42.2			60,000	5		[71] 75	26					(169)
	Rolled, soft	8.4			33.7			48,000	50	85	45	12					(169)

[65] The material is suitable for fittings exposed to the action of salt water, for gears, driving and main nuts of steering gears, and castings for other parts which require strength combined with good bearing qualities and incorrodibility.

[66] In 10 in (254 mm).

[67] Modulus of elasticity of brass: Annealed, 9,840 kg/mm² (14,000,000 lb./in.²), Carnegie Steel Co. Pocketbook, 1913. Cast, 8,000–10,000 kg/mm² (11,400,000–14,200,000 lb./in.²), Landolt-Börnstein, Phys.-Chem. Tabellen, Berlin, 1912. Cast, 9,630 kg/mm² (13,700,000 lb./in.²), Proc. Inst. Mech. Eng., 1912, p. 1155. Drawn, 9,400 kg/mm² (13,350,000 lb./in.²), Smithsonian Physical Tables, 1918.

Compressive strength of brass:

Cu	Zn	Cast	
		kg/mm²	lb./in.²
90	10	21.1	30,000
80	20	27.4	39,000
70	30	42.2	60,000
60	40	52.7	75,000
50	50	77.3	110,000

Erichsen values for brass: Soft slab, 1.3 mm or 0.05 in. thick; no rolling; depth of impression in standard sheet, 13.9 mm. Cu, 70; Zn, 30; hard sheet, 1.3 mm or 0.05 in. thick; rolled; 38 per cent reduction; depth of impression, 7.4 mm. Cu, 70; Zn, 30; hard sheet, 0.5 mm or 0.020 in. thick; rolled: 60 per cent reduction; depth of impression 3.8 mm.

Shearing strength: Brass, cast, 25.3 kg/mm² (36,000 lb./in.²). (Frye, Civ. Eng. Pocketbook, p. 496; 1918.)

[68] Modulus of elasticity, 10,800 kg/mm² (15,400,000 lb./in.²); modulus of elasticity in shear, 3,660 kg/mm² (5,200,000 lb./in.²); Poisson's ratio, 0.327 (Love, "The mathematical theory of elasticity;" 1906).

[69] The wire should be capable of being bent through an angle of 180° around a wire of the same diameter without breaking.

[70] Grade A, for use where the requirements are especially severe.

[71] Am. Soc. Test. Mat. specification B 19–19 requires Bhn. of 51–65 at 500 kg (1,102 lb.) load for 70–30 annealed sheet brass.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties.								Hardness number.		Thermal properties.				Reference.
			Metric kg/mm²			English lb./in.²			Elongation in 50.8 mm or 2 inches.	Reduction of area.	Brinell.	Scleroscope.	Melting point.	Linear coefficient of expansion ×10⁶ (per 1°C.)	Casting shrinkage.		
			Proportional limit.	Yield point.	Tensile strength.	Proportional limit.	Yield point.	Tensile strength.									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Copper—Contd.									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Zinc [72]—								min.	min.								
Cu, min. 60.0; Pb, max. 1.0; Fe, max. 0.1; Zn, remainder.	Seamless brass tubing, annealed.				28.1			40,000	25.0								(157)
Zinc (Muntz metal)[73]—																	
Cu, 60.4; Zn, 39.2; Pb, 0.33; Fe, 0.08; Sn, 0.03; Bi, 0.01.	Cast				36.8			52,400	17.1								(165)
	Rolled				46.9			66,800	37.7								(165)
Cu, 59–62; Zn, 38–41; Pb, max. 0.6; Fe, max. 0.2.[74]—	do			17.6	31.7		25,000	45,000	25								(195)
Zinc (Muntz metal or yellow brass)[75]—																	
Cu, 60; Zn, 40.	Cast, sand		15.4		32.2	21,800		45,800	15	22							(169)
	Rolled, hard	8.4	31.6		49.2	45,000		70,000	30	50							(169)
Zinc (brass)—																	
Cu, 70.0; Zn, 30.0.	Cast			10.25	26.3		14,600	37,400	58.0	57.0	[76] 55						(117)
	Forged, annealed.			12.6	33.9		17,900	48,200	68.0	65.0	[76] 57						(117)
Cu, 59.0; Zn, 41.0.	Cast			13.9	39.2		19,700	55,800	45.0	49.7	[76] 90						(117)
	Forged			14.2	41.0		20,200	58,200	47.0	62.0	[76] 90						(117)
	Forged, annealed at 650° C. (1,202° F.).			11.0	37.8		15,700	53,800	49.0	55.0	[76] 79						(117)
Cu, 53.3; Zn, 46.7.	Cast			14.2	46.8		20,200	66,500	24.0	21.5	[76] 108						(117)
	Forged			15.3	51.7		21,700	73,500	28.0	30.6	[76] 114						(117)
	Forged, annealed at 650° C. (1,202° F.).			11.8	45.8		16,800	65,200	22.5	31.6	[76] 108						(117)
Cu, 51.2; Zn, 48.8.	Cast			11.3	42.4		16,100	60,200	19.0	21.5	[76] 108						(117)
	Forged			14.5	52.6		20,600	74,800	37.0	33.5	[76] 114						(117)
	Forged, annealed at 650° C. (1,202° F.).			8.35	45.7		11,900	64,900	25.0	27.0	[76] 108						(117)

Cu, 50.19; Zn, 49.81.	Cast			9.45	13.9		13,400	19,700	1.0	1.5	[76] 108						(117)
	Forged			3.6	24.9		5,150	35,400	5.0	5.5	[76] 117						(117)
Cu. 64.5–67.5; Pb, max. 0.30; Fe, max. 0.05; other imp., max. 0.1; Zn, remainder.	Sheet thinner than 0.080 in. (2.03 mm), quarter hard.				31.6			min. 45,000	min. [77] 27.5		75–95						(158)
	Sheet thinner than 0.080 in. (2.03 mm), half hard.				36.9			min. 52,500	min. [77] 15.0		95–115						(158)
	Sheet thinner than 0.080 in. (2.03 mm), hard.				47.4			min. 67,500	min. [77] 5.0		130–150						(158)
	Sheet thinner than 0.080 in. (2.03 mm), extra hard.				56.2			min. 80,000	min. [77] 2.0		150–170						(158)
	Sheet thinner than 0.080 in. (2.03 mm), spring.				61.5			min. 87,500	min. [77] 1.0		160–180						(158)
	Sheet thinner than 0.080 in. (2.03 mm), light anneal.				31.6			min. 45,000	min. 32.0		65–75						(158)
	Sheet thinner than 0.080 in. (2.03 mm), drawing anneal.				29.5			min. 42,000	min. 38.0		55–65						(158)
	Sheet thinner than 0.080 in. (2.03 mm), soft drawing anneal.				28.1			min. 40,000	min. 42.0		47–55						(158)
Zinc (red metal)— Cu, 90; Zn, 10.	Cast, sand				20.4			29,000	22								(169)
	Rolled, hard				38.7			55,000	5		60	20					(169)
	Rolled, soft	8.7			26.0			37,000	40	70	47	10					(169)
Zinc (brazing metal) [78]— Cu, 84–86; Fe, max. 0.06; Pb, max. 0.3; Zn, remainder.																	(196)

[72] A pin having a taper of 1 to 8 shall be driven into one end of a tube until the diameter is increased 15 per cent. The tube shall withstand this test without showing cracks, splits, or other defects.

[73] Muntz metal should not be annealed at temperatures between 750 and 800° C. (1,382 and 1,472° F.), as this is a danger range, but it may be heated above 800° C. (1,472° F.) without destroying its good qualities.

[74] Shall be bent cold through 120° to a radius equal to the diameter or thickness without signs of cracking or failure. Suitable for bolts and nuts not subject to action of salt water for sheathing bottoms of wooden boats, etc.

[75] Winkelman's Handbuch der Physik, 1908, **1**, 1, gives for 60/40 cast brass the modulus of elasticity 9,220 kg/mm² (13,100,000 lb./in.²) and modulus of elasticity in shear 3,390 kg/mm² (4,820,000 lb./in.²).

[76] 10 mm ball and 1,000 kg (2,204 lb.) load.

[77] In very thin sheets, on account of the difficulties in testing, the elongation may be considerably less than the values given above.

[78] Suitable for all flanges for copper pipe and other fittings that are to be brazed.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Metric kg/mm² Yield point.	Metric kg/mm² Tensile strength.	English lb./in.² Proportional limit.	English lb./in.² Yield point.	English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Linear coefficient of expansion ×10⁶ (per 1°C.)	Casting shrinkage.		Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Copper—Contd.																	
Zinc, aluminum—									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Cu, 70.5; Zn, 26.4; Al, 3.1.			13.4		33.0	19,000		47,000	50.0								(169)
Cu, 62.9; Zn, 33.3; Al, 3.8.					56.2			80,000									(169)
Cu, 57; Zn, 42; Al, 1.	Cast				40.0			57,000	50.0								(169)
Cu, 55; Zn, 41; Al, 4.					60.0			85,400	16.5								(169)
Zinc, aluminum (aluminum brass)—																	
Cu, 69.79; Zn, 26.67; Al, 3.54.	Cast			21.4	46.1		30,450	65,600	26.0	27.6	[79] 104						(117)
	Forged			36.8	58.4		52,400	83,000	34.0	41.9	[79] 143						(117)
Cu, 69.13; Zn, 26.32; Al, 4.55.	Cast			27.7	50.2		39,400	71,500	8.0	11.7	[79] 134						(117)
	Forged			32.0	60.8		45,500	86,500	17.0	20.0	[79] 143						(117)
Cu, 69.42; Zn, 24.68; Al, 5.90.	Cast			44.2	59.8		62,900	85,100	3.0	1.5	[79] 185						(117)
	Forged			51.2	66.5		72,800	94,700	6.0	8.4	[79] 193						(117)
Cu, 59.48; Zn, 39.52; Al, 1.00.	Cast			23.3	50.4		33,150	71,700	30.0	33.5	[79] 114						(117)
	Forged			17.5	49.3		24,900	70,100	41.0	44.6	[79] 104						(117)
Cu, 58.26; Zn, 38.56; Al, 2.18.	Cast			25.2	57.3		35,800	81,500	16.0	21.5	[79] 138						(117)
	Forged			18.4	58.9		26,200	83,700	27.0	33.5	[79] 143						(117)
Cu, 59.85; Zn, 37.13; Al, 3.02.	Cast			35.1	66.2		50,000	94,100	18.5	21.5	[79] 159						(117)
	Forged			29.9	63.5		42,600	90,300	24.5	30.6	[79] 154						(117)
Zinc, aluminum, iron, vanadium (victor bronze)[80]—																	
Cu, 58.6; Zn, 38.5; Al, 1.5; Fe, 1.0; V, 0.03.	Cold, drawn		56.2		64.6	80,000		92,000	11.5	29.0							(169)
Zinc, aluminum, manganese, iron—																	
Cu, 59.45; Zn, 35.85; Al, 0.98; Mn, 3.49; Fe, 0.22; P, 0.01.	Cast			21.1	50.1		30,000	71,200	25.0	24.6	[81] 114						(118)
	Forged			32.6	55.3		46,300	78,600	36.0	47.2	[81] 134						(118)

Cu, 59.45; Zn, 36.6; Al, 1.56; Mn, 1.97; Fe, 0.40; P, 0.02.	Cast	....	....	26.8	56.5	....	38,100	80,400	22.0	20.0	[81] 138	....	....	....	....	....	(118)
	Forged	....	....	27.1	58.3	....	38,500	82,800	28.0	30.6	[81] 148	....	....	....	....	....	(118)
Cu, 58.15; Zn, 35.18; Al, 2.24; Mn, 4.10; Fe, 0.25; Pb, 0.08.	Cast	....	....	37.6	63.8	....	53,500	90,700	14.0	15.0	[81] 165	....	....	....	....	....	(118)
	Forged	....	....	39.1	68.4	....	55,600	97,300	18.5	21.5	[81] 159	....	....	....	....	....	(118)
Cu, 57.23; Zn, 37.9; Al, 2.59; Mn, 2.08; Fe, 0.20.	Cast	....	....	30.6	65.2	....	43,400	92,800	18.0	20.0	[81] 165	....	....	....	....	....	(118)
	Forged	....	....	32.3	67.1	....	45,900	95,400	24.0	24.5	[81] 159	....	....	....	....	....	(118)
Zinc, aluminum, manganese, iron (tensilite)[82]—																	
Cu, 64; Zn, 29; Al, 3.1; Mn, 2.5; Fe, 1.2.	Cast	....	21.1	....	68.9	30,000	....	98,000	16.0	17.0	130	....	....	....	....	....	(169)
Zinc, aluminum, manganese, vanadium—																	
Cu, 58.6; Zn, 38.5; Al, 1.5; Mn, 0.5; V, 0.03.	Cold, drawn	....	35.6	....	57.2	50,600	....	81,400	12.0	14.0	....	....	....	....	....	....	(169)
Zinc, iron, tin (sterro metal)—																	
Cu, 55; Zn, 42.4; Fe, 1.8; Sn, 0.8.	Cast	8.4	....	....	42.5	....	....	60,500	....	....	....	....	....	....	....	....	(125)
	Forged	....	....	....	53.6	....	....	76,200	....	....	....	....	....	....	....	....	(125)
	Hard, drawn	....	....	....	58.5	....	....	83,100	....	....	....	....	....	....	....	....	(125)
Zinc, iron, tin, aluminum, manganese (manganese bronze)[83]—																	
Cu, 56; Zn, 41; Fe, 1; Sn, 1; Al, 0.5; Mn, 0.5.	Cast	....	23.2	....	49.2	33,000	....	70,000	22–35	25.0	104–119	....	....	....	....	....	(164)
Zinc, iron—																	
Cu, 58.96; Zn, 41.04.	....do	....	....	13.9	39.2	....	19,700	55,700	45.0	49.7	[81] 90	....	....	....	....	....	(119)
	Forged	....	....	14.2	40.9	....	20,200	58,200	47.5	62.0	[81] 90	....	....	....	....	....	(119)
Cu, 59.37; Zn, 39.68; Fe, 0.95.	Cast	....	....	14.8	42.2	....	21,000	60,000	44.0	44.6	[81] 90	....	....	....	....	....	(119)
	Forged	....	....	21.9	45.3	....	31,100	64,500	44.0	63.7	[81] 107	....	....	....	....	....	(119)
Cu, 59.04; Zn, 38.95; Fe, 1.56; Pb, 0.45.	Cast	....	....	17.3	42.2	....	24,600	60,000	33.0	30.6	[81] 85	....	....	....	....	....	(119)
	Forged	....	....	21.4	43.4	....	30,400	61,800	43.0	59.3	[81] 98	....	....	....	....	....	(119)
Cu, 59.12; Zn, 38.36; Fe, 2.52.	Cast	....	....	15.7	41.7	....	22,400	59,300	46.0	49.7	[81] 92	....	....	....	....	....	(119)
	Forged	....	....	24.9	44.5	....	35,400	63,400	39.0	54.6	[81] 110	....	....	....	....	....	(119)

[79] 10 mm ball, 1,000 kg (2,204 lb.) load.

[80] Specification values, U. S. Navy 49 B1b, Jan. 3, 1916: Vanadium bronze castings; Cu, min. 61; Zn, 38; Sn, max. 1 (including V), min. values. Proportional limit, 15.8 kg/mm² (22,500 lb./in.²); tensile strength, 38.7 kg/mm² (55,000 lb./in.²), with 25 per cent elongation.

[81] 10 mm ball and 1,000 kg (2,204 lb.) load.

[82] Cu, 67; Zn, 24; Al, 4.4; Mn, 3.8; P, 0.01, compressive proportional limit 42.2 kg/mm² (60,000 lb./in.²) and 1.33 per cent set for 70.3 kg/mm² (100,000 lb./in.²) load.

[83] Compressive proportional limit 19.8 to 20.0 kg/mm² (27,500 to 28,500 lb./in.²).

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Metric kg/mm² Yield point.	Metric kg/mm² Tensile strength	English lb./in.² Proportional limit.	English lb./in.² Yield point.	English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Linear coefficient of expansion ×10⁶ (per 1°C.)	Casting shrinkage.	Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Copper—Contd. Zinc, iron (brass)—									Per ct.	Per ct.			°C.		mm/m.	in./ft.	
Cu, 64.71; Zn, 35.27; Fe, 0.02.	0.25 in. (6.35 mm) sheet; reduction by rolling 0.			8.0	30.1		11,450	42,700	77.5	76.6		7					(8)
	....do.[84]			8.0	30.3		11,400	43,150	77.2	75.0		7					(8)
	0.21 in. (5.33 mm) sheet; reduction by rolling 18.0 per cent.			29.3	36.6		41,600	52,000	45.3	70.1		18					(8)
	....do.[84]			27.7	36.0		39,350	51,150	49.0	69.6		18					(8)
	0.15 in. (3.81 mm) sheet; reduction by rolling 41.7 per cent.			51.2	51.2		72,750	72,750	11.2	63.4		31					(8)
	....do.[84]			43.4	51.8		61,750	73,700	12.7	57.7		31					(8)
	0.11 in. (2.79 mm) sheet; reduction by rolling 58.6 per cent.			61.3	61.3		87,150	87,150	6.0	51.8		36					(8)
	....do.[84]			48.1	62.5		68,350	88,800	10.5	52.5		36					(8)
	0.052 in. (1.32 mm) sheet; reduction by rolling 79.5 per cent.			70.5	70.5		100,350	100,350	3.8	55.5		43					(8)
	....do.[84]			71.5	76.0		101,700	108,150	4.7	35.5		43					(8)
	0.034 in. (0.86 mm) sheet; reduction by rolling 86.7 per cent.			75.4	75.4		107,350	107,350	1.5	57.6		47					(8)
	....do.[84]			77.5	81.8		110,300	116,350	2.3	31.4		47					(8)
Zinc, iron (Aich's metal)— Cu, 60; Zn, 38.2; Fe, 1.8.	Cast	8.42			40.3			57,300									(169)
Zinc (Aich's metal)[85]— Cu, 60; Zn, 38; Fe, 2–1.5.	....do.				35.2			50,000									(98)

Zinc, iron (delta metal)—																	
Cu, 57; Zn, 42; Fe, 1.	Cast, sand				31.7			45,000	10.0								(126)
	Rolled, hard				42.2			60,000	17.0								(126)
Zinc, iron (delta metal)[86]—																	
Cu, 60; Zn, 36; Fe, 2 (1–4); Sn, 2 (1–3).	Cast				31.7			45,000	10.0								(98)
	Rolled				49.2			70,000	17.0								(98)
	Wire				63.3–84.4			90,000–120,000									(98)
Zinc, iron—																	
Cu, 65; Zn, 30; Fe, 5.5.	Rolled, hard				45.7			65,000									(103)
Zinc, iron, manganese—																	
Cu, 60; Zn, 38.5; Fe, 1; Mn, tr.	Cast	8.31	24.6		49.2	35,000		70,000	25								(169)
	Rolled		31.6		63.2	45,000		90,000	25								(169)
Zinc, iron, manganese (manganese bronze)[87]—																	
Cu, 55.5; Zn, 41.3; Fe, 0.95; Mn, 0.87; Al, Sn, Pb.	Cast			35.7	50.5		50,700	71,900	21.6								(120)
Zinc, iron, tin, aluminum (manganese bronze)—																	
Cu, 56; Zn, 41.5; Fe, 1; Sn, 0.75; Al, 0.5.	do				50.7–59.1			72,000–84,000	35–22		109–119						(164)
Zinc, iron, tin, aluminum, manganese (manganese bronze)[88]—																	
Cu, 57.0;[89] Zn, 41.0; Sn, 0.80; Fe, 0.53; Al, 0.37; Mn, 0.18; Pb, 0.07.	do			21.8	49.7		31,000	70,700	26								(90)
Zinc, lead (yellow brass)—																	
Cu, 60–63.5; Zn, 35–33.5; Pb, 5.3.	do	8.5			23.2–27.5			33,000–39,000	30–26	35–30							(169)
	Sheet, annealed				29.5			42,000	50								(169)
	Sheet, hard				42.9			61,000	30								(169)

[84] First values are for longitudinal specimens; second for transverse specimens.

[85] Malleable at red heat and can be hammered, rolled, or drawn into fine wire. Addition of Fe increases strength. Aich's metal is about 50 per cent stronger than brass of the same composition but without Fe: At 200° F. (93° C.) tensile strength equals 31.6 kg/mm² (45,000 lb./in.²); at 500° F. (260° C.) tensile strength equals 21.1 kg/mm² (30,000 lb./in.²); at 900° F. (482° C.) tensile strength equals 7.0 kg/mm² (10,000 lb./in.²).

[86] Has great strength and toughness, gives good castings; can be rolled and forged hot; stands a fair amount of drawing and hammering when cold; when exposed to atmosphere tarnishes less than brass; takes high polish. According to Winkelman's Handbuch der Physik, 1908, **1**, p. 557, the modulus of elasticity 11,700 kg/mm² (16,600,000 lb./in.²).

[87] Scrap metal was used.

[88] The effect of various components: Sn increases tensile strength and raises yield point. More than 0.8 per cent of tin lowers ductility. Ordinarily the content of tin is 0.75 per cent; Fe increases tensile strength and raises yield point. Makes the grain smaller. Amount of iron usually about 0.7 per cent; Al is added to obtain fluidity in pouring; 0.3–0.5 per cent is considered sufficient; Mn increases hardness and strength: is added for deoxidizing, 0.3 per cent is sufficient; Pb weakens alloy, maximum permissible amount 0.2 per cent.

[89] Average of nine determinations.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Tensile properties. Metric kg/mm² Yield point.	Tensile properties. Metric kg/mm² Tensile strength.	Tensile properties. English lb./in.² Proportional limit.	Tensile properties. English lb./in.² Yield point.	Tensile properties. English lb./in.² Tensile strength.	Tensile properties. Elongation in 50.8 mm or 2 inches.	Tensile properties. Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Thermal properties. Linear coefficient of expansion ×10⁶ (per 1 °C.).	Thermal properties. Casting shrinkage.	Thermal properties. Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Copper—Contd. Zinc, lead, tin (yellow brass)[90]—									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Cu, 62.0–65.0; Zn, 31.0–36.0; Pb, 2.0–4.0; Sn, max. 1.0; Fe, max. 0.5; Al, none; other imp., 0.25.	Cast			8.4	17.6		min. 12,000	min. 25,000	min. 20								(159)
Cu, 70; Sn, 27; Pb, 2; Sn, 1.	do		7.4		20.7	10,500		29,500	25.0	28.5	53						(164)
Zinc, lead, tin (red brass)[91]—																	
Cu, 83; Zn, 7; Pb, 6; Sn, 4.	do	8.6	11.3		21.1	16,000		30,000	17.0	19.0		7.0					(103)
Copper, zinc, lead, tin—																	
Cu, 78; Zn, 9.5; Pb, 10; Sn, 2.	do	8.87	8.4		18.6	12,000		26,500	22.0	24.9							(169)
Zinc, manganese (manganese bronze)[92]—																	
Cu, 58; Zn, 39; Mn, 0.05; Sn; Fe; Al; Pb.	Cast, sand [93]			21.1–24.6	49.2–52.7		30,000–35,000	70,000–75,000	30–22	32–25	109–119	18–19					(169)
	Cast, chill			22.5–26.0	52.7–56.2		32,000–37,000	75,000–80,000	32–25	34–28	119–130	18–22					(169)
Zinc, tin, iron, aluminum, manganese (manganese bronze)—																	
Cu, 58.72; Zn, 39.05; Sn, 0.79; Fe, 1.06; Mn, 0.04; Al, 0.47; Pb, 0.12.	Cast, sand	8.4			49.2–52.7			70,000–75,000	22–30		109–119				20.8	0.25	(111)
	Cast, chill				52.7–56.2			75,000–80,000	25–32		119–130				20.8	.25	(111)

Zinc, manganese (manganese bronze)[94]—																	
Cu, 56-60; Zn, 37-42; Fe; Sn; Mn.	Cast	...	21.1	...	42.2	30,000	...	60,000	8-10	...	...	...	...	...	...	...	(98)
	Rolled	...	56.2	...	70.3	80,000	...	100,000	12-15	...	...	...	...	...	...	...	(98)
Zinc, manganese—																	
Cu, 60; Zn, 39; Mn, tr.	....do	8.3	31.6	...	52.7	45,000	...	75,000	25	28	...	30	...	...	...	...	(169)
Zinc, manganese, tin, aluminum (manganese bronze)—																	
Cu, 55-62; Zn, 38-42; Sn, 0-1.50; Mn, 0-3.50; Al, 0-1.50; Fe, 0-2.0; Pb, 0-0.2.	Cast	...	...	...	45.7	...	...	65,000	20	...	...	...	...	...	...	...	(197)
Zinc, manganese (manganese bronze)[95]—							min.	min.	min.								
Cu, 53.0-62.0; Zn, 38.0-47.0; Pb, max. 0.15.	Cast, sand	...	...	21.1	42.2	...	30,000	60,000	15	...	...	...	...	...	...	...	(160)
	Cast-iron mold	...	...	...	49.2	...	...	70,000	20	...	...	...	...	...	...	...	(160)
Zinc, manganese, aluminum, lead, (manganese bronze)—																	
Cu, 53-62; Zn, 36-54; Al, 0.05-0.5; Pb. max 0.15.	Cast, sand	...	...	...	49.2	...	...	70,000	20.0	...	...	...	...	...	...	...	(16)
Zinc, manganese, iron, silicon—																	
Cu, 58.95; Zn, 39.72; Mn, 1.01; Fe, 0.24; Si, 0.08.	Cast	...	...	15.9	39.5	...	22,600	56,200	51.0	49.7	[96] 80	...	...	...	...	...	(119)
	Forged	...	...	15.9	41.1	...	22,600	58,500	47.0	57.0	...	...	...	...	...	...	(119)
Cu, 58.42; Zn, 39.8; Mn, 1.48; Fe, 0.25; Si, 0.05.	Cast	...	...	14.0	40.9	...	19,900	58,200	49.0	61.5	[96] 90	...	...	...	...	...	(119)
Cu, 58.42; Zn, 39.25; Mn, 2.0; Fe, 0.28; Si, 0.05.	....do	...	...	14.3	42.3	...	20,400	60,200	45.0	52.7	[96] 90	...	...	...	...	...	(119)

[90] Good machining properties.

[91] Compressive strength 54.5 kg/mm² (77,500 lb./in.²).—Philadelphia & Reading Railway Co. letter to U. S. Bureau of Standards Apr. 25, 1917.

[92] Modulus of elasticity, sand cast 9,840 kg/mm² (14,000,000 lb./in.²).

[93] Specification values: U. S. Navy 46B16-a, cast, minimums, tensile strength 49.2 kg/mm² (70,000 lb./in.²) with 20 per cent elongation in 2 in. (50.8 mm); U. S. Navy 46B15a, rolled, minimums, proportional limit 24.6 kg/mm² (35,000 lb./in.²); tensile strength 49.2 kg/mm² (70,000 lb./in.²) with 30 per cent elongation in 2 in. (50.8 mm); Cu, 57-60; Zn, 40-37; Fe, max 2.0; Sn, 0.5-1.5 (2.9 per cent increase in values for thicknesses of 1 in. (25.4 mm) and under).

[94] Compressive strength of cast bronze is 91.4 kg/mm² (130,000 lb./in.²). Very ductile and may be bent hot or cold. Not easily corroded. Used in machinery where corrosion may occur.

[95] This metal may be hardened by the addition of small amounts of Sn, Fe, Mn, Al, or a combination of these metals. Used where strength and toughness are required.

[96] 10 mm ball and 1,000 kg (2,205 lb.) load.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Metric kg/mm² Yield point.	Metric kg/mm² Tensile strength.	English lb./in.² Proportional limit.	English lb./in.² Yield point.	English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Linear coefficient of expansion ×10⁶ (per 1 °C.).	Casting shrinkage.	Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Copper—Contd.																	
Zinc, nickel (white bronze)—									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Cu, 53.7; Zn, 42.0; Ni, 4.0; Fe, and Al, 0.3.	....	....	....	44.7	62.8	....	63,500	89,200	24.0	25.4	....	32	....	....	....	....	(183)
Zinc, nickel—																	
Cu, 50; Zn, 45; Ni, 5.[97]	Rolled and annealed.	....	....	....	50.3	....	....	71,600	45.0	....	....	....	....	....	....	....	(121)
Cu, 46.4; Zn, 42.2; Ni, 10.4.[98]	Cast, chill	....	....	....	48.3	....	....	68,700	31.0	....	....	....	....	....	....	....	(121)
	Rolled and annealed.	....	....	....	56.6	....	....	80,500	45.0	....	....	....	....	....	....	....	(121)
	Hard, drawn	....	....	....	71.6	....	....	101,800	14.0	....	....	....	....	....	....	....	(121)
Cu, 40.5; Zn, 46.5; Ni, 12.9.[98]	Cast, chill	....	....	....	64.5	....	....	91,700	7.0	....	....	....	....	....	....	....	(121)
	Rolled and annealed.	....	....	....	60.6	....	....	86,200	18.5	....	....	....	....	....	....	....	(121)
Zinc, nickel (white nickel brass)[99]—																	
Cu, 55.0-64.0; Ni, min 18.0; Fe, max 0.35; Al, none; other imp, 0.25; Zn, remainder.	Cast	....	....	....	21.1	....	....	min. 30,000	min. 20	....	....	....	....	....	....	....	(161)
Zinc, nickel—																	
Cu, 58; Zn, 24; Ni, 18.	Fine, wire, drawn, hard.	8.5	....	....	105.5	....	....	150,000	....	....	....	....	....	....	....	....	(169)
Cu, 60.6; Zn, 11.8; Ni, 27.3.[1]	....	8.8	16.7	....	37.6	23,700	....	53,500	32.0	31.4	67	....	....	....	....	....	(169)
Zinc, nickel (nickel-silver)[2]—																	
Cu, 60.6; Zn, 31.7; Ni, 7.6.[3]	Cast	8.48	....	11.3	26.6	....	16,040	37,800	34.5	37.2	50	....	....	....	....	....	(85, 86, 87)
Cu, 61.8; Zn, 21.7; Ni, 16.4.	do	8.60	....	14.2	28.0	....	20,200	39,800	39.5	32.7	61	....	....	....	....	....	(85, 86, 87)

Cu, 61.6; Zn, 15.9; Ni, 22.4.	....do....	8.71	...	13.4	27.1	...	19,100	38,500	24.5	26.7	86	...	...	...	...	...	(85, 86, 87)
Cu, 61.2; Zn, 9.8; Ni, 28.6.	....do....	8.74	...	13.8	31.1	...	19,600	44,200	32.0	36.7	69	...	...	...	...	...	(85, 86, 87)
Cu, 65.82; Ni, 6.17; Fe, 0.23; Mn, 0.06; Pb, 1.27; Zn, balance.	Cold rolled, mill annealed.	...	...	18.7	37.8	...	26,600	53,700	55.2	61.2	65	15	...	...	...	...	(47)
	Cold rolled, 28.3 per cent reduction.	...	...	47.7	52.2	...	67,700	74,200	14.2	45.9	140	32	...	...	...	...	(47)
	Cold rolled, 46.3 per cent reduction.	...	...	64.7	64.7	...	92,000	92,000	5.0	34.7	161	39	...	...	...	...	(47)
	Cold rolled, 74.5 per cent reduction.	...	...	75.8	75.8	...	107,800	107,800	2.2	18.0	175	49	...	...	...	...	(47)
Cu, 64.68; Ni, 6.73; Fe, 0.19; Mn, 0.06; Zn, balance.	Cold rolled, mill annealed.	...	...	17.4	37.8	...	24,700	53,800	64.5	65.7	65	15	...	...	...	...	(47)
	Cold rolled, 24.6 per cent reduction.	...	...	47.4	50.2	...	67,400	71,400	23.7	53.1	132	30	...	...	...	...	(47)
	Cold rolled, 49.8 per cent reduction.	...	...	67.8	67.8	...	96,400	96,400	4.7	34.1	170	43	...	...	...	...	(47)
	Cold rolled, 75.4 per cent reduction.	...	...	78.9	78.9	...	112,300	112,300	2.5	26.5	176	49	...	...	...	...	(47)

[97] Can be rolled and worked both hot and cold.
[98] The alloy can be hot worked.
[99] Used for parts requiring a metallic-white finish. The higher the nickel content the more permanent the color.
[1] Modulus of elasticity 11,450–13,300 kg/mm² (16,300,000–18,900,000 lb./in.²).
[2] The correlation between the heat treatment of nickel-silvers and their mechanical properties is shown in Figures 15 and 16. The chemical composition of the three alloys tested is given in the table below.

Copper	59.26	59.72	60.20	Manganese	Trace.	Trace.	Trace.
Nickel	10.65	15.91	19.29	Sulphur	0.039	0.055	0.052
Lead	Nil.	Nil.	.09	Carbon	.116	.185	.185
Iron	.39	.46	.47	Zinc	Balance.	Balance.	Balance.

[3] The commercial nickel-silvers have small amount of lead (less than 0.5 per cent) and iron (about 0.30 per cent); total amount of impurities, less than 1 per cent. An addition of manganese (about 0.25 per cent) increases ductility without loss of strength.

Compression at 157.5 kg/mm² (224,000 lb./in.²).

Alloy.			Compression.
Cu	Ni	Zn	Per cent.
60.6	7.6	31.7	57.2
61.8	16.4	21.7	56.2
61.6	22.4	15.9	57.8
61.2	28.6	9.8	55.0

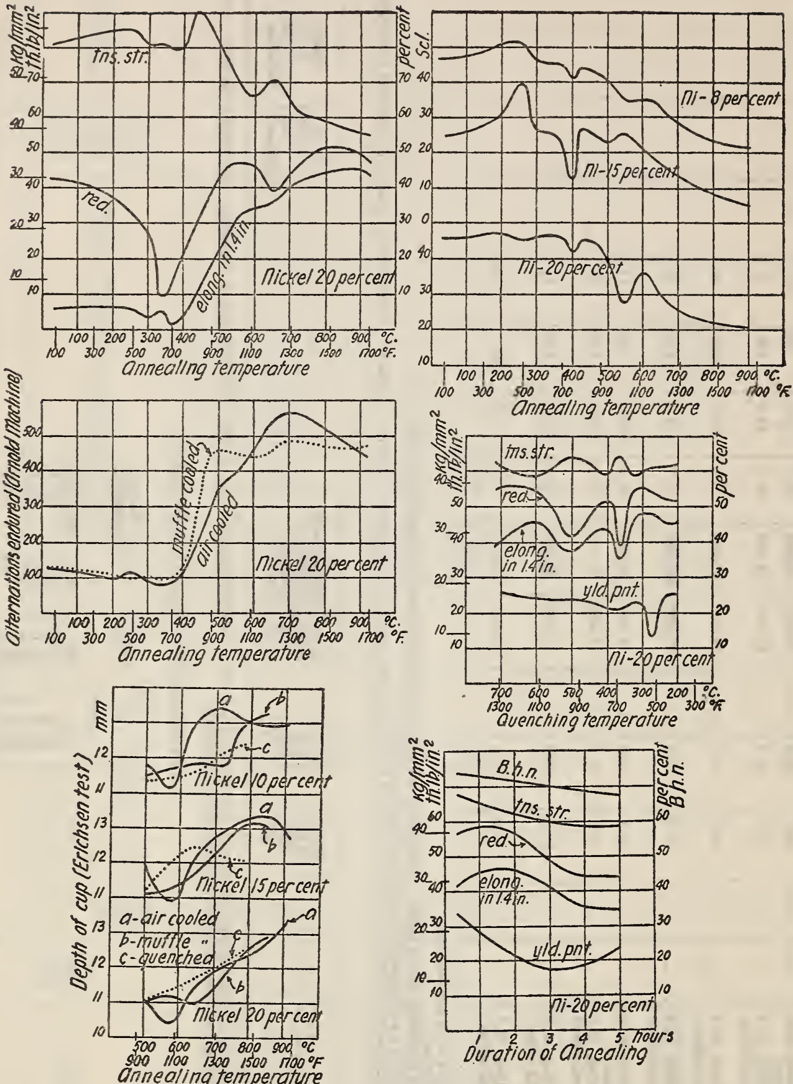

FIG. 15.—*Correlation between the heat treatment and the tensile properties of nickel-silvers.*

F. C. Thompson, Jour. Inst. Met., 15, p. 230; 1916; 17, p. 119; 1917; 27, p. 227; 1922. For chemical composition see Table 1.

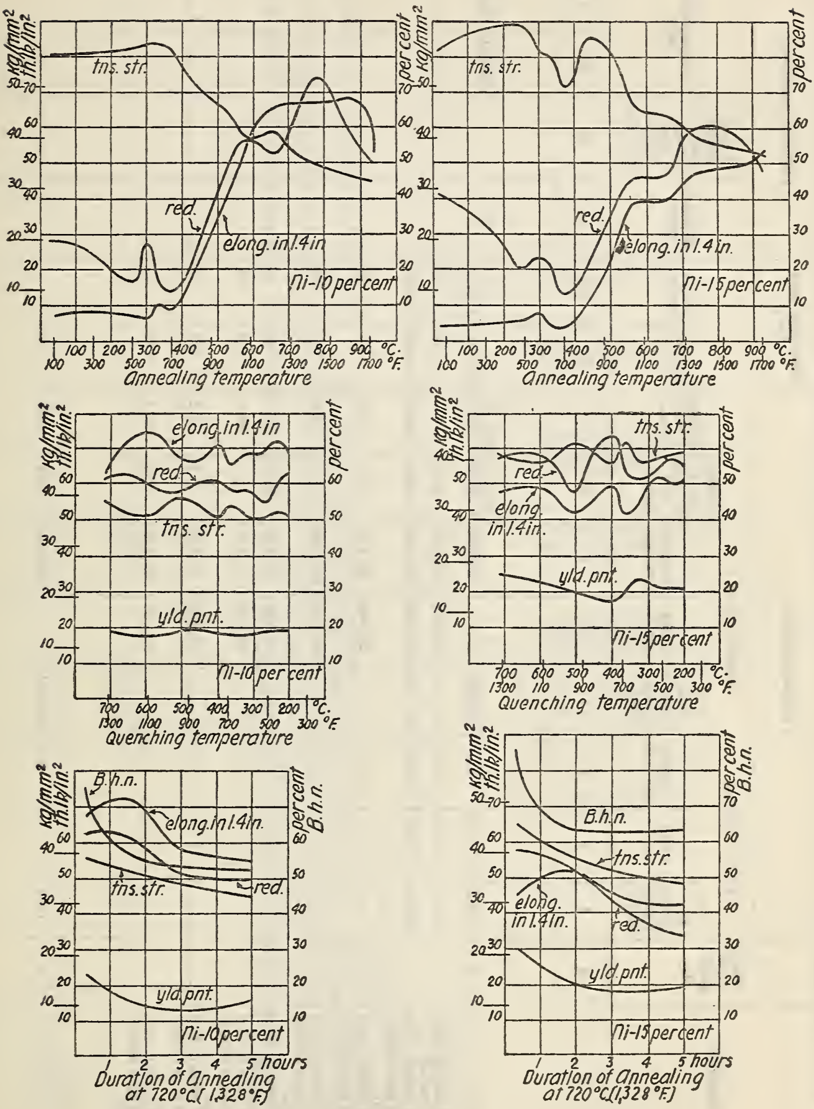

FIG. 16.—*Correlation between the heat treatment and the tensile properties of nickel-silvers.*

F. C. Thompson, Jour. Inst. Met., **15**, p. 230; 1916; **17**, p. 119; 1917; **27**, p. 227; 1922. For chemical composition see Table 1.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Tensile properties. Metric kg/mm² Yield point.	Tensile properties. Metric kg/mm² Tensile strength.	Tensile properties. English lb./in.² Proportional limit.	Tensile properties. English lb./in.² Yield point.	Tensile properties. English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Thermal properties. Linear coefficient of expansion ×10⁶ (per 1 °C.).	Thermal properties. Casting shrinkage.		Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Copper—Contd. Zinc, nickel (nickel-silver)—									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Cu, 60.4; Zn, 31.8; Ni, 7.7.	Cast	8.5	10.8		25.3	15,400		36,000	40.5	42.0	[4]46						(169)
Cu, 65.60; Ni, 17.77; Fe, 0.24; Mn, 0.06; Pb, 1.08; Zn, balance.	Cold rolled, mill annealed.			22.8	41.6		32,400	59,100	35.0	54.2	89	17					(47)
	Cold rolled, 25.9 per cent reduction.			55.4	57.1		78,800	81,100	5.0	42.2	156	32					(47)
	Cold rolled, 46.0 per cent reduction.			62.9	62.9		89,400	89,400	3.5	28.3	164	36					(47)
	Cold rolled, 76.0 per cent reduction.			71.5	71.5		101,700	101,700	1.5	17.0	173	44					(47)
Cu, 65.44; Ni, 17.83; Fe, 0.35; Mn, 0.08; Zn, balance.	Cold rolled, mill annealed.			23.2	40.9		33,000	58,100	40.2	62.5	82	16					(47)
	Cold rolled, 26.8 per cent reduction.			54.0	55.1		76,700	78,300	6.5	48.7	152	28					(47)
	Cold rolled, 48.0 per cent reduction.			63.4	63.4		90,100	90,100	3.2	33.3	163	35					(47)
	Cold rolled, 76.0 per cent reduction.			70.2	70.2		99,800	99,800	2.0	27.2	173	43					(47)
Zinc, nickel (German or nickel-silver)—																	
Cu, 61.6;[5] Zn, 17.2; Ni, 21.1.		8.7	13.2		28.8	18,800		40,900	28.5	25.1	80						(169)
Zinc, nickel (nickel-silver).[6]																	(97)

Zinc, nickel, tungsten (platinoid)[7]—Cu, 60; Zn, 24; Ni, 14; W, 1-2.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	(44)
Zinc, tin (Naval brass)[8]—Cu, 61; Zn, 38; Sn, 1.	Cast, sand........	....	11.0	....	30.0	15,700	....	42,600	29.6	32.0	....	....	....	....	....	....	(169)
	Annealed after rolling.	....	26.0	....	43.6	37,000	....	62,000	25.0	37.0	....	....	....	....	....	....	(169)
Zinc, tin (Tobin bronze)—Cu, 58.2; Zn, 39.5; Sn, 2.3.	Cast........	8.3	17.6	....	42.2	25,000	....	60,000	....	....	....	....	....	....	....	....	(169)
	Rolled........	8.4	38.0	....	55.5	54,000	....	79,000	35.0	40.0	....	....	....	....	....	....	(169)
Zinc, tin (Durana metal)[9]—Cu, 58.7; Zn, 39.6; Sn, 1.0; Pb, 0.4; Fe, 0.34.	....	....	....	18.0	40.8	....	25,600	58,000	32.0	36.0	....	....	....	....	....	....	(76)

[4] Brinell hardness of nickel-silver (with Ni, 9 per cent)=130 as rolled and 50 as annealed at 930° C. (1,706° F.).

[5] U. S. Navy Department specification 46S3a, June 1, 1917. German silver: Cu, 60–67; Zn, 18–22; Ni, min. 15; no mechanical requirements. For list of 30 German-silver alloys see Brannt "Metallic Alloys," p. 314, "best" (Hiorns), "hard Sheffield", Cu, 46; Zn, 20; Ni, 34.

[6] Modulus of elasticity, 11,000 kg/mm² (15,640,000 lb./in.²). Poisson's ratio 0.37. Winkelman's Handbuch der Physik, 1908, **1**, 1, gives for modulus of elasticity of drawn nickel-silver 11,450 kg/mm² (16,270,000 lb./in.²) and for modulus of elasticity in shear (condition not specified) 3,870 kg/mm² (5,500,000 lb./in.²).

[7] Has high electrical resistance, which does not decrease with heat. Mechanical properties as those of nickel-brass.

[8] Specification values, naval brass castings, U. S. Navy 46B10C, July 1, 1922, normal proportions: Cu, 62; Zn, 37; Sn, 1. Minimum tensile strength, 17.6 kg/mm² (25,000 lb./in.²) with 15 per cent elongation in 2 in. (50.8 mm).

[9] Modulus of elasticity, 7,430 kg/mm² (10,600,000 lb./in.²).

Effect of High Temperature on Tensile Properties of Durana Metal of Above Composition.

Temperature.		Proportional limit.		Tensile strength.		Elongation.	Reduction of area.
°C.	°F.	kg/mm²	lb./in.²	kg/mm²	lb./in.²	Per cent.	Per cent.
24	75	18.0	25,600	40.8	58,000	32	36
95	203	17.2	24,500	34.5	49,000	27	33
148	298	17.0	24,200	31.4	44,700	44	50
170	338	16.4	23,300	28.0	39,800	50	51
214	417	12.5	17,800	18.0	25,600	62	52
320	608	4.5	6,400	6.5	9,230	61	53
420	788	1.6	2,270	2.0	2,840	39	40
542	1,008	....	....	.5	710	30	42

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Tensile properties. Metric kg/mm² Yield point.	Tensile properties. Metric kg/mm² Tensile strength.	Tensile properties. English lb./in.² Proportional limit.	Tensile properties. English lb./in.² Yield point.	Tensile properties. English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Thermal properties. Linear coefficient of expansion $\times 10^6$ (per 1 °C.).	Thermal properties. Casting shrinkage.		Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Copper—Contd.									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Zinc, tin (Naval brass or Tobin bronze)[10]—Cu, 59.0–62.0; Sn, 0.5–1.5; Fe, max. 0.1; Pb, max. 0.3; other imp., max. 0.1; Zn, remainder.	Tubing thickness of wall up to ⅛ in. (3.17 mm).	......	......	16.9	42.2	......	min. 24,000	min. 60,000	min. 28	......	......	......	......	......	......	......	(162)
	Tubing thickness of wall ⅛–¼ in. (3.17–6.34 mm).	......	......	15.5	38.7	......	min. 22,000	min. 55,000	min. 32	......	......	......	......	......	......	......	(162)
	Tubing thickness of wall over ¼ in. (6.34 mm).	......	......	14.1	35.2	......	min. 20,000	min. 50,000	min. 35	......	......	......	......	......	......	......	(162)
Zinc, tin (Naval brass or Tobin bronze)[11]—Cu, 59.0–62.0; Sn, 0.5–1.5; Fe, max. 0.1; Pb, max. 0.3; other imp., max. 0.1; Zn, remainder.	Rod, up to 1 in. (25.4 mm).	......	......	21.8	43.6	......	min. 31,000	min. 62,000	min. 25	......	......	......	......	......	......	......	(163)
	Rod, 1–2½ in. (25.4–63.5 mm).	......	......	21.1	42.2	......	min. 30,000	min. 60,000	min. 30	......	......	......	......	......	......	......	(163)
	Rod, 2½–3½ in. (63.5–88.8 mm).	......	......	17.6	39.4	......	min. 25,000	min. 56,000	min. 35	......	......	......	......	......	......	......	(163)
	Rod, over 3½ in. (88.8 mm).	......	......	15.5	38.0	......	min. 22,000	min. 54,000	min. 40.0	......	......	......	......	......	......	......	(163)
Zinc, tin (torpedo bronze)[12]—Cu, 59–62; Sn, 0.5–1.5; Pb, max. 0.3; Fe, max. 0.1; Zn, remainder; to contain no Al.	Rod, 0–0.5 in. (0–12.7 mm).	......	......	21.1	42.2	......	30,000	60,000	25	36	......	......	......	......	......	......	(198)
	Rod, 0.5–1 in. (12.7–25.4 mm).	......	......	20.4	40.8	......	29,000	58,000	27	40	......	......	......	......	......	......	(198)
	Rod, over 1 in. (25.4 mm).	......	......	16.2	38.7	......	23,000	55,000	30	45	......	......	......	......	......	......	(198)
	Tubing and sheet, wall or thickness, 0–0.125 in. (3.17 mm).	......	......	25.3	42.2	......	36,000	60,000	22	......	......	......	......	......	......	......	(198)

	Tubing and sheet, wall or thickness, 0.125–0.25 in. (3.17–6.34 mm).			23.2	38.7		33,000	55,000	25								(198)
	Tubing and sheet, wall or thickness, over 0.25 in. (6.34 mm).			21.1	35.2		30,000	50,000	27								(198)
Zinc, tin (Naval brass)—																	
Cu, 59–63; Sn, 0.5–1.5; Fe, max. 0.06; Pb. max. 0.2; Zn, remainder.	Rods 0–0.5 in. (12.7 mm) diameter.[13]		19.0		42.2	27,000		60,000	35.0								(199)
	Rods 0.5–1.0 in. (12.7–25.4 mm) diameter.[13]		18.3		40.8	26,000		58,000	40.0								(199)
	Rods over 1 in. (25.4 mm) diameter.[13]		17.6		38.0	25,000		54,000	40.0								(199)
	Shapes (all)[13]		15.7		39.4	22,400		56,000	30.0								(199)
	Plates to 0.5 in. (12.7 mm) thick, average.[13]		19.3		38.7	27,500		55,000	32.0								(199)
	Plates over 0.5 in. (12.7 mm) thick.[13]		17.6		39.4	25,000		56,000	35.0								(199)
	Tubing wall up to 0.125 in. (3.17 mm) thick.		21.1		42.2	30,000		60,000	28.0								(199)
	Tubing wall 0.125 0.25 in. (3.17–6.35 mm) thick.		19.7		38.7	28,000		55,000	32.0								(199)
	Tubing wall over 0.25 in. (6.35 mm) thick.		18.3		35.1	26,000		50,000	35.0								(199)
Zinc, tin, lead (U. S. Navy brass)—																	
Cu, 78; Zn, 16; Sn, 4; Pb, 3.	Cast		11.3		20.3	16,100		28,900	19.0	23.2							(169)
Zinc, tin, iron—																	
Cu, 59.95; Zn, 39.38; Sn, 0.47; Fe, 0.20.	do			17.3	41.3		24,600	58,700	44.0	42.0	[14]87						(119)
	Forged			24.6	45.4		35,000	64,500	38.0	60.0	[14]107						(119)
Cu, 58.90; Zn, 40.10; Sn, 1.00; Fe, trace.	Cast			15.1	42.0		21,500	59,800	32.0	33.5	[14]98						(119)
	Forged			21.4	45.1		30,400	64,100	38.0	44.6	[14]107						(119)
Cu, 58.82; Zn, 38.76; Sn, 2.11; Fe, 0.31.	Cast			18.6	41.1		26,400	58,500	13.0	15.0	[14]114						(119)
Cu, 59.17; Zn, 37.63; Sn, 2.98; Fe, 0.22.	do			25.8	33.4		36,800	47,600	1.5	3.2	[14]136						(119)

[10] A pin having a taper of 1 to 8 shall be driven into one end of a tube until the diameter is increased 15 per cent. The tube shall withstand this test without showing cracks, splits, or other defects.

[11] The rods shall stand cold bending without fracture through an angle of 120° around a pin, the radius of which is equal to the diameter or thickness of the rod or bar.

[12] Must stand hammering hot to a fine point and bending cold through 120° with inner radius equal to diameter or thickness of bar.

[13] Required to bend 120° cold about radius equal to diameter.

[14] 10 mm ball and 1,000 kg (2,204 lb.) load.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Tensile properties. Metric kg/mm² Yield point.	Tensile properties. Metric kg/mm² Tensile strength.	Tensile properties. English lb./in.² Proportional limit.	Tensile properties. English lb./in.² Yield point.	Tensile properties. English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Thermal properties. Linear coefficient of expansion ×10⁶ (per 1 °C.).	Thermal properties. Casting shrinkage.	Thermal properties. Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Genelite [15, 21]				5.6	5.6		8,000	8,000									(122)
Glucinum—[16] (Berryllium)—																	
Gl		1.64															(48)
Gl, 99.5													1,278±5				(209)
Gold: [17]																	
Au	Rolled				27.0			38,400									(97)
	Annealed				10.0			14,200									(97)
Au, 100	Cast	19.3			17.6			25,000	25.0				[18] 1,063	[18] 14.43			(169)
	Drawn, hard				26.0			37,000									(169)
Copper—																	
Au, 90; Cu, 10	do	17.2			45.8			65,100			[19] 73						(169)
Au, 83; Cu, 17					35.1			50,000									(71)
Silver-copper— Au, 58; Ag, 12; Cu, 30.	Drawn, hard				102.0			145,000									(169)
Iridium: [20]																	
Ir		[18] 22.42											[18] 2,350	[18] 9.0			(97)
Iron:																	
(Pure)[22]— C, max. 0.02; other impurities less than 0.03.	Annealed and normalized.		10.5		29.5	15,000		42,000	40.5	82.5	70						(51)
(Electrolytic remelt)[23]— C, 0.0125; other impurities, less than 0.05 per cent.	Forged	7.8		34.1	38.7		48,400	54,800	33.0	83.0	[24] 95	18					(42, 93)
	Annealed at 900° C. (1,652° F.).			12.7	26.8		17,960	38,100	52.0	87.0	[24] 75						(42, 93)
Iron [25]	Sheet												[26] 1,530	[26] 12.1			(169)
(Electrolytic)	Round, bars				23–25			32,700–35,500			55–59						(166)
	Sheet				24–26			34,100–37,000									(166)
Aluminum—																	
Al, 0 (laboratory product).	As forged			35.7	38.5		50,700	54,700	26.0	84.3							(94)
	Annealed at 1,000° C. (1,832° F.).			12.4	24.5		17,600	34,900	60.0	93.5							(94)

Al, 3.08	As forged	....	....	48.0	54.5	....	68,200	77,500	21.0	76.4	....	....	....	....	....	....	(94)
	Annealed at 1,000° C. (1,832° F.).	....	....	22.4	37.5	....	31,800	53,400	51.0	85.3	....	....	....	....	....	....	(94)
Al, 6.24	As forged	....	....	54.6	60.5	....	77,700	86,000	28.0	74.7	....	....	....	....	....	....	(94)
	Annealed at 1,000° C. (1,832° F.).	....	....	37.6	49.1	....	53,400	69,800	27.0	55.5	....	....	....	....	....	....	(94)
Silicon—																	
Si,0.01; C,0.01; (laboratory product).	As forged	....	....	29.4	31.8	....	41,800	45,200	35.0	78.0	....	....	....	....	....	....	(95)
	Melted in vacuo and annealed at 970°C. (1,778° F.).	....	....	11.2	24.5	....	16,000	34,900	53.0	81.5	....	....	....	....	....	....	(95)
Si, 1.71	As forged	....	....	48.0	53.6	....	68,100	76,300	29.0	87.2	....	....	....	....	....	....	(95)
	Annealed at 970° C. (1,778° F.).	....	....	25.2	38.1	....	35,800	54,200	50.0	90.6	....	....	....	....	....	....	(95)
Si, 4.40	As forged	....	....	66.1	74.0	....	94,000	105,000	6.0	7.5	....	....	....	....	....	....	(95)
	Annealed at 970° C. (1,778° F.).	....	....	51.3	64.4	....	72,900	91,600	24.0	25.1	....	....	....	....	....	....	(95)

[15] Genelite is a bearing metal. It is a mixture of high-grade synthetic bronze and graphite (40 per cent); made of oxides of tin, lead, and copper, and graphite. All in a finely divided state. Mixture is pressed together and subjected to heat which sinters the metals together; has self-lubricating qualities; possesses high degree of porosity; can absorb 2.5 per cent of oil, and this is made use of in high-speed bearings.

[16] White malleable metal: can be easily forged and cold-rolled into sheets; takes high polish; scratches glass, hardness between 6 and 7 (Mohs' scale); not altered by air, does not burn even when heated to redness; not affected by cold or boiling water or steam; not attacked by nitric acid or ammonia but dissolves in a potash solution. It is attacked by hydrochloric acid gas and by concentrated sulphuric acid.

[17] Modulus of elasticity, 7,000–9,500 kg/mm² (9,950,000–13,500,000 lb./in.²); modulus of elasticity in shear, 2,600–3,900 kg/mm² (3,700,000–5,540,000 lb./in.²). Poisson's ratio 0.42.

[18] Smithsonian Physical Tables, 7th edition, 1920.

[19] At 200 kg (441 lb.) load.

[20] Modulus of elasticity, 53,000 kg/mm² (75,400,000 lb./in.²).

[21] Compressive strength, 35.1 kg/mm² (50,000 lb./in.²), General Electric Review, November, 1921.

[22] The effects of carbon and manganese on mechanical properties of pure iron.—The results obtained on annealed and normalized specimens of alloys containing from 0 to 1.6 per cent carbon and 0 to 1.6 per cent manganese were as follows: (1) The tensile strength of iron-manganese alloys containing from 0 to 1.6 per cent manganese had been increased by addition of carbon up to 1.0 per cent. The rate of increase of strength was from 0.615 to 0.808 kg/mm² (875 to 1,150 lb./in.²) for each 0.01 per cent between 0 and 0.70 per cent carbon. The higher the manganese content the greater was the strengthening effect of carbon. Above 1 per cent of carbon its effect was the decrease of tensile strength. (2) The hardness of iron-manganese alloys was influenced by carbon in about the same manner as their tensile strength. The increase of hardness was 1.8–2.6 Brinell units for each 0.01 per cent carbon, the higher value corresponding to high manganese content. (3) With the increase of carbon content the elongation and reduction of area decreased up to 1 per cent carbon. Beyond that percentage the effect of carbon content was small. (4) Carbon influenced the proportional limit less than the other properties. Maximum values were reached at lower carbon contents than the maximum values for tensile strength and remained about constant over a wide range of carbon content. (5) Manganese increased tensile strength from 0.063 to 0.176 kg/mm² (90 to 250 lb./in.²) for each 0.01 per cent manganese, the lower limit corresponding to irons with low-carbon content. (6) Proportional limit was influenced by manganese in about the same manner as the tensile strength. (7) Brinell hardness numbers were increased about 0.5 Brinell unit by each 0.01 per cent of manganese, the rate of increase being lower in alloys with low-carbon content than in alloys with high carbon. (8) Manganese had very little effect on ductility. (9) The effect of carbon and manganese were each influenced by the other. The increase of carbon increased the effect of manganese, and vice versa.

[23] Properties of Swedish iron (impurities less than 1 per cent) approximately equal those of electrolytic iron. Compressive strength (specimens, 25.4 mm, or 1 inch, diameter, 76.2 mm, or 3 inches, long), 56.3 kg/mm² (80,000 lb./in.²). Modulus of elasticity in tension and compression, 17,600 kg/mm² 25,000,000 lb./in.²). Modulus of elasticity in shear, 7,030 kg/mm² (10,000,000 lb./in.²). Shearing proportional limit, 8.4 kg/mm², or 12,000 lb./in.² Shearing strength, 21.1 kg/mm², or 30,000 lb./in.².

[24] 500 kg (1,102 lb.) load.

[25] Erichsen values for good trade quality sheets, 0.4 mm (0.0156 in.) thickness, soft annealed:

Kind of sheet.	Depth of cup.	
	mm	in.
Sheet metal, hoop iron, polished	9.5	0.374
Charcoal iron, tinned sheet	7.5	.295
Second quality, tinned sheet	6.7	.264

[26] Smithsonian Physical Tables, 7th edition, 1920.

TABLE 9.—Standard Terminology for the Ferrous Materials in Principal European Languages.

English.	French.	Italian.	Spanish.	German.	Swedish.	Danish.	Dutch.
Species.							
Cast iron	Fonte	Ghisa	Fundición de hierro.	Roheisen if not remelted, Gusseisen if remelted.	Tackjern Gjutjern.	Raajern naar detikke er omsmeltet eller Stöbejern.	Gietyzer (ruwyzer).
Varieties.							
White cast iron or pig iron.	Fonte blanche	Ghisa bianca in pani, Ghisa bianca.	Lingote de hierro blanco y fundición de hierro blanco.	Weisses Roheisen	Hvitt tackjern	Hvidtjern	witgietyzer (witruwyzer).
Gray cast iron or pig iron.	Fonte grise	Ghisa grigia	Lingote de hierro gris y fundición de hierro gris.	Graues Roheisen	Grått tackjern	Graatjern Graat Raajern.	Grauw gietyzer.
Mottled cast iron or pig iron.	Fonte truitée	Ghisa trotata	Lingote de hierro truchado y fundición de hierro truchado.	Halbiertes Roheisen.	Hagelstatt or Halfhwitt or halfgrått tackjern.	Spragletjern	wit korreliggietyzer.
Pig iron (white, gray, mottled, etc.).	Gueuses de fonte ou fonte en gueuse.	Ghisa	Lingote de hierro	Gusseisen Roheisen (in Masseln oder Gänsen), Gusseisen (weiss, grau, halbiert).	Tackjern	Pigjern or Raajern.	Ruwyzer (gemeleerd).
Hot metal, or direct metal.	Fonte de première fusion.	Ghisa da prima fusione liquida.	Metal caliente ó metal directo.	Remeisen Roheisen, Gusseisen erster Schmelzung.	Tackjern direct gjutet från Masugnen.	Smeltet Raajern	Ruwyzer cerste gieting.
Basic cast iron or pig iron.		Ghisa basica in pani.	Lingote de hierro básico.	Thomasroheisen		Thomas Raajern	Thomas ruwyzer.
Hematite cast iron or pig iron.		Ghisa ematite in pani.	Lingote de hierro hematites.	Hämatitroheisen		Haematit Raajern	Haematitruwyzer.
Malleable pig iron		Ghisa per affinazione.	Lingote de hierro para fundición maleable.	Schmiedbares Gusseisen.		Hammerbart-Stöbejern.	Smeedbaargietyzer.
Washed metal	Fonte épurée	Metallo defosforato	Fundición de hierro refinada ó lavada.	Entphosphortes Roheisen.	Tvåttad	Affosforet Raajern	Ontphospherd gietyzer.
Refined cast iron	Fonte mazée	Ghisa affinata	Fundición de hierro refinada ó depurada.	Gesseintes Eisen	Raffineradtjern	Raajern til Hardfriskning.	Gezuiverd gietyzer.
Charcoal hearth cast iron.	Fonte mazée	Ghisa al carbone di legna.	Fundición refinada al carbón vegetal, en fuego de afinéria.	Herdfrischeisen Holzkohlen Herdfrisch-Roheisen.	Tackjern för härdfärskning.	Raffineret Raajern	Houtskolen gietyzer.
Alloy cast iron	Fontes spéciales	Lega di ghise (ghise speciali).	Aleaciones de hierro colado.	Sondergusseisen	Special tackjern	Special Raajern	Special gietyzer.

Species.

Malleable castings....	Fonte malléable.....	Pezzi fusi (getti) di ghisa malleabile.	Piezas de fundición de hierro maleable.	Schmiedbares Gusseisen or schmiedbarer Guss.	Aduceradt jern......	Hammerbart Stöbejern, Hammerbart Stöbegods.	Smeedbare gieting.
Steel................	Acier...............	Acciaio.............	Acero...............	Stahl...............	Stål................	Staal...............	Staal.
Variety A.							
Called steel because cast initially into a malleable mass:							
1. Soft or low carbon steel, or ingot iron.	Acier doux, acier extra doux, fer fondu.	Lingotto di ferro omogeneo acciaio dolce).	Hierro fundido......	Flusseisen [1].........	Götmetall...........	Staal Blödstaal......	Smeltyzer Vloeiyzer.
2. Half hard and hard, or medium and high carbon steel, or ingot steel.	Acier fondu, acier mi-dur, acier dur.	Lingotto d'acciaio, duro, semi-duro.	Acero fundido.......	Flussstahl [1].........	....	Haardtstaal.........	Vloeistaal.
Subvarieties.							
Bessemer steel.......	Acier Bessemer.....	Acciaio Bessemer...	Acero Bessemer.....	Bessemer-Flusseisen, Bessemer Flussstahl.	Bessemerstål........	Bessemer staal......	Bessemer staal.
Open-hearth steel....	Acier Martin Siemens, acier sur sole.	Acciaio Martin......	Acero de Solera.....	Flammofen-Flusseisen, Flammofen-Flussstahl.	Martinstål..........	Martinstaal.........	Frischstaal, Siemens-Martinstaal.
Crucible steel........	Acier au creuset.....	Acciaio al crogiuolo..	Acero de crisoles....	Tiegelflusseisen, Tiegelflussstahl.	Degelstål or Degelgjutstål.	Digelstaal...........	Kroerzenstaal.
Cast steel............	Acier au creuset.....	Acciaio fuso.........	Acero fundido.......	Gussstahl...........	Gjutstål.............	Stöbestaal...........	Gietstaal.
Steel castings.........	Moulages d'acier....	Pezzi di acciaio colato.	Piezas de acero colado.	Flusswaren..........	Stålgjutgods.........	Staalstöbegods, or Facongods.	Vormgietstaal.
Variety B.							
Weld steel, or wrought steel, called steel because it is capable of hardening greatly by sudden cooling.	Fer fort ou fer dur...	Acciaio saldato, Acciaio fucinato.	Acero Soldado.......	Schweissstahl or Schweisseisen.[1]	Wäll stål, rarely used, no equivalent.	Svejsestaal..........	Welyzer Welstaal.

[1] According to Wedding cast metal having a tenacity greater than 50 kg/mm ^{2} should be called Flussstahl, while with a smaller tenacity it should be called Flusseisen. Weld metal with a tenacity exceeding 42 kg/mm ^{2} should be called Schweissstahl and with a less tenacity, Schweisseisen.

TABLE 9.—Standard Terminology for the Ferrous Materials in Principal European Languages—Continued.

Names.							
English.	French.	Italian.	Spanish.	German.	Swedish.	Danish.	Dutch.
Subvarieties.							
Blister steel, also called cemented and converted steel.	Acier poule, acier cémenté, acier de cémentation.	Acciaio cementato, Acciaio al crogiulo, Acciaio a carburazione esterna cementato.	Acero cementado	Zemenstahl	Blåsstål, Brännstål, Cementstål.	Blaerestaal or Cementstaal.	Cementstaal.
Shear steel	Acier rafiné une fois corroyé.	Acciaio damascato (acciaio saldato).		Schweissstahl		Svejsestaal	Welstaal.
Puddled steel	Acier puddlé	Acciaio pudellato	Acero Pudelado	Puddelstahl	Puddlestål	Puddelstaal	Puddelstaal.
Variety C.							
Alloy steels	Alliages à base de fer, aciers spéciaux.	Lega di acciaii (acciai speciali).	Aleaciones de Acero.	Sonderstahl	Special stål	Special staal	Specialostaal.
Species.							
Wrought iron (or weld iron, or, in Great Britain, malleable iron).	Fer soudé	Ferro fucinato, Ferro saldato.	Hierro forjado, Hierro soldado.	Schmiedeisen and Stabeisen.	Smidesjern Lancashire jern.	Svejsejern	Welyzer.
Varieties.							
Puddled iron	Fer puddlé	Ferro pudellato	Hierro pudelado	Puddeleisen	Puddeljern	Puddjern	Puddelyzer.
Bloomary or knobbied iron.	Fer au bois (obtenu au Bas-Foyer).			Herdfrischeisen	Lancashire Franche-Comté or Walloon jern.	Haerd frisket jern (always refers to Lancashire iron from Sweden).	Puddel of frischyzer.

X. IRON AND STEEL SPECIFICATIONS. (S. A. E.)

1. CLASSIFICATION.

A numeral index system is used for the specifications given below, which makes it possible to use specification numerals on shop drawings and blue prints that are partially descriptive of the quality of material covered by such numbers. The first figure indicates the class to which the steel belongs. Thus, "1" indicates a carbon steel, "2" a nickel steel, and "3" a nickel-chromium steel. In the case of the alloy steels the second figure generally indicates the approximate percentage of the predominant alloying element. Usually the last two or three figures indicate the average carbon content in "points," or hundredths of 1 per cent. Thus, "2340" indicates a nickel steel of approximately 3 per cent nickel (3.25 to 3.75) and 0.40 per cent carbon (0.35 to 0.45) and 71360 indicates a tungsten steel of about 13 per cent tungsten (12 to 15) and 0.60 per cent carbon (0.50 to 0.70). The basic numerals for the various qualities of steels specified are:

Carbon steels	1	Chromium steels	5
Nickel steels	2	Chromium-vanadium steels	6
Nickel-chromium steels	3	Tungsten steels	7
Molybdenum steels	[1] 4	Silico-manganese steels	8

2. CHEMICAL COMPOSITIONS.

CARBON STEELS.

S. A. E. steel No.	Carbon, range.	Manganese, range.	Phosphorus, maximum.	Sulphur, maximum.
1010	0.05–0.15	0.30–0.60	0.045	0.05
1015	.10– .20	.30– .60	.045	.05
1020	.15– .25	.30– .60	.045	.05
1025	.20– .30	.50– .80	.045	.05
1030	.25– .35	.50– .80	.045	.05
1035	.30– .40	.50– .80	.045	.05
1040	.35– .45	.50– .80	.045	.05
1045	.40– .50	.50– .80	.045	.05
1046	.40– .50	.30– .50	.045	.05
1050	.45– .55	.50– .80	.045	.05
1095	.90–1.05	.25– .50	.040	.05

SCREW STOCKS.

1112	0.08–0.16	0.60–0.80	0.09–0.13	0.075–0.15
1120	.15– .25	.60– .90	.06	.075– .15

STEEL CASTINGS.

1235	As required by physical properties.	....	0.05	0.05

[1] This numeral has been agreed upon as the index to the molybdenum group, but no specific compositions have as yet been approved.

2. CHEMICAL COMPOSITIONS—Continued.

NICKEL STEELS.

S. A. E. steel No.	Carbon, range.	Manganese, range.	Phosphorus, maximum.	Sulphur, maximum.	Nickel range.
2315	0.10–0.20	0.30–0.60	0.04	0.045	3.25–3.75
2320	.15– .25	.50– .80	.04	.045	3.25–3.75
2330	.25– .35	.50– .80	.04	.045	3.25–3.75
2335	.30– .40	.50– .80	.04	.045	3.25–3.75
2340	.35– .45	.50– .80	.04	.045	3.25–3.75
2345	.40– .50	.50– .80	.04	.045	3.25–3.75
2350	.45– .55	.50– .80	.04	.045	3.25–3.75
2512	Max. .17	.30– .60	.04	.045	4.50–5.25

NICKEL-CHROMIUM STEEL.

S. A. E. steel No.	Carbon, range.	Manganese, range.	Phosphorus, maximum.	Sulphur, maximum.	Nickel, range.	Chromium, range.
3115	0.10–0.20	0.30–0.60	0.04	0.040	1.00–1.50	0.45–0.75
3120	.15– .25	.30– .60	.04	.045	1.00–1.50	.45– .75
3125	.20– .30	.50– .80	.04	.045	1.00–1.50	.45– .75
3130	.25– .35	.50– .80	.04	.045	1.00–1.50	.45– .75
3135	.30– .40	.50– .80	.04	.045	1.00–1.50	.45– .75
3140	.35– .45	.50– .80	.04	.045	1.00–1.50	.45– .75
3215	.10– .20	.30– .60	.04	.040	1.50–2.00	.90–1.25
3220	.15– .25	.30– .60	.04	.040	1.50–2.00	.90–1.25
3230	.25– .35	.30– .60	.04	.040	1.50–2.00	.90–1.25
3240	.35– .45	.30– .60	.04	.040	1.50–2.00	.90–1.25
3245	.40– .50	.30– .60	.04	.040	1.50–2.00	.90–1.25
3250	.45– .55	.30– .60	.04	.040	1.50–2.00	.90–1.25
3312	Max. .17	.30– .60	.04	.040	3.25–3.75	1.25–1.75
3325	.20– .30	.30– .60	.04	.040	3.25–3.75	1.25–1.75
3335	.30– .40	.30– .60	.04	.040	3.25–3.75	1.25–1.75
3340	.35– .45	.30– .60	.04	.040	3.25–3.75	1.25–1.75
3415	.10– .20	.45– .75	.04	.040	2.75–3.25	.60– .95
3435	.30– .40	.45– .75	.04	.040	2.75–3.25	.60– .95
3450	.45– .55	.45– .75	.04	.040	2.75–3.25	.60– .95

CHROMIUM STEEL.

S. A. E. steel No.	Carbon, range.	Manganese, range.	Phosphorus, maximum.	Sulphur, maximum.	Chromium, range.
5120	0.15–0.25	0.30–0.60	0.04	0.045	0.60–0.90
5140	.35– .45	.50– .80	.04	.045	.80–1.10
5150	.45– .55	.50– .80	.04	.045	.80–1.10
52100	.95–1.10	.20– .50	.03	.030	1.20–1.50

CHROMIUM-VANADIUM STEELS.

S. A. E. steel No.	Carbon, range.	Manganese, range.	Phosphorus, maximum.	Sulphur, maximum.	Chromium, range.	Vanadium.	
						Minimum.	Desired.
6120	0.15–0.25	0.50–0.80	0.04	0.04	0.80–1.10	0.15	0.18
6125	.20– .30	.50– .80	.04	.04	.80–1.10	.15	.18
6130	.25– .35	.50– .80	.04	.04	.80–1.10	.15	.18
6135	.30– .40	.50– .80	.04	.04	.80–1.10	.15	.18
6140	.35– .45	.50– .80	.04	.04	.80–1.10	.15	.18
6145	.40– .50	.50– .80	.04	.04	.80–1.10	.15	.18
6150	.45– .55	.50– .80	.04	.04	.80–1.10	.15	.18
6195	.90–1.05	.20– .45	.03	.03	.80–1.10	.15	.18

2. CHEMICAL COMPOSITIONS—Continued.

TUNGSTEN STEELS.

S. A. E. steel No.	Carbon, range.	Manganese, maximum.	Phosphorus, maximum.	Sulphur, maximum.	Chromium, range.	Tungsten, range.
71360	0.50–0.70	0.30	0.035	0.035	3.00–4.00	12.00–15.00
71660	.50– .70	.30	.035	.035	3.00–4.00	15.00–18.00
7260	.50– .70	.30	.035	.035	.50–1.00	1.50– 2.00

SILICO-MANGANESE STEELS.

S. A. E. steel No.	Carbon, range.	Manganese, range.	Phosphorus, maximum.	Sulphur, maximum.	Silicon, range.
9250	0.45–0.55	0.60–0.90	0.045	0.045	1.80–2.20
9260	.55– .65	.60– .90	.045	.045	1.80–2.20

3. HEAT TREATMENT.

The charts below (see figs. 17 to 25) are intended as a guide to the proper heat treatment and to the physical properties that may be expected of a standard 0.505 by 2 in. (12.82 by 50.8 mm) test specimen machined from rolled bars up to 1½-in. (38.10 mm) diameter or square.

Brinell and scleroscope hardnesses are taken at a distance from the center equal to one-half the radius and are not to be compared with surface readings on heat-treated bars. For bars over 1½ in. (38.10 mm) in diameter or square these charts do not apply.

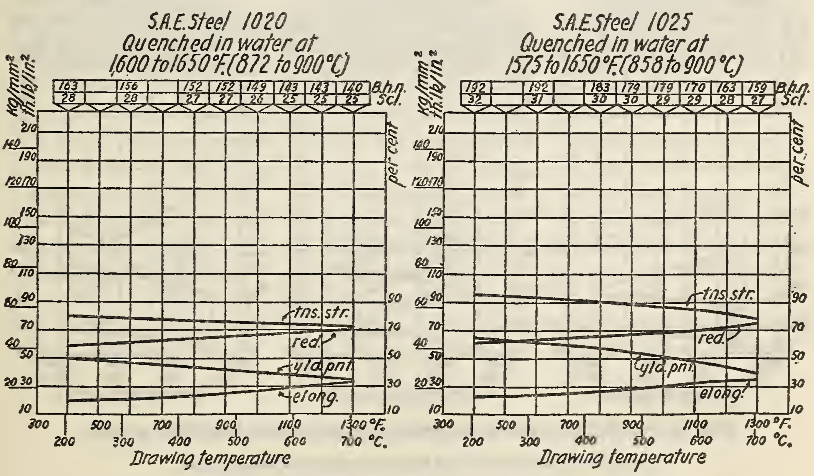

FIG. 17.—*Effect of drawing temperature on the tensile properties of steel.*

S. A. E. Standard Iron and Steel Specifications, March, 1922.

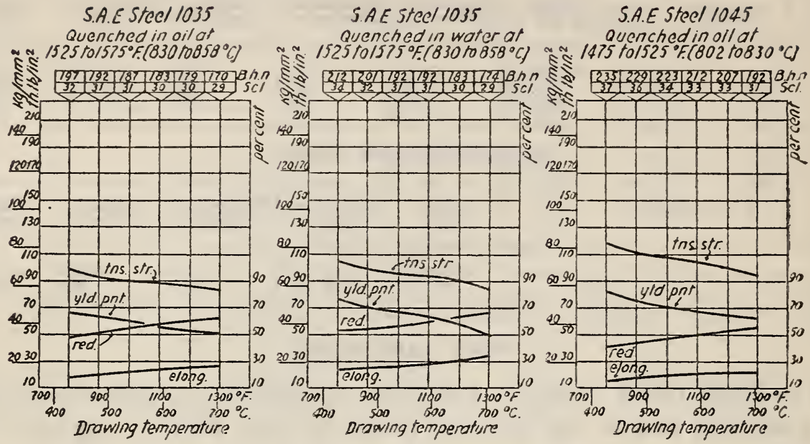

Fig. 18.—*Effect of drawing temperature on the tensile properties of steel.*

S. A. E. Standard Iron and Steel Specifications, March, 1922.

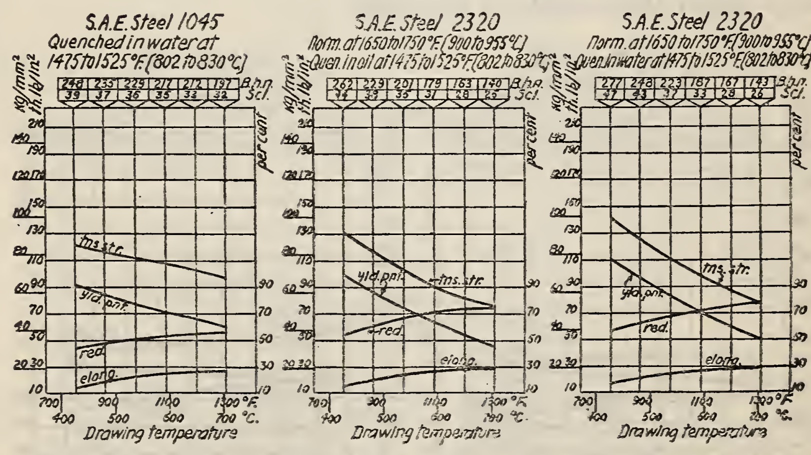

Fig. 19.—*Effect of drawing temperature on the tensile properties of steel.*

S. A. E. Standard Iron and Steel Specifications, March, 1922.

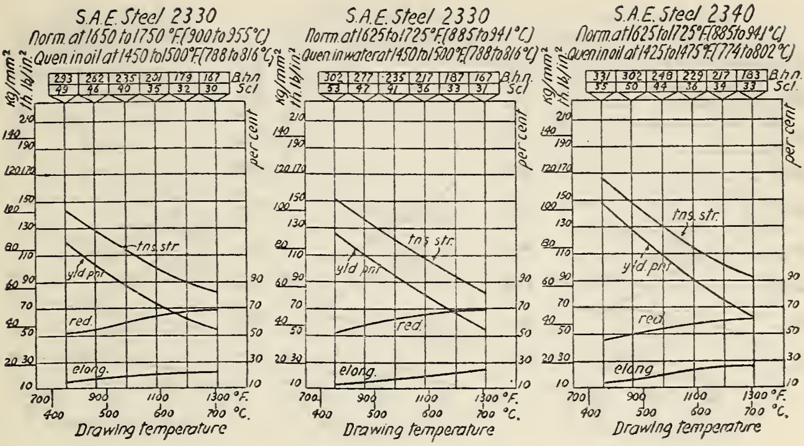

FIG. 20.—*Effect of drawing temperature on the tensile properties of steel.*

S. A. E. Standard Iron and Steel Specifications, March, 1922.

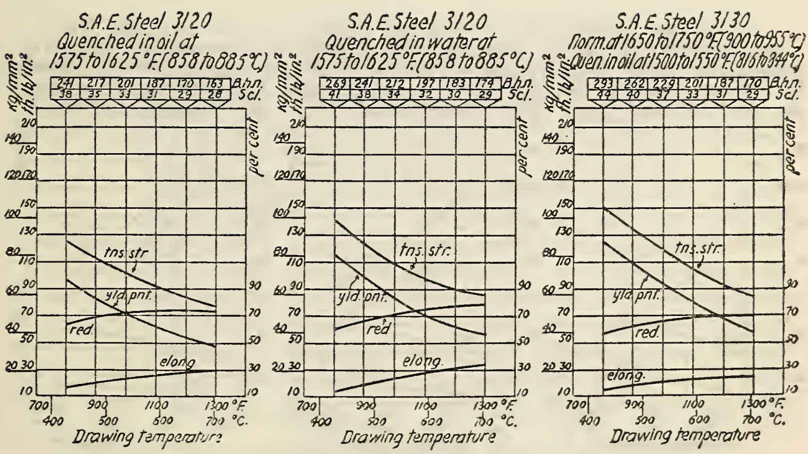

FIG. 21.—*Effect of drawing temperature on the tensile properties of steel.*

S. A. E. Standard Iron and Steel Specifications, March, 1922.

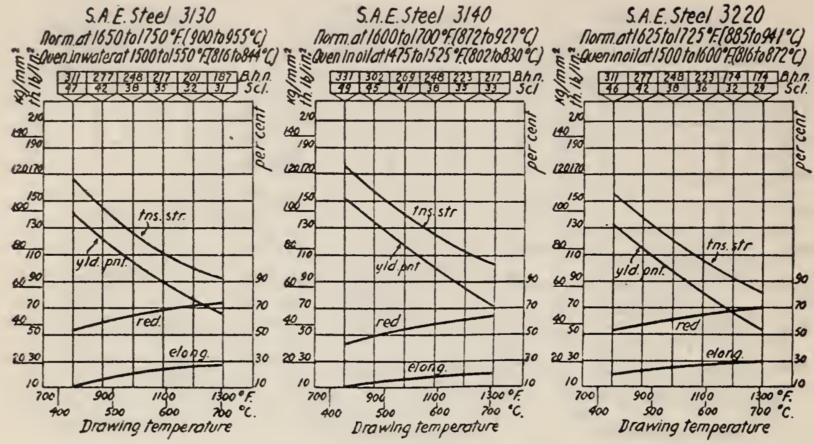

FIG. 22.—*Effect of drawing temperature on the tensile properties of steel.*

S. A. E. Standard Iron and Steel Specifications, March, 1922.

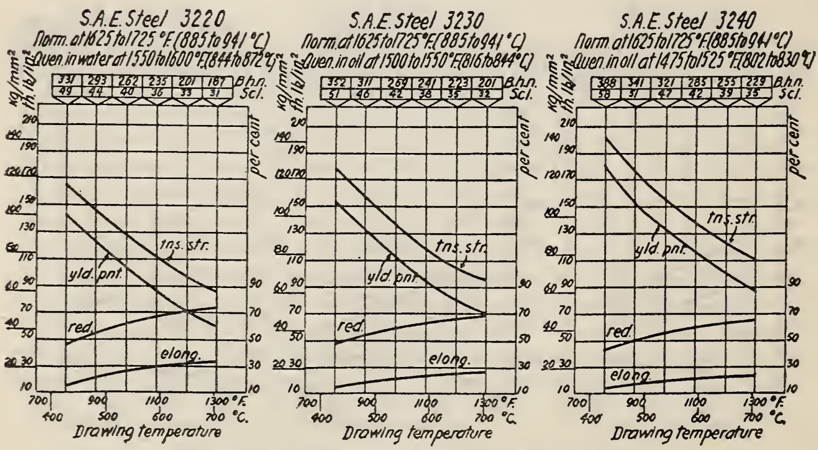

FIG. 23.—*Effect of drawing temperature on the tensile properties of steel.*

S. A. E. Standard Iron and Steel Specifications, March, 1922.

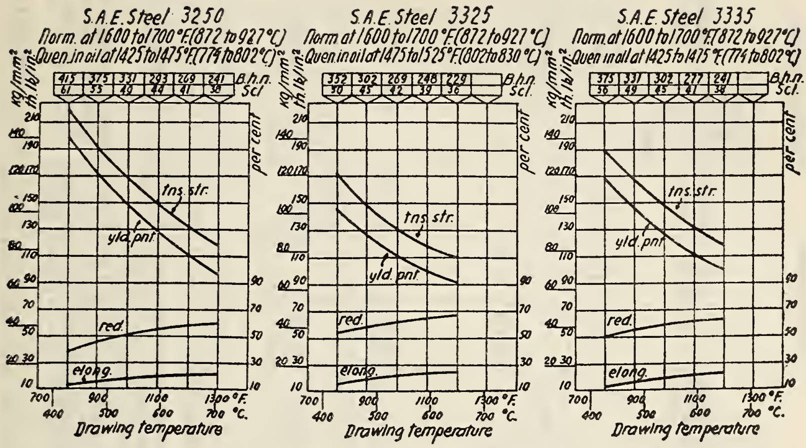

Fig. 24.—*Effect of drawing temperature on the tensile properties of steel.*

S. A. E. Standard Iron and Steel Specifications, March, 1922.

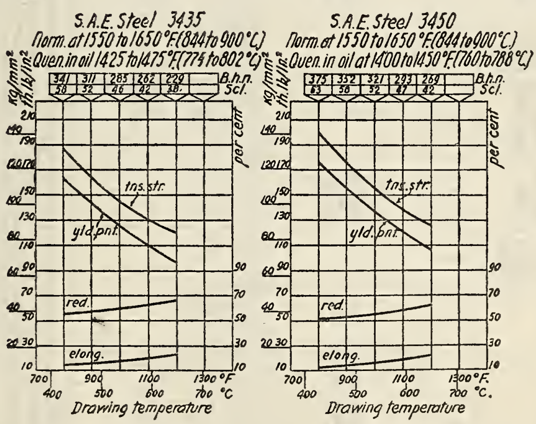

Fig. 25.—*Effect of drawing temperature on the tensile properties of steel.*

S. A. E. Standard Iron and Steel Specifications, March, 1922.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm²: Proportional limit.	Metric: Yield point.	Metric: Tensile strength.	English lb./in.²: Proportional limit.	English: Yield point.	English: Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number: Brinell.	Hardness number: Scleroscope.	Thermal properties: Melting point.	Linear coefficient of expansion ×10⁶ (per 1°C.)	Casting shrinkage.	Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Iron—Continued.									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Cast iron [1]																	(167)
Cast iron (gray)[2]—C, 3.0; Si, 1.3–2.0; Mn, 0.6–0.9; S, max. 0.1; P, max. 1.2.[3]	Bars, 0.75 in. (19.1 mm) diameter.	7.2		Indeterminate.	17.5–26.8		Indeterminate.	25,000–38,000	Negligible.		100–150	24–40					(169)
Cast iron (gray)[4, 5]—C, 2.5–4.0		[6] 7.03–7.13	([7])		8.4–24.6			12,000–35,000	—		90–200		[8] 1,220 (2,228° F.)	[6] 10.6	([9])		(100)
Cast iron (white)[5, 10]		[6] 7.58–7.73			28.1–35.1			40,000–50,000					[8] 1,135 (2,075° F.)				(100)
Semisteel [11]—C (total), 3.50; C (graph.), 2.89; Si, 1.37; Mn, 0.70; P, 0.10; S, 0.16.					7.0–26.7			9,950–38,000			105–207						(136)

[1] Modulus of elasticity, in tension or compression, 7,500–10,500 kg/mm² (10,660,000–14,920,000 lb./in.²). Landolt Börnstein Physical Tables (1912) give for Poisson's ratio of gray cast iron 0.25. Modulus of elasticity in shear, 2,900–4,000 kg/mm² (4,125,000–5,690,000 lb./in.²).

[2] U. S. Navy specifications 49I2a, minimum tensile strength 14.1 kg/mm² (20,000 lb./in.²). Compressive strength, specimen 25.4 mm (1 in.) diameter, 76.2 mm (3 in.) long, 56.3–84.4 kg/mm² (90,000–120,000 lb./in.²). A. S. T. M. specification A 48–18, arbitration bar 31.8 mm (1¼ in.) diameter on 304.8 mm (12 in.) span; minimum central load at rupture, 1,130–1,500 kg (2,500–3,300 lb.); minimum central deflection at rupture, 2.5 mm (0.1 in.); tensile strength, 12.7–16.9 kg/mm² (18,000–24,000 lb./in.²).

[3] A. S. T. M. specification, A 48–18; S, max. 0.10; except S, max. 0.12, for heavy castings.

[4] Compressive strength from 24.6 (soft) to 140.6 kg/mm² (hard, close-grained), or 35,000–200,000 lb./in.²). For machinery grades of good quality compressive strength from 63.3–105.5 kg/mm² (90,000–150,000 lb./in.²). Transverse tests preferred for testing cast iron. Modulus of rupture for good cast iron, 31.6 kg/mm² (45,000 lb./in.²). Modulus of elasticity in tension, compression, or cross bending, 8,430–10,550 kg/mm² (12,000,000–15,000,000 lb./in.²); for strong cast irons, up to 14,060 kg/mm² (20,000,000 lb./in.²). Shearing strength: Soft (Brinell hardness 92), 14.4 kg/mm² (20,500 lb./in.²); fine-grained (Brinell hardness 150), 23.7 kg/mm² (33,700 lb./in.²); hard, fine-grained (Brinell hardness 217), 28.0 kg/mm² (39,900 lb./in.²). Modulus of elasticity in shear, 4,500–5,770 kg/mm² (6,400,000–8,200,000 lb./in.²); modulus of rupture in torsion, about 24.6 kg/mm² (35,000 lb./in.²).

[5] If in cooling the carbon is largely precipitated, more or less uniformly in the form of graphite flakes, the iron is soft, presents dull-gray fracture, and is called gray cast iron. When the carbon is retained in combined form (Fe_3C), the cast iron is hard and brittle, it has silvery white fracture, and is called white cast iron. (Johnson's Materials of Construction, p. 697, 1918.)

[6] Smithsonian Physical Tables, 1920.

[7] Not well defined.
[8] Kent's Mechanical Engineers Pocketbook, p. 559; 1916.
[9] Expands on solidification.
[10] Compressive strength, up to about 175.8 kg/mm² (250,000 lb./in.²).
[11] Compressive strength, 36.6–106.0 kg/mm² (52,000–150,700 lb./in.²); elastic limit in compression, 22.0–50.0 kg/mm² (31,300–71,100 lb./in.²); compression, 9.0–28.1 per cent. Compression specimens were cylinders 16 mm (0.63 in.) diameter and 16 mm (0.63 in.) long.

TABLE 10.—Properties of Semisteel—Experimental Results.[1]

[Test results at Bureau of Standards on 155 mm shell, January, 1919. Microstructure: Matrix resembling pearlitic steel, embedded in which are flakes of graphite. Composition: Combined C, 0.60–0.76; graphitic C, 2.84–2.94; Mn, 0.88; P, 0.42–0.43; S, 0.077–0.088; Si, 1.22–1.23.]

Metal.	Tensile test.				Compressive test.				Brinell hardness.
	Proportional limit.		Tensile strength.		Proportional limit.		Compressive strength.		
	kg/mm²	lb./in.²	kg/mm²	lb./in.²	kg/mm²	lb./in.²	kg/mm²	lb./in.²	
Semisteel:									
Graphitic C, 2.85; combined C, 0.76	7.9	11,200	19.8	28,200	24.3	34,500	72.6	103,300	176
Graphitic C, 2.92; combined C, 0.60	4.2	6,000	14.9	21,200	18.3	26,000	61.4	87,300	170

[1] Semisteel—Gray iron to which steel has been added while in the molten condition. It may also be produced by other methods.

NOTE.—Tension specimens 12.7 mm (0.5 in.), diameter, 50.8 mm (2 in.), gauge length; elongation and reduction area negligible.
Compression specimens 20.3 mm (0.8 in.), diameter, 61.0 mm (2.4 in.), long; failure occurred in shear.
Modulus of elasticity in tension, 9,560 kg/mm², or 13,600,000 lb./in.²

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties.								Hardness number.		Thermal properties.				Reference.
			Metric kg/mm²			English lb./in.²			Elongation in 50.8 mm or 2 inches.	Reduction of area.	Brinell.	Scleroscope.	Melting point.	Linear coefficient of expansion ×10⁶ (per 1°C.)	Casting shrinkage.		
			Proportional limit.	Yield point.	Tensile strength.	Proportional limit.	Yield point.	Tensile strength.									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Malleable iron:[1]									Per ct.	Per ct.			°C.		mm/m	in./ft.	
S, max. 0.10; P, max. 0.23.	Cast				26.7			38,000 min.	5 min.								(200)
Malleable iron	do				31.6			45,000	7.5								(140)
Malleable iron:[2] Cast—																	
C, 2.8–3.5; Si, 0.6–0.8; Mn, max. 0.4; S, max. 0.07; P, max. 0.2.	American "black heart," medium.	7.6		14.2–31.6	25.2–40.9		20,240–45,000	35,800 58,200	15.0–4.5	15.0–4.5							(42)
C, 2.8–3.5; Si, 0.6–0.8; Mn, 0.15; S, max. 0.35; P, max. 0.2 ("steely fracture").	European (decarbonized), medium.	7.6		19.0–28.3	29.9–45.7		27,000–40,300	42,500–65,000	6.0–2.0	6.0–2.0							(42)
Cast	American practice, 1918, "black heart."[3]	7.6		18.6–20.0	33.7–35.1 min.		26,500–28,500	48,000–50,000 min.	10.0–15.0 min.	15.0–20.0	101–145						(42)
Cast[4]					31.6			45,000	7.5								(17)
Wrought iron	Rolled or forged blooms.			0.5 tensile strength.	31.6			45,000	[5] 22.0	30.0							(18)
P, max. 0.10; S, max. 0.015.	Grade A[6]			min. 0.5 tensile strength.	33.7			48,000	[7] 26	40							(201)
P, max. 0.15; S, max. 0.020.	Grade B[8]			min. 0.5 tensile strength.	31.6			45,000	[7] 25	40 (r'nds). 35 (flats).							(201)
Commercial range.[9]		7.85		19.7–22.5	34.0–37.3		28,000–32,000	48,000–53,000	40.0–30.0	45.0–35.0		25–30	[10] 1,500 (2,732 °F.)	[11] 11.4			(169)
Wrought iron[12]	For welded pipes.			16.9	28.1		24,000	40,000	[13] 12.0								(19)
Wrought iron[14]	For stay bolt (grade A), area less than 1¼ in.² (806 mm²).			0.6 tensile strength.	33.7–36.5		0.6 tensile strength.	48,000–52,000	[13] 30.0	48.0							(20)

For engine bolt (grade B), area less than 1¼ in.² (806 mm²).	....	....	0.6 tensile strength.	34.4–37.3	....	0.6 tensile strength.	49,000–53,000	[13] 25.0	40.0	....	....	....	....	....	....	(20)
For engine bolt (grade B), area over 1¼ in.² (806 mm²).	....	....	0.55 tensile str.[15]	33.0–37.3	....	0.55 tensile strength.	47,000–53,000	[13] 25.0	40.0	....	....	....	....	....	....	(20)
Extra refined bars (grade C), area less than 1¼ in.² (806 mm²).	....	....	0.6 tensile strength.	33.7–38.0	....	0.6 tensile strength.	48,000–54,000	[13] 25.0	37.0	....	....	....	....	....	....	(20)
Extra refined bars (grade C), area over 1¼ in.² (806 mm²).	....	....	0.55 tensile str.[15]	33.7–38.0	....	0.55 tensile strength.	48,000–54,000	[13] 25.0	37.0	....	....	....	....	....	....	(20)

[1] Transverse tests: Specimens 14 in. (356 mm) in length and 1 in. (25.4 mm) wide; span 12 in. (305 mm):

Thickness of specimen.		Minimum load applied at center.	Minimum deflection at center.	
mm	in.	lb.	mm	in.
12.7	1/2	900	31.7	1.25
15.9	5/8	1,400	25.4	1.00
19.1	3/4	2,000	19.1	.75

[2] Modulus of elasticity in tension and compression 17,600 kg/mm² (25,000,000 lb./in.²).

[3] H. A. Schwartz, Proc. Am. Soc. Test. Mat., **2**, p. 247; 1919.

[4] Am. Soc. Test. Mat. Specification A47-19.

[5] In 4 in. (101.6 mm).

[6] Shall be bent cold through 180° around a diameter of one thickness.

[7] Elongation will be measured in 8 in. (203.2 mm) with the following exceptions: Flats ¼ in. (6.35 mm), and less thickness will be measured on a length equal to 25 times the thickness. On all other materials less than ¾ in. (19.1 mm) diameter or thickness, the elongation will be measured on a length equal to 10 times the diameter or thickness.

[8] Flats ⅜ in. (9.51 mm) and less shall be bent cold around a diameter of two thicknesses, all other material to 180° around a diameter of one thickness. Both grades A and B to be bent to same requirements as cold bends after being heated to 927° C. (1,700° F.) and quenched in water, the temperature of which should be about 27° C. (80° F.).

[9] Compressive strength (specimen 25.4 mm or 1 in. diameter, 76.2 mm or 3 in. long) approximately equal to tensile yield point. Modulus of elasticity in tension and compression, 17,600 kg/mm² (25,000,000 lb./in.²); modulus of elasticity in shear, 7,030 kg/mm² (10,000,000 lb./in.²); shearing proportional limit, 21.1 kg/mm² (30,000 lb./in.²); shearing strength, 35.2 kg/mm² (50,000 lb./in.²).

[10] Kent's, Mechanical Engineers Pocketbook, p. 559; 1916.

[11] Smithsonian Physical Tables, 7th edition; 1920.

[12] Pipe less than 2 in. (50.8 mm) in diameter shall withstand being bent cold through 90° around a cylindrical mandrel, the diameter of which is 15 times the diameter of the pipe, without developing cracks and without opening the weld.

[13] In 8 in. (203.2 mm).

[14] Cold-bend tests: Grade A.—Test specimen shall withstand being bent through 180° flat on itself in both directions without fracture on the outside of the bent portion. Grade B.—Test specimen shall withstand being bent through 180° around a pin, the diameter of which is equal to the diameter of the specimen, without fracture on the outside of the bent portion. Grade C.—Bars having cross-sectional area under 4 in.² (2,580 mm²) shall withstand being bent through 180° around a pin, the diameter of which is equal to the thickness of bar, without fracture on the outside of the bent portion. Hot bend tests: Grades B and C.—The test specimen when heated to a temperature between 1,700 and 1,800° F. (938 and 982° C.) shall withstand being bent through 180° flat on itself without fracture on the outside of the bent portion.

[15] 0.5 tensile strength for an area over 4 in.² (2,580 mm²).

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Tensile properties. Metric kg/mm² Yield point.	Tensile properties. Metric kg/mm² Tensile strength.	Tensile properties. English lb./in.² Proportional limit.	Tensile properties. English lb./in.² Yield point.	Tensile properties. English lb./in.² Tensile strength.	Tensile properties. Elongation in 50.8 mm or 2 inches.	Tensile properties. Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Thermal properties. Linear coefficient of expansion $\times 10^6$ (per 1 °C.).	Thermal properties. Casting shrinkage.	Thermal properties. Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Wrought iron [16]	Plates, class A, width 6 to 24 in. (152.5 to 610 mm).			18.3	34.4		26,000	49,000	[20] 16.0								(21)
	Plates, class A, width 24 to 90 in. (610 to 2,290 mm).			18.3	33.7		26,000	48,000	[20] 12.0								(21)
	Plates, class B, width 6 to 24 in. (152.5 to 610 mm).			18.3	33.7		26,000	48,000	[20] 14.0								(21)
	Plates, class B, width 24 to 90 in. (610 to 2,290 mm).			18.3	33.0		26,000	47,000	[20] 10.0								(21)
Wrought iron [17]																	(63)
Steel: Extra soft—[18] Mn, 0.30-0.50; P, max. 0.04; S, max. 0.04.	Extra soft			min. 0.5 tensile strength.	31.7-38.7		min. 0.5 tensile strength.	45,000-55,000	([19])	min. 50							(202)
Low carbon— P, max. 0.10; (Bessemer); P, max. 0.05; (open hearth).	Splice bars				38.7-45.7			55,000-65,000	[20] 25.0								(22)
C, 0.15; Mn, 0.35; S, 0.045; P, 0.014.	Tubing quenched at 1,625-1,650° F. (885-899° C.) in oil and drawn at 1,000° F. (538° C.).			41.8	45.7		59,500	65,000									(49)
C, 0.25; Mn, 0.50; S, 0.045; P, 0.045.	Sheet, quenched at 1,600° F. (871° C.) in oil and drawn at 1,250° F. (677° C.).			42.4	49.6		60,250	70,500	30.0								(49)

C, 0.20; Mn, 0.50; S, 0.06; P, 0.045.	Carbonizing steel, quenched at 1,625° F. (885° C.) and drawn at 900° F. (482° C.).	...	...	35.9	49.2	...	51,000	70,000	34.0	70	...	...	...	...	...	...	(49)
Mild carbon [21] ...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	
Welding [22]—																	
C, 0 to 0.12; Si, max. 0.10; Mn, 0 to 0.25; P, max. 0.04; S, max. 0.04; Cu, Ni, Cr, not more than a trace.	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	(203)
Structural, building—																	
P, max. 0.10 (Bessemer); P, max. 0.06 (open hearth).	Rolled or forged ...	...	...	0.5 tensile strength.	38.7–45.7	...	0.5 tensile strength.	55,000–65,000	22	...	...	...	...	...	...	...	(23)

[16] The test specimen shall bend cold through 90° without fracture on the outside of the bent portion around a pin, the diameter of which is equal to—for class A, 1½ times the thickness, and for class B, 3 times the thickness.

[17] Shearing strength, 28.1 kg/mm² (40,000 lb./in.²).

[18] Shall be bent cold through 180° flat on itself without fracture.

[19] The minimum elongation of test specimen shall be 35 per cent for type 1 specimen and 30 per cent for types 2 and 3. The elongation shall be measured in accordance with the following table:

Types 2 and 3 from flat bars.			Type 3 from round, square, and hexagon bars.		
Nominal thickness.	Length in which measured.		Nominal thickness.	Length in which measured.	
	in.	mm		in.	mm
⅛ in. (3.17 mm) or less	2	50.8	Up to ¼ in. (6.35 mm), inclusive	2	50.8
Over ⅛ in. (3.17 mm) to 3/16 in. (4.76 mm), inclusive	4	101.6	Over ¼ in. (6.35 mm) to ½ in. (12.7 mm), inclusive	4	101.6
Over 3/16 in. (4.76 mm) to ¼ in. (6.35 mm), inclusive	6	152.4	Over ½ in. (12.7 mm) to ¾ in. (19.05 mm), inclusive	6	152.4
Over ¼ in. (6.35 mm)	8	203.2	Over ¾ in. (19.05 mm) to 1½ in. (38.1 mm), inclusive	8	203.2
			Over 1½ in. (38.1 mm), type 1 test specimen	2	50.8

[20] In 8 in. (203.2 mm).

[21] According to W. Dalby, Engineering, April 6, 1917, the correlation between the content of carbon and the strength of mild steel after annealing to allow the perlite to form, may be represented by formula: $f=35{,}800+114{,}370$ C lb./in.² or $25.15+80.4$ C kg/mm², where C is carbon content in per cent. W. Webster, Trans. Amer. Inst. Mech. Eng., 21 and 22, 1893–94, gives for the tensile strength of ⅜ in. (9.52 mm) plates of basic Bessemer steel the following correlation: $f=34{,}750+80{,}000$ C$+50{,}000$ S+P×(90,000 to 150,000, corresponding to carbon content from 0.09 to 0.17 per cent) lb./in.² or $24.4+56.3$ C$+35.2$ S+P×(63.3 to 105.5, corresponding to carbon content from 0.09 to 0.17 per cent) kg/mm². According to H. H. Campbell, Kent's Mechanical Engineer's Pocketbook, p. 477; 1916; the tensile strength of: Acid steel, $40{,}000+68{,}000$ C$+100{,}000$ P$+80{,}000$ C×Mn lb./in.² or $28.1+47.8$ C$+70.3$ P$+56.3$ C×Mn kg/mm²; basic steel, $38{,}800+65{,}000$ C$+100{,}000$ P$+9{,}000$ Mn$+40{,}000$ C×Mn lb./in.² or $27.3+45.7$ C$+70.3$ P$+6.3$ Mn$+28.1$ C×Mn kg/mm². (See also p. 73, Bureau of Standards results.

[22] Suitable for electrical or autogenous welding of steel castings, forgings, etc.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Tensile properties. Metric kg/mm² Yield point.	Tensile properties. Metric kg/mm² Tensile strength.	Tensile properties. English lb/in.² Proportional limit.	Tensile properties. English lb/in.² Yield point.	Tensile properties. English lb/in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Thermal properties. Linear coefficient of expansion ×10⁶ (per 1° C.).	Thermal properties. Casting shrinkage.	Thermal properties. Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Steel—Continued. Structural, for ships [23]—									Per ct.	Per ct.			°C.		mm/m	in./ft.	
P, max. 0.06 (acid), 0.04 (basic); S, max. 0.06.	Rolled			0.5 tensile strength.	40.8–47.8		0.5 tensile strength.	58,000–68,000	([24])								(24)
Low carbon [25]		[26] 7.60–7.80											[27] 1,400 (2,552° F.)	([26])			(78)
Steel [28]— Mn, 0.30–0.50; P, max. 0.04; S, max. 0.045.	For boiler rivets			0.5 tensile strength.	31.6–38.7		0.5 tensile strength.	45,000–55,000	([29])								(25)
Steel [30, 31]																	(184)
Concrete reinforcement bars [32]—																	
P, max. 0.10 (Bessemer); 0.05 (open hearth).	Structural grade, plain bars.			23.2	38.6–49.2		33,000	55,000–70,000	([33, 34])								(26)
	Structural grade, deformed bars.			23.2	38.6–49.2		33,000	55,000–70,000	([35, 34])								(26)
	Intermediate grade, plain bars.			28.1	49.2–59.7		40,000	70,000–85,000	([36, 34])								(26)
	Intermediate grade, deformed bars.			28.1	49.2–59.7		40,000	70,000–85,000	([37, 34])								(26)
	Hard grade, plain bars.			35.1	56.2		50,000	80,000	([38, 34])								(26)
	Hard grade, deformed bars.			35.1	56.2		50,000	80,000	([39, 34])								(26)

[23] Shall bend cold through 180° without cracking on the outside of the bent portion around a pin, the diameter of which is equal to the thickness of the specimen for material ¾ in. (19.1 mm) or under; 1½ times the thickness of the specimen for material ¾–1¼ in. (19.1–31.8 mm), inclusive; twice the thickness of the specimen for material over 1¼ in. (31.8 mm).

[24] Elongation in 8 in. (203.2 mm) 1,500,000÷tensile strength in lb./in.² or 1,055÷tensile strength in kg/mm². A deduction of 0.25 per cent shall be made for every $\frac{1}{32}$ in. (0.79 mm) above ¾ in. (19.1 mm) to a minimum of 18 per cent.

[25] Modulus of rupture in torsion: Cold rolled C, 0.083–48.5 kg/mm² (69,000 lb./in.²); cold rolled C, 0.093–50.6 kg/mm² (72,000 lb./in.²); cold rolled C, 0.375–58.3 kg/mm² (83,000 lb./in.²); machinery (open hearth) C, 0.084–41.5 kg/mm² (59,000 lb./in.²). According to Upton, Johnson's "Materials of construction," p. 616; 1918) shearing strength is equal to ¾ modulus of rupture in torsion.

[26] Smithsonian Physical Tables, 7th edition, 1920. The following values refer to steel in general: Coefficient of expansion for cast steel, 13.22×10^{-6}; coefficient of expansion for annealed steel, 10.95×10^{-6}.

[27] Kent's Mechanical Engineer's Pocketbook, p. 559; 1916.

[28] Shall bend cold through 180° flat on itself without cracking on the outside of the bent portion. Heated to not less than 650° C. (1,200 °F.) and quenched in water between 27 and 32° C. (80–90° F.) shall bend through 180° flat on itself without cracking on the outside of the bent portion.

[29] Elongation in 8 in. (203.2 mm) minimum per cent 1,500,000 ÷ tensile strength in lb./in.² or 1,055 ÷ tensile strength in kg/mm². Need not exceed 30 per cent.

[30] Average value for the modulus of elasticity, 20,750 kg/mm² (29,500,000 lb./in.²).

[31] The modulus of elasticity in shear, 8,190 kg/mm² (11,700,000 lb./in.²). Poisson's ratio from 0.268 to 0.310 (Love, The Mathematical Theory of Elasticity, 1906).

[32] Shall bend cold around a pin without cracking on the outside of the bent portion, as follows:

Thickness or diameter of bar.	Plain bars.			Deformed bars.		
	Structural grade.	Intermediate grade.	Hard grade.	Structural grade.	Intermediate grade.	Hard grade.
Under ¾ in. (19.1 mm)................	180°, $d=t$	180°, $d=2t$	180°, $d=3t$	180°, $d=t$	180°, $d=3t$	180°, $d=4t$
¾ in. or over (19.1 mm)................	180°, $d=t$	90°, $d=2t$	90°, $d=3t$	180°, $d=2t$	90°, $d=3t$	90°, $d=t$

d = diameter of pin about which the specimen is bent.
t = thickness or diameter of the specimen.

[33] 1,400,000 ÷ tensile strength in lb./in.² or 984 ÷ tensile strength in kg/mm².

[34] Elongation in 8 in. (203.2 mm). A deduction of 0.25 per cent shall be made for every $\frac{1}{32}$ in. (0.79 mm) above ¾ in. (19.1 mm) and 0.5 per cent for every $\frac{1}{32}$ in. (0.79 mm) below $\frac{7}{16}$ in. (11.1 mm).

[35] 1,250,000 ÷ tensile strength in lb./in.² or 879 ÷ tensile strength in kg/mm².

[36] 1,300,000 ÷ tensile strength in lb./in.² or 914 ÷ tensile strength in kg/mm².

[37] 1,125,000 ÷ tensile strength in lb./in.² or 791 ÷ tensile strength in kg/mm².

[38] 1,200,000 ÷ tensile strength in lb./in.² or 843 ÷ tensile strength in kg/mm².

[39] 1,000,000 ÷ tensile strength in lb./in.² or 703 ÷ tensile strength in kg/mm².

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Tensile properties. Metric kg/mm² Yield point.	Tensile properties. Metric kg/mm² Tensile strength.	Tensile properties. English lb./in.² Proportional limit.	Tensile properties. English lb./in.² Yield point.	Tensile properties. English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Thermal properties. Linear coefficient of expansion ×10⁶ (per 1 °C.).	Thermal properties. Casting shrinkage.	Thermal properties. Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Steel: [40]									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Mn, 0.40–0.70; P, max. 0.05; S, max. 0.05; C [41].	Quenched and tempered forgings up to 4 in. (101.6 mm) outside diameter or thickness; 2 in (50.8 mm) max. wall.	....	38.6	....	63.3	55,000	....	90,000	20.5	39.0	....	....	....	....	....	....	(27)
	Quenched and tempered forgings 4–7 in. (101.6–177.7 mm) outside diameter or thickness; 3½ in. (88.8 mm) max. wall.	....	35.1	....	59.7	50,000	....	85,000	20.5	39.0	....	....	....	....	....	....	(27)
	Quenched and tempered forgings 7–10 in. (177.7–254 mm) outside diameter or thickness; 5 in (127 mm) max. wall.	....	35.1	....	59.7	50,000	....	85,000	19.5	37.0	....	....	....	....	....	....	(27)
	Quenched and tempered forgings 10–20 in. (254–508 mm) outside diameter or thickness; 8 in. (203.2 mm) max. wall.	....	33.7	....	58.0	48,000	....	82,500	19.0	36.0	....	....	....	....	....	....	(27)

[40] Shall bend cold through 180° without cracking on the outside of the bent portion. Around a pin 1 in. (25.4 mm) in diameter for material up to 7 in. thick (177.7 mm); around pin 1½ in. (38.1 mm) in diameter for material 7 to 20 in. thick (177.7 to 508 mm).

[41] Carbon content: 0.25–0.60 for material up to 4 in. thick (101.6 mm); 0.35–0.60 for material 4 to 7 in. thick (101.6–177.7 mm); 0.35–0.65 for material 7 to 10 in. thick (177.7–254 mm); 0.35–0.70 for material 10 to 20 in. thick (254–508 mm).

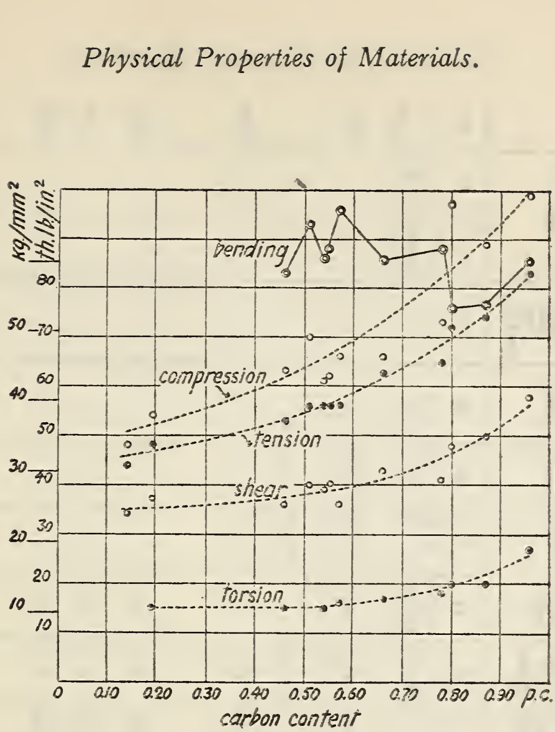

FIG. 26.—*Effect of carbon content on the strength of Bessemer steel.*

Landolt Börnstein Physikalisch-Chemische Tabellen; 1912.

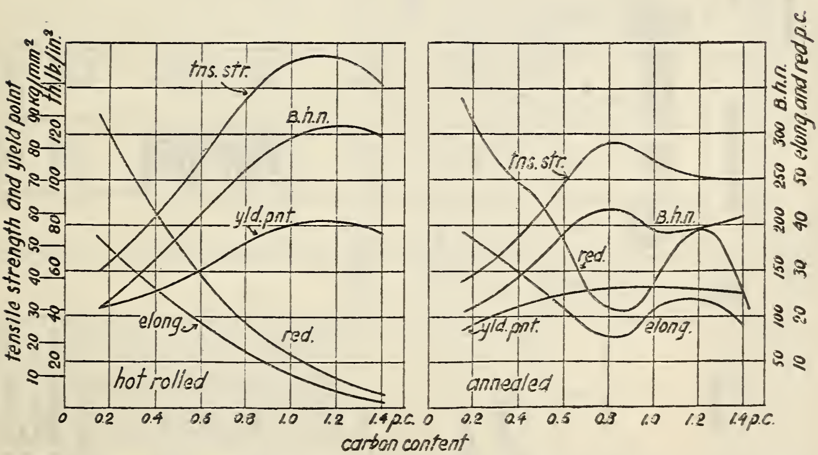

FIG. 27.—*Effect of carbon content on the mechanical properties of hot rolled and annealed steel.*

Johnson, Materials of Construction; 1918.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Metric kg/mm² Yield point.	Metric kg/mm² Tensile strength.	English lb./in.² Proportional limit.	English lb./in.² Yield point.	English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Linear coefficient of expansion ×10⁶ (per 1°C.).	Casting shrinkage.	Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Steel [42]	Hot rolled or forged.																(204)
Steel: [43]																	
P, max. 0.05; S, max. 0.05 (grade F); may contain Ni or other alloying element.	Cast			37.3	59.8		53,000	85,000	22.0	35.0							(205)
P, max. 0.06; S, max. 0.06 (grade E); may contain Ni or other alloying element.	do			31.0	56.2		44,000	80,000	22.0	30.0							(205)
P, max. 0.06; S, max. 0.06 (grade A).	do			min. 0.45 tens. str.	56.2		min. 0.45 tens. str.	80,000	17.0	20.0							(205)
P, max. 0.05; S, max. 0.05 (grade D).	do			min. 0.45 tens. str.	49.2		min. 0.45 tens. str.	70,000	22.0	30.0							(205)
P, max. 0.06; S, max. 0.06 (grade B).	do			min. 0.45 tens. str.	42.2		min. 0.45 tens. str.	60,000	22.0	30.0							(205)
Medium carbon [44]—																	
C, min. 0.30; P, max. 0.04.	Splice bars				47.8			68,000	([45])								(28)
C, min. 0.30; P, max. 0.04.[46]	Quenched track bolts.			49.2	70.3		70,000	100,000	12.0								(29)
Medium carbon [47]	Cast																(63)
P, max. 0.06 (acid); max. 0.05 (basic); S, max. 0.06.[48]	Cast, hard			0.45 tns. str.	56.2		0.45 tns. str.	80,000	15.0	20.0							(30)
	Cast, medium			0.45 tns. str.	49.2		0.45 tns. str.	70,000	18.0	25.0							(30)

	Cast, soft........	....	....	0.45 tns. str.	42.2	....	0.45 tns. str.	60,000	22.0	30.0	....	....	....	....	....	....	(30)
P, max. 0.06; S, max. 0.06 (class A).[49]	Cold-rolled or cold-drawn rods and bars $\frac{1}{4}$–$\frac{1}{2}$ in. (6.35–12.7 mm) diam. or thickness.	....	....	min. 0.75 tns. str.	56.2–77.4	....	min. 0.75 tns. str.	80,000–110,000	12.0	....	....	....	....	....	....	....	(206)
	Cold-rolled or cold-drawn rods and bars over $\frac{1}{2}$ to $1\frac{1}{2}$ in. (12.7–38.1 mm) diam. or thickness.	....	....	min. 0.75 tns. str.	52.8 70.4	....	min. 0.75 tns. str.	75,000–100,000	16.0	....	....	....	....	....	....	....	(206)
	Cold-rolled or cold-drawn rods and bars over $1\frac{1}{2}$ in. (38.1 mm) diam. or thickness.	....	....	min. 0.70 tns. str.	49.2–63.3	....	min. 0.70 tns. str.	70,000–90,000	18.0	....	....	....	....	....	....	....	(206)
P, max. 0.13; S, max. 0.15 (class B).	Cold-rolled or cold-drawn, for automatic screw and bolt machines.	....	....	min. 0.50 tns. str.	49.2	....	min. 0.50 tns. str.	70,000	10.0	....	....	....	....	....	....	....	(206)

[42] NOTE.—

Identification (class).	Carbon.		Manganese.		Phosphorus.	Sulphur.
	Limits.	Desired.	Limits.	Desired.	Not to exceed—	Not to exceed—
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
C 10........	1.05–0.90	0.95	0.50–0.25	0.35	0.025	0.025
C 8........	.90– .75	.80	.50– .25	.35	.025	.025
C 6........	.65– .55	.60	.80– .50	.65	.04	.04
C 5........	.55– .45	.50	.80– .50	.65	.04	.04
C 4........	.45– .35	.40	.80– .50	.65	.04	.04
C 3........	.35– .25	.30	.80– .50	.65	.04	.04
C 2........	.25– .15	.20	.80– .50	.65	.04	.04
C 1........	.15– .05	.10	Not to exceed .60	....	.04	.04

[43] Shall bend cold about a diameter of 1 in. (25.4 mm) through 120° (class B, D, E, and F) and 90° (class A).
[44] Shall bend cold through 180° around a pin, the diameter of which is equal to twice the thickness of the specimen, without cracking on the outside of the bent portion.
[45] 1,600,000÷tensile strength in lb./in.^{2} or 1,123÷tensile strength in kg/mm^2, but in no case under 20 per cent.
[46] Full-size bolts shall bend cold through 45° around a pin, the diameter of which is equal to the diameter of the bolt, without cracking on the outside of the bent portion.
[47] Shearing strength, 42.2 kg/mm^2 (60,000 lb./in.^{2}).
[48] Shall bend cold around a pin 1 in. (25.4 mm) diameter without cracking on the outside of the bent portion; soft castings through 120° and medium castings through 90°.
[49] Class A shall be bent cold through 180° to 3 diameters; class B shall be bent cold through 120° to 3 diameters.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties.								Hardness number.		Thermal properties.				Reference.
			Metric kg/mm²			English lb./in.²			Elongation in 50.8 mm or 2 inches.	Reduction of area.	Brinell.	Scleroscope.	Melting point.	Linear coefficient of expansion ×10⁶ (per 1 °C.).	Casting shrinkage.		
			Proportional limit.	Yield point.	Tensile strength.	Proportional limit.	Yield point.	Tensile strength.									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Steel—Continued. (S. A. E. specif. 1235)[50]—									Per ct.	Per ct.			°C.		mm/m	in./ft.	
C, as required by physical properties; P, max. 0.05; S, max. 0.05.	Cast, hard			min. 25.3	56.2		min. 36,000	min. 80,000	min. 15.0	min. 20.0							(140)
	Cast, medium			min. 22.1	49.2		min. 31,500	min. 70,000	min. 18.0	min. 25.0							(140)
	Cast, soft			min. 19.0	42.2		min. 27,000	min. 60,000	min. 22.0	min. 30.0							(140)
Medium carbon[51]— C, 0.35; Mn, 0.65; S, 0.04; P, 0.032.	Raw stock			38.4	56.8		54,600	80,800	33	62	153	30					(50)
	Quenched in oil at 1,550° F. (843° C.) and drawn at 965° F. (518° C.).			47.8	67.5		68,000	96,000	22	68	194	36					(50)
Steel:[52] C, max. 0.40; Mn, 0.40–0.80; P, max. 0.05; S, max. 0.05.	Cold-rolled axles		42.2		49.2	60,000		70,000	18.0	35.0							(31)
Mn, 0.40–0.70; P, max. 0.05; S, max. 0.05.	Untreated forgings (not over 8 in. (203.2 mm).			0.5 tns. str.	52.7		0.5 tns. str.	75,000	[53] 18.0	[53] 24.0							(32)
	Annealed forgings (not over 8 in. (203.2 mm).			0.5 tns. str.	56.2		0.5 tns. str.	80,000	[54] 20.0	[54] 32.0							(32)
High carbon[55]— C, min. 0.45; P, max. 0.04.	Splice bars				59.7			85,000	14.0								(33)
C, max. 0.60; Mn, max. 0.80; P, max. 0.04.	Quenched splice bars.			45.7	70.3		65,000	100,000	10.0								(34)

C, 0.50–0.70; Mn, max. 0.75; Si, 0.15–0.35; P, max. 0.05; S, max. 0.05.	For tires				73.8			105,000	12.0	16.0							(35)
C, 0.60–0.80; Mn, max. 0.75; Si, 0.15–0.35; P, max. 0.05; S, max. 0.05.	do				81.0			115,000	10.0	14.0							(35)
C, 0.70–0.85; Mn, max. 0.75; Si, 0.15–0.35; P, max. 0.05; S, max. 0.05.	do				88.0			125,000	8.0	12.0							(35)
High carbon [56]— C, 0.93; Mn, 0.35; S, 0.16; P, 0.035.	Raw stock			50.8	79.5		72,200	113,000	20.0	38.0	223	38					(50)
	Quenched at 1,450° F. (788° C.) and drawn at 650° F. (343° C.).			92.8	129.4		132,000	184,000	11.0	33.0	385	60					(50)
Extra high carbon [57]— P, max. 0.04	Splice bars				70.3			100,000	10.0								(36)
Steel [58]																	(101)

[60] The test specimens for soft castings shall bend cold through 120° and for medium castings through 90° around a 1 in. (25.4 mm) diameter pin without cracking on the outside. Hard castings shall not be subjected to bend test.

[61] Used in aviation for propeller hubs, wing plates, strut sockets, and hinges.

[62] Shall bend cold through 180° around a pin 1 in. (25.4 mm) diameter without cracking on the outside of the bent portion.

[63] For forgings 8–12 in. (203.2–304.8 mm), elongation 17.0 and reduction 22.0 per cent.

[64] For forgings 8–12 in. (203.2–304.8 mm), elongation 19.0 and reduction 30.0 per cent; for forgings 12–20 in. (304.8–508 mm), elongation 18.0 and reduction 28.0 per cent.

[65] Shall bend cold through 90° around a pin, the diameter of which is equal to three times the thickness of the specimen, without cracking on the outside of the bent portion.

[66] Used in aviation for tail skid shoes, cable wire, and springs.

[67] Shall bend cold through 60° around a pin, the diameter of which is equal to three times the thickness of the specimen, without cracking on the outside of the bent portion.

[68] Shearing strength: Swedish, crucible steel, C, 0.12–29.2 kg/mm² (41,500 lb./in.²); C, 0.48–45.3 kg/mm² (64,500 lb./in.²); C, 0.71–57.7 kg/mm² (82,000 lb./in.²); C, 0.77–60.0 kg/mm² (85,400 lb./in.²).

TABLE 11.—Tensile Strength of Commercial Steel Music Wire (Hard-Drawn).

[This table represents average values. In sizes finer than shown the values may range from 210.9 to 281.2 kg/mm² (300,000 to 400,000 lb./in.).[2]]

[Experimental data of American Steel and Wire Co., 1923.]

Diameter.		Tensile strength.		Diameter.		Tensile strength.	
mm	in.	kg/mm²	lb./in.²	mm	in.	kg/mm²	lb./in.²
0.74	0.029	253.0	360,000	1.14	0.045	224.8	320,000
.84	.033	246.0	350,000	1.25	.049	217.9	310,000
.94	.037	239.0	340,000	1.40	.055	210.8	300,000
1.04	.041	232.0	330,000	1.60	.063	203.9	290,000

TABLE 12.—Properties of High-Tensile Steel Wire.

[British Engineering Standards Association specifications, March, 1919.]

Diameter.		Minimum breaking load.		Number of bends through 180°.	Diameter.		Minimum breaking load.		Number of bends through 180°.
mm	in.	kg	lb.		mm	in.	kg	lb.	
4.06	0.160	1,634	3,603	3	1.42	0.056	250	552	15
3.66	.144	1,324	2,919	3	1.22	.048	184	405	18
3.25	.128	1,111	2,450	3½	1.02	.040	128	282	21
2.95	.116	967	2,131	4	.91	.036	104	229	22
2.64	.104	777	1,713	5	.81	.032	81.2	179	24
2.34	.092	607	1,339	6	.71	.028	62	137	26
2.03	.080	485	1,070	8	.61	.024	46.3	102	28
1.83	.072	393	866	10	.56	.022	38.1	84	30
1.63	.064	327	721	12					

Note.—A torsion test shall be made on a sample cut from each length of wire. It shall stand before breaking the number of turns given by the formula:

Number of turns=20 turns per length of 100 *d*, where *d* is the diameter of the wire.

Bending test shall be made on a sample cut from each length of wire. The sample shall be bent through 90°, first in one direction then in the other (180° reversal over a radius of 5 mm, 0.197 in.).

TABLE 13.—Tensile Requirements of Steel Wire Rope.

[Federal Board specifications, 1923.]

[The values below are given for uncoated wire; those followed by (g) are for galvanized wire. These values are 10 per cent less than the manufacturer's values; additional 10 per cent were subtracted for galvanized wire. Recommended diameter of drum or sheave, 1 ft. for every ¼ in. (48 cm for every 10 mm) of the diameter of rope. The construction of ropes and the sizes given in this table are those most generally used.]

Construction: Number of strands and wires in a strand.	Number of fiber cores.	Diameter.		Approximate weight.		Minimum breaking strength.							
						Cast steel.		Extra strong cast steel.		Plow steel.		High grade plow steel.	
		mm	in.	kg/m	lb./ft.	kg	lb.	kg	lb.	kg	lb.	kg	lb.
6 by 7	1	9.52	3/8	0.33	0.22	...	...	3,858	8,505(g)	...	...	...	...
	1	12.70	1/2	.58	.39	...	...	6,503	14,337(g)	...	...	...	...
	1	14.28	9/16	.74	.50	...	...	8,083	17,820(g)	...	...	...	...
	1	15.88	5/8	.92	.62	...	...	10,655	23,490(g)	...	...	...	...
	1	19.06	3/4	1.32	.89	...	...	15,431	34,020(g)	...	...	...	...
	1	22.24	7/8	1.79	1.20	...	...	20,575	45,360(g)	...	...	...	...
	1	25.40	1	2.35	1.58	...	...	25,719	56,700(g)	...	...	...	...
6 by 19	1	9.52	3/8	.33	.22	3,919	8,640	4,327	9,540	4,695	10,350	5,443	12,000
								3,896(g)	8,590(g)	4,228(g)	9,320(g)	4,899(g)	10,800(g)
	1	12.70	1/2	.58	.39	6,858	15,120	7,512	16,560	8,165	18,000	9,072	20,000
								6,759(g)	14,900(g)	7,348(g)	16,200(g)	8,165(g)	18,000(g)
	1	15.88	5/8	.92	.62	10,206	22,500	11,431	25,200	12,655	27,900	14,515	32,000
								10,297(g)	22,700(g)	11,385(g)	25,100(g)	13,064(g)	28,800(g)
	1	19.06	3/4	1.32	.89	14,288	31,500	16,493	36,360	18,779	41,400	21,319	47,000
								14,833(g)	32,700(g)	16,896(g)	37,250(g)	19,187(g)	42,300(g)
	1	22.24	7/8	1.79	1.20	18,779	41,400	21,228	46,800	23,678	52,200	28,577	63,000
								19,096(g)	42,100(g)	21,310(g)	46,980(g)	25,719(g)	56,700(g)
	1	25.40	1	2.35	1.58	24,494	54,000	27,760	61,200	31,026	68,400	36,741	81,000
								24,993(g)	55,100(g)	27,923(g)	61,560(g)	33,067(g)	72,900(g)
	1	28.57	1 1/8	2.97	2.00	31,026	68,400	35,108	77,400	38,374	84,600	45,723	100,800
								31,570(g)	69,600(g)	34,537(g)	76,140(g)	41,141(g)	90,700(g)
	1	31.74	1 1/4	3.64	2.45	38,374	84,600	43,273	95,400	47,356	104,400	56,337	124,200
								38,919(g)	85,800(g)	42,620(g)	93,960(g)	50,712(g)	111,800(g)
	1	34.92	1 3/8	4.46	3.00	45,723	100,800	52,254	115,200	58,786	129,600	68,584	151,200
								47,038(g)	103,700(g)	52,889(g)	116,600(g)	61,735(g)	136,100(g)
	1	38.10	1 1/2	5.28	3.55	52,254	115,200	59,603	131,400	66,951	147,600	80,015	176,400
								53,615(g)	118,200(g)	60,238(g)	132,800(g)	72,031(g)	158,800(g)
6 by 37	1	9.52	3/8	.33	.22	...	...	3,797	8,370	...	...	4,327	9,540
								3,416(g)	7,530(g)			3,896(g)	8,590(g)
	1	12.70	1/2	.58	.39	...	...	6,736	14,850	...	...	7,961	17,550
								6,065(g)	13,370(g)			7,167(g)	15,800(g)
	1	15.88	5/8	.92	.62	...	...	10,279	22,680	...	...	13,064	28,800
								9,258(g)	20,410(g)			11,748(g)	25,900(g)
	1	19.06	3/4	1.32	.89	...	...	15,513	34,200	...	...	18,779	41,400
								13,971(g)	30,800(g)			16,874(g)	37,200(g)
	1	22.24	7/8	1.79	1.20	...	...	20,412	45,000	...	...	23,678	52,200
								18,371(g)	40,500(g)			21,319(g)	47,000(g)
	1	25.40	1	2.35	1.58	...	...	26,127	57,600	...	...	30,210	66,600
								23,043(g)	50,800(g)			27,170(g)	59,900(g)

TABLE 13.—Tensile Requirements of Steel Wire Rope—Continued.

Construction: Number of strands and wires in a strand.	Number of fiber cores.	Diameter.		Approximate weight.		Minimum breaking strength.							
						Cast steel.		Extra strong cast steel.		Plow steel.		High grade plow steel.	
		mm	in.	kg/m	lb./ft.	kg	lb.	kg	lb.	kg	lb.	kg	lb.
8 by 19	1	9.52	$\frac{3}{8}$	.30	.20	3,434	7,570	3,806	8,390				
	1	12.70	$\frac{1}{2}$	.52	.35	5,960	13,140	6,532	14,400				
	1	15.88	$\frac{5}{8}$	.83	.56	8,900	19,620	10,070	22,200				
	1	19.06	$\frac{3}{4}$	1.19	.80	12,497	27,550	14,370	31,680				
	1	22.24	$\frac{7}{8}$	1.61	1.08	16,329	36,000	18,779	41,400				
	1	25.40	1	2.11	1.42	21,228	46,800	24,249	53,460				

Modulus of elasticity of wire rope: American Steel and Wire Co. gives for new 6-strand rope maximum 12,000,000 lb./in.^{2} (8,430 kg/mm^2). According to A. W. Brown, 11,180,000 lb./in.^{2} (7,860 kg/mm^2) is a good average for rope after it has been in use long enough for strands to bed into the core. For the old rope he gives 19,000,000 lb./in.^{2} (13,360 kg/mm^2). Various authorities give for the modulus of elasticity of wire rope 35 per cent that for steel wire; that is, 10,150,000 lb./in.^{2} (7,130 kg/mm^2).

TABLE 14.—Tensile Strength of Steel Wire Rope.[1]

[Experimental results of the Bureau of Standards.]

Description and analysis.	Diameter.		Tensile strength.		Tensile strength (net area).	
	mm	in.	kg	lb.	kg/mm²	lb./in.²
Plow steel, 6 strands, 19 wires: C, 0.90; S, 0.034; P, 0.024; Mn, 0.48; Si, 0.172	50.8	2	137,900	304,000	129.5	184,200
Plow steel, 6 strands, 25 wires: C, 0.77; S, 0.036; P, 0.027; Mn, 0.46; Si, 0.152	69.9	2¾	314,800	694,000	151.2	214,900
Plow steel, 6 strands, 37 wires plus 6 strands, 19 wires: C, 0.58; S, 0.032; P, 0.033; Mn, 0.41; Si, 0.160	82.6	3¼	392,800	866,000	132.2	187,900
Monitor plow steel, 6 strands, 61 wires, plus 6 strands, 19 wires: C, 0.82; S, 0.025; P, 0.019; Mn, 0.23; Si, 0.169	82.6	3¼	425,000	937,000	142.5	202,400

[1] For additional data on strength and other properties of wire rope, see B. S. Tech. Paper No. 121, by Griffith and Bragg, giving results of 275 tensile tests of wire-rope specimens ranging in diameter from ¼ in. (6.35 mm) to 3¼ in. (82.5 mm) and comprising five of the more common classes used in engineering practice.

Note.—Recommended allowable working load for a wire rope running over a sheave is equal to one-fifth of specified minimum strength.

XI. ALLOY STEELS.[1]

1. CARBON STEEL.

Contains maximum C, 1.50 per cent; Mn, 1.00 per cent; Si, 0.35 per cent; P, 0.05 per cent; and S, 0.05 per cent.

2. MANGANESE STEEL.

Contains usually from 10 to 13 per cent of Mn and 1.0 per cent C. Practically nonmagnetic. Has a peculiar hardness, to which it owes its remarkable resistance to abrasion; extremely difficult to machine; has high strength and toughness,[2] but relatively low elastic limit; has a peculiar property of being toughened and softened by quenching in water, resembling copper in this respect. Principal applications—in castings for crushing and grinding machinery and for railroad crossings.

3. SILICON STEEL.

There are two types of silicon steel, one of which has found application in mechanical engineering. This steel, frequently called silico-manganese steel, has usually the following composition: C, 0.45–0.65; Si, 1.50–2.00; and Mn, 0.50–0.80. It is very brittle in the direction at right angle to rolling.[3] Application—used for automobile springs and gears. The other type of silicon steel contains 3–5 per cent silicon; it is low in carbon and manganese; used for electrical transformer sheets on account of high permeability to magnetism; structurally weak and has no constructional value.

[1] (Definition, properties, and uses of alloy steels, as described below, are after G. Norris, Chem. and Met. Eng., 13, p. 739; 1915.

[2] In cast or rolled form the steel is glassy brittle, but by reheating to a temperature between 1,000 and 1,100° C. (1,832 to 2,012° F.) and quenching in water the ductility and toughness are wonderfully improved. (Johnson's Materials of Construction, p. 678; 1918.)

[3] According to Bullens, silicon manganese steels are quite difficult to heat treat successfully.

4. NICKEL STEEL.

Of all nickel steels by far the most important is low and medium carbon steel with 3–4 per cent Ni (called usually 3½ per cent nickel steel). The presence of manganese in that steel is very essential, and should range from 0.50 to 0.80 per cent. It is a good, all-round engineering steel, with considerably higher elastic limit and tensile strength than corresponding carbon steel and with the same degree of ductility.[4] Low carbon (0.10–0.20) nickel steel is used extensively for case hardening parts. Nickel steel with carbon 0.20–0.35 is much used for bridge construction. Nickel steel rolls and forges readily and machines easily. Drop forging of nickel steels is falling off in favor of other alloy steels.

5. CHROMIUM STEEL.

Contains about 1 per cent carbon and 1 per cent chromium; has high mineralogical hardness. This steel is not in general use but is confined to a few specialties, as ball and ball races, burglar-proof safes, and bars in jails. Low and medium carbon types are not used to any great extent, other alloy steels being superior. It is liable to crack and check in heat treatment.

6. NICKEL-CHROMIUM STEEL.

Addition of chromium to nickel steel increases greatly the strength and resistance to shock and mineralogical hardness. It is more difficult to forge and heat treat and harder to machine than nickel steel; is liable to seaminess. Steel containing 0.25–0.40 C, 1.50 Cr, and 3.5 Ni[5] is used for armor plates and projectiles. Steel with 0.10–0.45 C, 1.0 Cr, and 2.0 Ni is largely used for automobile forgings. This steel has high tensile strength, great hardness, and good shock and fatigue resistance. Steel with 0.10–0.45 C, 0.50 Cr, and 1.50 Ni is used for automobile forgings and is excellent case hardening steel. It is somewhat lower in tensile strength than the other two types.[6]

7. VANADIUM STEEL.

Addition of vanadium (generally under 0.25 per cent) to carbon steel increases considerably (about 30 per cent) the elastic limit and tensile strength without affecting materially the ductility. To an even greater extent it increases the resistance to shock and fatigue. Vanadium steel generally used is a chrome-vanadium steel of the following composition: C, 0.10–0.55; Mn, 0.50–0.80; Cr, 0.80–1.00; V, over 0.15 per cent. 0.10–0.20 C steel is used mainly for case hardening and is the best for this

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[4] Nickel steels have higher resistance to impact than carbon steels. (W. Hatt, Trans. Am. Soc. Civ. Eng., **63**, p. 307.)

[5] Bullens says that the most effective ratio of Ni to Cr is 2½ to 1.

[6] Comparing with chromium steels of equal strength, nickel chromium steels are tougher, more ductile, and less liable to injury through overheating. (Johnson's Materials of Construction, p. 684; 1918.)

purpose; 0.25–0.35 C steel is used for automobile forgings of all kinds; 0.35–0.45 C steel is used for crank shafts, locomotive axles, crank pins, connecting rods, piston rods, automobile transmissions, and rear axle shafts; 0.45–0.55 C steel is extensively used for locomotive and automobile springs and gives remarkable resilience and endurance.

Vanadium steels have a wider heat treatment range than other steels. Cr–V steel forges and machines better than Ni–Cr steel; it is not as liable to injury in forging or heat treatment and is free from seaminess. Vanadium steel is as easily worked as carbon steel. While Ni and Cr interfere seriously with the welding quality of steel, vanadium improves this quality.

8. TUNGSTEN STEEL.

Principally used for tools, magnets, magnetos, and hack saws. Tungsten steels are seldom used in engineering construction.

9. COMPLEX ALLOY STEELS.

The only steel of importance in this class is high-speed steel which contains W, Cr, V, and Co.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Metric kg/mm² Yield point.	Metric kg/mm² Tensile strength.	English lb./in.² Proportional limit.	English lb./in.² Yield point.	English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Linear coefficient of expansion ×10⁶ (per 1°C.)	Casting shrinkage.	Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Chromium: Molybdenum steel—									Per ct.	Per ct.			°C.		mm/m	in./ft.	
C, 0.30; Cr, 0.70; Mo,0.35.	Drawn at 843° C. (1,550° F.).[1]	....	100.1	....	113.14	156,625	....	160,925	18.0	62.2	....	....	....	....	....	....	(11)
	Drawn at 871° C. (1,600° F.).[1]	....	105.4	....	109.6	149,925	....	155,850	17.5	60.2	....	....	....	....	....	....	(11)
	Drawn at 899° C. (1,650° F.).[1]	....	102.5	....	109.9	145,775	....	156,375	17.0	60.2	....	....	....	....	....	....	(11)
	Drawn at 927° C. (1,700° F.).[1]	....	99.5	....	107.9	141,570	....	153,450	17.0	60.1	....	....	....	....	....	....	(11)
	Drawn at 955° C. (1,750° F.).[1]	....	100.3	....	108.5	142,500	....	154,350	18.0	60.0	....	....	....	....	....	....	(11)
	Drawn at 982° C. (1,800° F.).[1]	....	101.2	....	108.9	144,000	....	154,900	17.5	59.0	....	....	....	....	....	....	(11)
C, 0.40; Cr, 1.00; Mo,0.35.	As rolled, 1 in. (25.4 mm), round.	....	73.8	....	98.4	105,000	....	140,000	15.0	32.0	....	....	....	....	....	....	(11)
Molybdenum vanadium steel—																	
C, 0.38; Mn, 0.60; Cr,1.00; V, 0.18; Mo, 0.80.	Drawn at 600° F. (316° C.).[2]	....	152.6	....	170.8	217,000	....	243,000	9.0	38.2	....	....	....	....	....	....	(51)
	Drawn at 800° F. (427° C.).[2]	....	145.5	....	158.2	207,000	....	225,000	10.8	45.4	....	....	....	....	....	....	(51)
	Drawn at 1,000° F. (538° C.).[2]	....	138.5	....	147.6	197,000	....	210,000	14.0	52.5	....	....	....	....	....	....	(51)
	Drawn at 1,200° F. (649° C.).[2]	....	122.3	....	130.8	174,000	....	186,000	18.2	59.7	....	....	....	....	....	....	(51)
C, 0.51; Si, 0.15; Mn, 0.75; Mo, 1.45; Cr,1.08; V, 0.16.	Quenched in oil at 850° C. (1,562° F.); drawn at 205° C. (401° F.) for one hour.	....	73.8	147.5	166.7	105,000	209,900	237,200	2.3	4.1	540	71	....	....	....	....	(176)

[1] Quenching medium, water, ¾ in. (19.1 mm) round bar.
[2] ⅞ in. (22.2 mm) rounds, quenched in oil from 1,600° F. (871° C.).

TABLE 15.—Effect of Heat Treatment on Properties of High Chromium Steels.

[L. Aitchison, Engineering, December 2 and 9, 1921.]

Chemical composition.	Heat treatment.	Tempering temperature.		Yield point.		Tensile strength.		Elongation.	Reduction of area.	Notched bar test.	
		°C.	°F.	kg/mm²	lb./in.²	kg/mm²	lb./in.²	Per cent.	Per cent.	kgm	ft.-lb.
C, 0.45; Mn, 0.72; Si, 0.12; Cr, 1.28	Quenched in oil from 860° C. (1,580° F.).	600	1,112	92.1	131,000	102.0	145,000	20.0	54.1	2.8	21
		650	1,202	78.7	112,000	91.4	130,000	23.0	60.8	3.8	42
		700	1,292	68.2	97,000	82.3	117,000	26.0	63.7	12.2	88
		750	1,382	50.6	72,000	73.8	105,000	30.5	69.8	13.3	96
C, 0.37; Mn, 0.48; Si, 0.11; Cr, 2.8	Quenched in oil from 830° C. (1,526° F.).	600	1,112	88.6	126,000	97.1	138,000	20.0	60.4	3.9	28
		650	1,202	74.5	106,000	85.8	122,000	24.0	62.6	12.7	92
		700	1,292	64.6	92,000	78.0	111,000	25.0	67.8	13.5	98
		750	1,382	59.1	84,000	69.3	98,500	29.0	70.8	15.3	111
C, 0.34; Mn, 0.43; Cr, 5.09	Quenched in oil from 850° C. (1,562° F.).	700	1,292	51.3	73,000	70.3	100,000	14.7	57.3	9.3	67
C, 0.44; Mn, 0.33; Si, 0.19; Cr, 6.0	do	500	932	130.1	185,000	144.8	206,000	10.0	30.5		
		600	1,112	77.3	110,000	92.1	131,000	18.2	49.7	2.1	15
		700	1,292	55.5	79,000	76.6	109,000	23.0	60.4	10.4	75
C, 0.44; Si, 0.24; Cr, 9.6	Quenched in oil from 875° C. (1,607° F.).	500	932	132.9	189,000	149.0	212,000	9.0	24.8		
		600	1,112	73.1	104,000	89.3	127,000	17.8	50.1	4.0	29
		700	1,292	52.7	75,000	72.1	103,000	22.0	56.9	11.3	82
C, 0.37; Mn, 0.15; Si, 0.19; Cr, 12.0; Ni, 0.55	Quenched in oil from 900° C. (1,652° F.).	500	932			165.2	235,000	8.6	24.0	1.1	8
		600	1,112	90.0	128,000	101.2	144,000	14.8	41.8	2.1	15
		700	1,292	73.8	105,000	85.1	121,000	21.0	52.2	4.1	30
C, 0.47; Mn, 0.64; Si, 0.24; Cr, 16.07	Quenched in oil from 875° C. (1,607° F.).	500	932	106.2	151,000	132.9	189,000	4.0	5.1		
		600	1,112	69.6	99,000	92.8	132,000	13.5	37.6	5.1	37
		700	1,292	45.7	65,000	71.0	101,000	20.0	40.5	9.7	70
		750	1,382	49.9	71,000	74.5	106,000	23.0	49.7	8.0	58
C, 0.07; Mn, 0.12; Si, 0.08; Cr, 11.7; Ni, 0.57 (iron).	Quenched in oil from 930° C. (1,706° F.).			105.5	150,000	115.3	164,000	13.5	41.9	3.9	28
		200	392	107.6	153,000	115.3	164,000	12.0	37.8	4.6	33
		300	572	108.3	154,000	113.9	162,000	12.5	36.4	5.4	39
		400	752	108.3	154,000	113.9	162,000	15.5	51.0	5.4	39
		500	932	92.8	132,000	113.9	162,000	18.0	52.2	5.0	36
		600	1,112	59.7	85,000	77.3	110,000	20.0	59.3	3.9	28
		700	1,292	48.5	69,000	64.0	91,000	26.5	65.8	10.9	79
		750	1,382	43.6	62,500	57.6	82,000	31.0	68.8	12.0	87
		800	1,472	52.7	75,000	84.4	120,000	13.5	44.6	7.1	51
C, 0.07; Mn, 0.29; Si, 0.32; Cr, 13.3; Ni, 0.40 (iron).	do			92.8	132,000	109.7	156,000	18.5	51.0	1.7	12
		500	932	88.6	126,000	106.9	152,000	21.5	61.5	1.7	12
		600	1,112	55.5	79,000	71.7	102,000	25.5	71.8	12.7	92
		750	1,382	57.7	82,000	60.5	86,000	34.0	68.8	15.2	110
C, 0.15; Mn, 0.16; Si, 0.09; Cr, 11.8; Ni, 0.77.	do	500	932			141.3	201,000	10.0	36.0	2.2	16
		600	1,112	66.1	94,000	88.6	126,000	20.0	52.2	4.8	35
		700	1,292	59.8	85,000	73.8	105,000	26.0	58.1	8.3	60
		750	1,382	49.2	70,000	68.9	98,000	28.0	61.5	9.4	68
C, 1.01; Mn, 0.28; Si, 0.06; Cr, 11.8	Quenched in air from 900° C. (1,652° F.).	650	1,202	72.4	103,000	93.5	133,000	19.0	40.6	1.7	12
		700	1,292	70.3	100,000	83.7	119,000	21.0	55.9	2.8	20
		750	1,382	57.6	82,000	78.8	112,000	24.0	47.2	3.2	23

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Metric kg/mm² Yield point.	Metric kg/mm² Tensile strength.	English lb./in.² Proportional limit.	English lb./in.² Yield point.	English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Linear coefficient of expansion $\times 10^6$ (per 1°C.)	Casting shrinkage.		Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Steel:																	
Stainless[1]—									Per ct.	Per ct.			°C.		mm/m	in./ft.	
C, 0.10 (stainless iron).[2]					[8] 47.2–110.4			[8] 67,200–157,000									(66)
C, 0.10–0.20 (mild stainless steel).[4]					[8] 63.0–126.0			[8] 89,600–179,200									(66)
C, 0.20–0.30 (medium stainless steel).[5]					[8] 71.0–142.0			[8] 101,000–202,000									(66)
C, 0.30–0.40 (stainless steel).[6]					[8] 78.8–174.0			[8] 112,000–247,000									(66)
C, over 0.50 (hard stainless steel).[7]																	(66)
C, 0.24; Mn, 0.36; S, 0.013; P, 0.02; Cr, 10.44; V, 0.30 (see fig. 28).																	(52)
Chrome:																	
Nickel steel—																	
C, 0.30; Si, 0.19; Mn, 0.51; S, 0.029; P, 0.042; Ni, 1.79; Cr, 0.61.	Raw stock			76.5	85.8		108,800	122,000	13.0	56.0	255	40					(52)
Nickel molybdenum steel[8]—																	
C, 0.44; Mn, 0.42; Cr, 0.99; Ni, 2.04; Mo, 0.36.	Drawn at 400° F. (204° C.).[9]		212.3		236.6	302,000		336,600	10.0	22.4							(51)
	Drawn at 600° F. (316° C.).[9]		169.4		193.3	241,000		275,000	11.3	43.0							(51)
	Drawn at 800° F. (427° C.).[9]		154.7		168.7	220,000		240,000	12.0	46.0							(51)
	Drawn at 1,000° F. (538° C.).[9]		130.1		143.5	185,000		204,000	15.0	51.0							(51)
	Drawn at 1,200° F. (649° C.).[9]		94.2		106.9	134,000		152,000	20.5	61.0							(51)

Vanadium steel—C, 0.35; Mn, 0.78; S, 0.027; P, 0.025; Cr, 0.94; V, 0.17.	Raw stock	...	...	60.0	96.1	...	85,200	136,700	15.6	45.5	302	42	...	...	...	...	(52)
C, 0.72; Cr, 0.49; V, 0.145.[10]	do	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	(78)
Cobalt: Steel—																	
C, 0.16; Si, 0.61; S, 0.10; P, 0.07; Mn, 1.04; Co, 0.53.	Unannealed bars	...	42.5	...	59.8	60,500	...	85,100	29.0	43.0	...	...	...	...	...	...	(80)
	Annealed bars	...	34.6	...	48.8	49,200	...	69,400	34.0	47.0	...	...	...	...	...	...	(80)
C, 0.25; Si, 0.64; S, 0.11; P, 0.07; Mn, 1.04; Co, 1.80.	Unannealed bars	...	39.4	...	64.5	56,000	...	91,800	19.0	24.0	...	...	...	...	...	...	(80)
	Annealed bars	...	36.2	...	55.1	51,500	...	78,400	29.0	39.0	...	...	...	...	...	...	(80)
C, 0.38; Si, 1.21; S, 0.14; P, 0.07; Mn, 0.65; Co, 2.50.	Unannealed bars	...	59.8	...	81.8	85,100	...	116,400	15.0	15.0	...	...	...	...	...	...	(80)
	Annealed bars	...	42.6	...	67.8	60,500	...	96,400	14.0	24.0	...	...	...	...	...	...	(80)
C, 0.55; Si, 0.69; S, 0.11; P, 0.06; Mn, 0.79; Co, 4.50.	Unannealed bars	...	58.3	...	89.8	82,900	...	127,700	15.0	17.0	...	...	...	...	...	...	(80)
	Annealed bars	...	39.4	...	72.4	56,000	...	103,000	19.0	22.0	...	...	...	...	...	...	(80)
C, 0.52; Si, 0.75; S, 0.14; P, 0.06; Mn, 0.79; Co, 6.90.	Unannealed bars	...	...	...	86.6	...	...	123,200	13.0	13.0	...	...	...	...	...	...	(80)
	Annealed bars	...	47.3	...	69.3	67,200	...	98,600	22.0	25.0	...	...	...	...	...	...	(80)

[1] Typical analyses of stainless steels:

Chemical component.	Stainless iron.	Mild stainless steel.	Stainless steel.
C	0.07	0.15	0.37
Si	.08	.09	.19
Mn	.12	.16	.15
Cr	11.7	11.8	12.0
Ni	.57	.77	.55

With the increase of carbon content the forging becomes more and more difficult. Four to six times as much work may be done on stainless iron as on ordinary stainless steel. Between 900 and 1,150° C. (1,652 to 2,102° F.) the material can be forged with rapid blows. Below 850° C. (1,562° F.) the deformation becomes difficult. Important quality.—immune from rusting if the surface is not distorted by rough cut. On harder varieties rash grinding may produce soft spots, which may stain or crack; most resistant to corrosion when in hardened condition. Nitric acid, cold, and boiling, does not appreciably attack stainless steel. It is corroded in sea water when in contact with copper; retains considerable hardness and strength at high temperatures; tensile strength at 700° C. (1,292° F.) 33,600 lb./in.^{2} or 23.7 kg/mm.^{2} Loss of weight by scaling at high temperatures is considerably lower than for any other steel.

[2] Easy to forge, machine, and work cold.

[3] According to heat treatment.

[4] Easily forged by power hammer; can be hardened; used for cutting tools for soft materials.

[5] Can be forged by power hammer; is hardened if allowed to cool in the air; suitable for sharp and durable cutting tools, and for hard wearing surfaces.

[6] Forging qualities, etc., as for medium stainless steel.

[7] Difficult to forge; possesses great strength at high temperatures; stains more easily than milder varieties.

[8] Chrome-molybdenum (C, about 0.35; Cr, about 0.80; and Mo, about 0.25) steel compared with other alloy steels which are in the same category from a commercial standpoint and which are treated to the same tensile strength shows: (1) A slightly higher elastic limit; (2) a higher elongation, hence greater ductility; and (3) a much higher reduction of area, hence greater toughness. For constant tensile strength and nearly constant elastic limit molybdenum steel shows increase of elongation and of reduction of area with increase in molybdenum up to 1.0 per cent.

[9] ⅞ in. (22.2 mm) rounds quenched in oil from 1,450° F. (788° C.).

[10] Modulus of rupture in torsion 97.0 kg/mm^2 (138,000 lb./in.^{2}); modulus of rupture in torsion (annealed) 68.8 kg/mm^2 (98,000 lb./in.^{2}).

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm^2			English lb./in.^{2}			Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number.		Thermal properties.				Reference.
			Proportional limit.	Yield point.	Tensile strength.	Proportional limit.	Yield point.	Tensile strength.			Brinell.	Scleroscope.	Melting point.	Linear coefficient of expansion ×10^6 (per 1 °C.).	Casting shrinkage.		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Cobalt—Contd.																	
Steel—Contd.									Per ct.	Per ct.			°C.		mm/m	in./ft.	
C,0.64; Co,2.68.	As received from forge.			46.0	76.2		65,400	108,300	17.5	26.7							(80)
C,0.62; Co,5.50.	....do			52.0	76.9		73,900	109,300	22.5	42.5							(80)
C, 0.84; Co, 11.18.	....do			51.3	102.3		73,000	145,500	11.5	21.5							(80)
C, 0.93; Co, 16.97.	....do			59.9	118.6		85,100	168,600	9.5	12.7							(80)
Molybdenum:																	
Steel—																	
C, 0.05; Si, 0.018; Mn, 0.06; Mo, 0.31.[11]	Cast, unannealed		17.3		28.4	24,600		40,300	11	29	124						(81)
C, 0.06; Si,0.05; Mn,0.01; Mo, 0.52.[12]	....do		17.3		34.7	24,600		49,300	12	21	95						(81)
	Cast, annealed at 800° C. (1,472° F.).		17.3		36.2	24,600		51,500	25	34	87						(81)
	Forged, unannealed.		31.5		33.0	44,800		47,000			126						(81)
	Forged, annealed at 800° C. (1,472° F.).		20.5		30.0	29,100		42,600			90						(81)
C, 0.11; Mo, 0.94.[13]	Cast, unannealed.		36.2		45.7	51,500		65,000	6	14	160						(81)
	Cast, annealed at 800° C. (1,472° F.).		30.0		44.1	42,600		62,700	8	20	126						(81)
	Forged, unannealed.		53.5		63.0	76,100		89,600									(81)
	Forged, annealed at 800° C. (1,472° F.).		33.0		42.5	47,000		60,400			127						(81)
C,0.13; Si,0.08; Mn,0.02; Mo, 1.78.[14]	Cast, unannealed.		31.5		45.7	44,800		65,000	2	4	194						(81)
	Cast, annealed at 800° C. (1,472° F.).		26.8		36.2	38,100		51,500	5	11	131						(81)

	Forged, unannealed.	....	42.5	....	47.2	60,400	....	67,200	24	59	179	....	....	....	....	....	(81)
	Forged, annealed at 800° C. (1,472° F.).	....	47.2	....	53.5	67,200	....	76,100	30	62	121	....	....	....	....	....	(81)
C, 0.32; Si, 0.01; Mn, 0.03; Mo, 7.55.[16]	Cast, unannealed.	....	47.3	....	69.3	67,200	....	98,500	2	3	248	....	....	....	....	....	(81)
	Cast, annealed at 800° C. (1,472° F.).	....	42.5	....	67.8	60,500	....	96,400	5	5	196	....	....	....	....	....	(81)
	Forged, unannealed.	....	55.1	....	78.8	78,400	....	112,000	19	44	188	....	....	....	....	....	(81)
	Forged, annealed at 800° C. (1,472° F.).	....	45.6	....	74.0	64,900	....	105,200	21	42	192	....	....	....	....	....	(81)
C, 0.44; Si, 0.028; Mn, 0.05; Mo, 11.74.[16]	Cast, unannealed.	....	31.5	....	53.5	44,800	....	76,100	1	2	188	....	....	....	....	....	(81)
	Cast, annealed at 800° C. (1,472° F.).	....	29.9	....	53.6	42,600	....	76,200	2	2	212	....	....	....	....	....	(81)
	Forged, unannealed.	....	58.2	....	85.1	82,800	....	121,000	15	21	212	....	....	....	....	....	(81)
	Forged, annealed at 800° C. (1,472° F.).	....	56.7	....	83.4	80,700	....	118,700	15	29	223	....	....	....	....	....	(81)
C, 0.92; Si, 0.03; Mn, 0.06; Mo, 17.40.[17]	Cast, annealed at 800° C. (1,472° F.).	....	....	....	53.6	....	....	76,200	Nil.	Nil.	300	....	....	....	....	....	(81)
C, 0.08; Si, 0.05; Mn, 0.09; Mo, 18.70.[18]	Cast, unannealed.	....	....	....	36.2	....	....	51,500	Nil.	Nil.	306	....	....	....	....	....	(81)
	Cast, annealed...	....	....	....	36.2	....	....	51,500	Nil.	Nil.	306	....	....	....	....	....	(81)
	Forged unannealed.	....	59.9	....	91.4	85,100	....	130,000	2	2	275	....	....	....	....	....	(81)
	Forged, annealed at 800° C. (1,472° F.).	....	52.0	....	85.1	73,900	....	121,000	1	1	364	....	....	....	....	....	(81)
C, 0.10; Si, 0.08; Mn, 0.08; Mo, 23.75.[11, 19]	Cast, unannealed	....	....	....	34.7	....	....	49,300	Nil.	1	280	....	....	....	....	....	(81)
	Cast, annealed at 800° C. (1,472° F.).	....	....	....	18.9	....	....	26,900	Nil.	Nil.	280	....	....	....	....	....	(81)

[11] Would not forge.
[17] Would not forge. Cast unannealed; too hard to machine.

Impact Values of Molybdenum Steels.

Footnote indicating the steel.	Cast unannealed.		Cast annealed at 800° C. (1,472° F.).		Forged unannealed.		Forged annealed at 800° C. (1,472° F.).		Footnote indicating the steel.	Cast unannealed.		Cast annealed at 800° C. (1,472° F.).		Forged unannealed.		Forged annealed at 800° C. (1,472° F.).	
	kgm	ft.-lb.	kgm	ft.-lb.	kgm	ft.-lb.	kgm	ft.-lb.		kgm	ft.-lb.	kgm	ft.-lb.	kgm	ft.-lb.	kgm	ft.-lb.
(11)........	1.0	7.2	....	....	....	....	....	....	(16)........	Nil.	Nil.	1.0	7.2	4.0	28.9	3.5	25.3
(12)........	.5	3.6	1.0	7.2	0.5	3.6	2.0	14.5	(17)........	....	....	Nil.	Nil.	....	....	....	....
(13)........	2.0	14.5	1.0	7.2	....	....	3.0	21.7	(18)........	Nil.	Nil.	1.0	7.2	2.0	14.4	.5	3.6
(14)........	1.0	7.2	1.0	7.2	4.0	28.9	14.0	101.3	(19)........	1.0	7.2	.5	3.6	....	....	....	....
(15)........	2.0	14.5	.5	3.6	5.0	36.2	7.5	54.3									

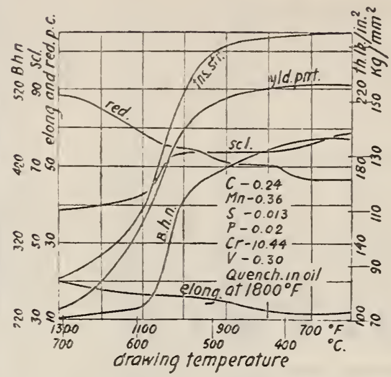

FIG. 28.—*Effect of drawing temperature on the tensile properties of stainless steel.*

F. Grotts, Chem. ann Met. Eng. **19**; 1918.

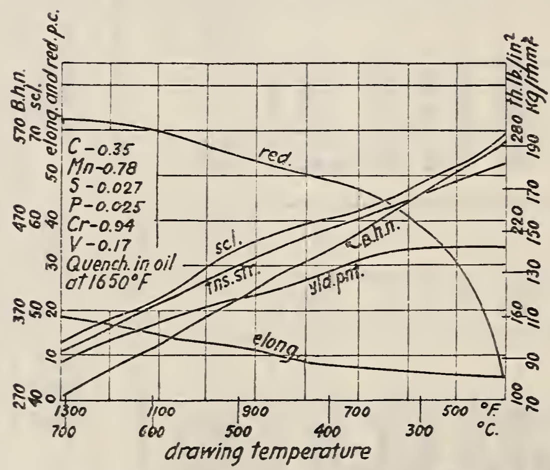

FIG. 29.—*Effect of drawing temperature on the tensile properties of chrome-vanadium steel.*

F. Grotts, Chem. and Met. Eng. **19**; 1918.

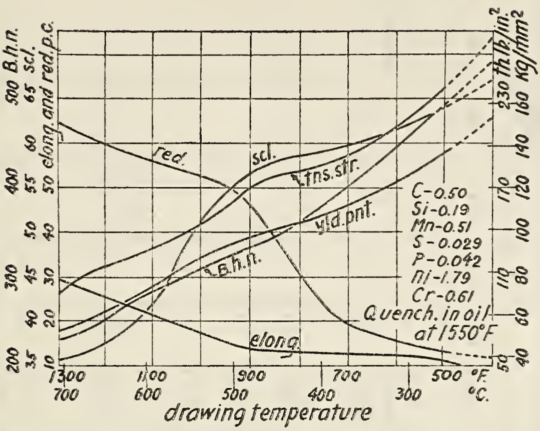

FIG. 30.—*Effect of drawing temperature on the tensile properties of chrome-nickel steel.*

F. Grotts, Chem. and Met. Eng. 19; 1918.

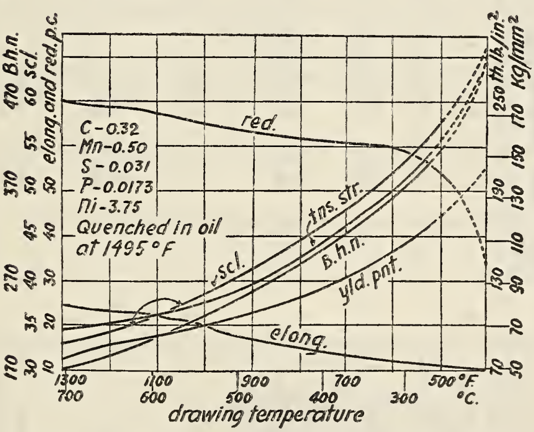

FIG. 31.—*Effect of drawing temperature on the tensile properties of nickel steel.*

F. Grotts, Chem. and Met. Eng., 19; 1918.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Tensile properties. Metric kg/mm² Yield point.	Tensile properties. Metric kg/mm² Tensile strength.	Tensile properties. English lb./in.² Proportional limit.	Tensile properties. English lb./in.² Yield point.	Tensile properties. English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Thermal properties. Linear coefficient of expansion ×10⁶ (per 1 °C.).	Thermal properties. Casting shrinkage.		Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Molybdenum—Continued.																	
Steel—Continued.									Per ct.	Per ct.			°C.		mm/m	in./ft.	
C, 0.78; Si, 0.078; Mn, 0.25; P, 0.018; S, 0.026; Mo, 2.43; Al, under 0.01.	Annealed			39.8	72.1		56,500	102,500	15.6	29.1							(82)
C, 0.75; Si, 0.066; Mn, 0.24; P, 0.017; S, 0.031; Mo, 4.95; Al, under 0.01.	do			60.3	77.7		85,600	110,400	11.6	19.9							(82)
C, 0.71; Si, 0.071; Mn, 0.23; P, 0.016; S, 0.036; Mo, 10.15; Al, under 0.01.	do			61.2	77.6		87,000	110,200	11.6	23.5							(82)
C, 0.79; Si, 0.084; Mn, 0.22; P, 0.016; S, 0.042; Mo, 15.46; Al, under 0.01.	do			64.6	87.0		91,800	123,800	14.5	24.9							(82)
C, 0.82; Si, 0.098; Mn, 0.21; P, 0.017; S, 0.046; Mo, 20.70; Al, under 0.01.	do			62.5	84.8		88,800	120,400	13.6	19.3							(82)
Nickel-molybdenum steel:																	
C, 0.40; Ni, 1.50; Mo, 0.40.	As rolled, 1 in. (25.4 mm), round.		65.4		84.4	93,000		120,000	18.0	39.0							(11)
Nickel steel:																	
Structural—																	
C, max. 0.30; Mn, max.	For rivets			31.6	49.2–56.3		45,000	70,000–80,000	(21)	40.0							(37)

0.60; P, max.: acid, 0.04; basic, 0.03; S, max. 0.045; Ni, min. 3.25.[20]																	
C, max. 0.45; Mn, max. 0.70; P, max.: acid, 0.05; basic, 0.04; S, max. 0.05; Ni, min. 3.25.[22]	Plates, shapes, and bars.	....	....	35.2	59.8–70.3	....	50,000	85,000–100,000	([21])	25.0	....	....	....	....	....	....	(37)
	Eyebar flats and rollers, unannealed.	....	....	38.7	66.8–77.3	....	55,000	95,000–110,000	16.0	25.0	....	....	....	....	....	....	(37)
	Eyebar flats and pins, annealed.	....	....	36.6	63.2–73.8	....	52,000	90,000–105,000	20.0	35.0	....	....	....	....	....	....	(37)
	Full size, annealed bars.	....	....	33.7	59.8–70.3	....	48,000	85,000–100,000	[23] 10.0	30.0	....	....	....	....	....	....	(37)
Nickel steel: C, 0.32; Mn, 0.50; S, 0.035; P, 0.017; Ni, 3.74[24]	Raw stock........	....	....	68.3	78.8	....	97,200	112,200	....	50.0	217	40	....	....	....	....	(52)
C, 0.19; Ni, 25.0.[25]	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	(78)
Invar[26]— C, 0.1; Mn, 0.5; Ni, 36.0; S, P, negligible quantities.	....	8.0	....	21.1–49.3	35.1–70.3	....	30,000–70,000	50,000–100,000	25–50	40–70	160	19	1,425 (2,597° F.)	1.0–2.0	....	....	(172)
Platinite— Ni, 46.0........	....	....	....	....	....	....	....	....	....	....	....	....	....	([27])	....	....	(102)
Nickel-silicon steel: C, 0.49; Si, 0.52; Mn, 0.65; Ni, 3.25; Al, 0.02; Ti, 0.03.	Normalized at 770° C. (1,418° F.).	....	47.2	....	82.3	67,100	....	117,200	11.3	18.9	241	....	....	....	....	....	(176)
	Heat treated[28]....	....	119.5	....	201.0	170,000	....	286,000	0.6	1.1	444	....	....	....	....	....	(176)
C, 0.36; Si, 1.15; Mn, 0.85; Ni, 3.20; Al, 0.01.	Normalized at 840° C. (1,544° F.).	....	28.1	56.6	96.5	40,000	80,600	137,300	13.1	27.1	241	....	....	....	....	....	(176)
	Heat treated[28]....	....	63.3	....	193.4	90,000	....	275,100	8.0	22.9	402	....	....	....	....	....	(176)
C, 0.49; Si, 1.30; Mn, 0.78; Ni, 3.05.	Normalized at 800° C. (1,472° F.).	....	37.3	64.9	90.6	53,000	92,300	128,900	21.0	53.3	266	....	....	....	....	....	(176)
	Heat treated[28]....	....	102.0	163.5	208.6	145,000	232,500	296,500	7.5	12.9	591	....	....	....	....	....	(176)
C, 0.49; Si, 2.20; Mn, 0.94; Ni, 3.05.	Normalized at 840° C. (1,544° F.).	....	50.6	75.8	109.4	72,000	108,000	155,600	14.5	40.9	317	....	....	....	....	....	(176)
	Heat treated[28]....	....	....	181.5	219.8	....	258,100	312,600	8.0	24.9	532	....	....	....	....	....	(176)

[20] Shall bend cold through 180° flat on itself without cracking on the outside of the bent portion.

[21] 1,055 ÷ tensile strength in kg/mm² or 1,500,000 ÷ tensile strength in lb./in.² per cent. For every 1/32 in. (0.79 mm) above 1 in. (25.4 mm) in thickness a deduction of 0.25 per cent shall be made to a minimum of 14 per cent.

[22] Shall bend cold through 180° without cracking on the outside of the bent portion around a pin, the diameter of which is equal to the thickness of the specimen for plates, shapes, and bars under ¾ in. (19.1 mm) in thickness; twice the thickness of the specimen for plates, shapes, and bars over ¾ in. (19.1 mm); 1 in. (25.4 mm) for pins and rollers.

[23] In 216 in. (5,486.4 mm).

[24] Used for bolts, nuts, and parts subjected to shock.

[25] Modulus of rupture in torsion, 64.6 kg/mm² (92,000 lb./in.²). Winkelman's Handbuch der Physik, 1908, 1, 1, gives for modulus of elasticity of 25 per cent nickel steel 18,600 kg/mm² (26,450,000 lb./in.²).

[26] Invar can be forged, rolled, turned, filed, and drawn into wire; takes beautiful polish; withstands corrosive action of water even when immersed for several days; subject to changes in length due to "after effects" following cooling from a high temperature. Invar also gradually elongates with time. Applications.—In clocks and watches, in instruments for geodetic survey, and for measuring lengths standards. Landolt-Börnstein tables (1912) give for modulus of elasticity 15,000 kg/mm² (21,300,000 lb./in.²).

[27] Has the same coefficient of expansion as glass.

[28] Quenched in oil at the temperature given for normalized specimens and drawn at 175° C. (347° F.) for three hours.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Tensile properties. Metric kg/mm² Yield point.	Tensile properties. Metric kg/mm² Tensile strength.	Tensile properties. English lb./in.² Proportional limit.	Tensile properties. English lb./in.² Yield point.	Tensile properties. English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Thermal properties. Linear coefficient of expansion ×10⁶ (per 1 °C.).	Thermal properties. Casting shrinkage.	Thermal properties. Casting shrinkage.	Reference
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Nickel-silicon-cerium steel:									Per ct.	Per ct.			°C.		mm/m	in./ft.	
C, 0.45; Si, 1.30; Mn, 0.71; Ni, 2.95; Ce, 0.01.	Normalized at 820° C. (1,508° F.).	...	...	94.3	101.1	...	134,300	143,900	15.6	40.8	269	...	...	...	...	...	(176)
	Heat treated [28]	...	...	145.1	218.7	...	206,500	311,100	8.5	37.2	555	...	...	...	...	...	(176)
C, 0.41; Si, 1.70; Mn, 0.73; Ni, 2.80; Ce, 0.06.	Normalized at 840° C. (1,544° F.).	...	42.2	...	100.9	60,000	...	143,400	7.5	37.6	285	...	...	...	...	...	(176)
	Heat treated [28]	...	123.0	172.1	209.5	175,000	244,900	298,000	7.5	7.2	555	...	...	...	...	...	(176)
C, 0.46; Si, 1.55; Mn, 0.98; Ni, 2.90; Ce, 0.10.	Normalized at 840° C. (1,544° F.).	...	37.9	72.5	124.0	54,000	103,200	176,300	9.5	5.4	321	...	...	...	...	...	(176)
	Heat treated [28]	...	129.4	165.1	219.5	184,000	235,000	312,100	4.6	7.3	...	...	...	...	...	...	(176)
Nickel-silicon-copper steel:																	
C, 0.45; Si, 1.10; Mn, 0.84; Ni, 1.90; Cu, 1.35.	Normalized at 800° C. (1,472° F.).	...	56.2	90.0	106.0	80,000	128,200	150,800	11.0	27.2	320	...	...	...	...	...	(176)
	Heat treated [28]	...	...	192.0	220.3	...	237,400	313,300	7.5	36.6	546	...	...	...	...	...	(176)
C, 0.46; Si, 1.30; Mn, 0.82; Ni, 2.55; Cu, 0.64.	Normalized at 800° C. (1,472° F.).	...	49.2	94.4	101.0	70,000	134,300	143,700	12.0	38.1	292	...	...	...	...	...	(176)
	Heat treated [28]	...	130.7	196.2	230.5	186,000	279,100	327,900	4.5	7.9	555	...	...	...	...	...	(176)
Nickel-silicon-molybdenum steel:																	
C, 0.42; Si, 1.45; Mn, 0.83; Ni, 3.25; Mo, 0.78.	Normalized at 780° C. (1,436° F.).	...	46.4	...	102.6	66,000	...	146,000	23.0	25.9	286	...	...	...	...	...	(176)
	Quenched in oil at 780° C. (1,436° F.); drawn at 175° C. (347° F.) for three hours.	...	58.3	...	211.0	83,000	...	300,100	5.5	8.4	444	...	...	...	...	...	(176)

Nickel-silicon-uranium steel: C,0.43; Si,1.30; Mn,0.90; Ni, 3.00; Al,0.01; U, 0.34.	Normalized at 820° C. (1,508° F.).	...	...	93.7	129.0	...	133,500	183,500	6.0	12.9	289	...	...	...	...	...	(176)
	Quenched in oil at 820° C.(1,508° F.); drawn at 175° C. (347° F.) for three hours.	...	105.5	137.2	217.7	150,000	195,000	309,800	10.5	35.2	627	...	...	...	...	...	(176)
Nickel-silicon-vanadium steel: C,0.60; Si,1.30; Mn,0.79; Ni, 3.15; V, 0.32.	Normalized at 800° C. (1,472° F.).	...	58.3	72.5	97.7	83,000	103,200	139,000	19.5	48.4	302	...	...	...	...	...	(176)
	Quenched in oil at 800° C.(1,472° F.); drawn at 175° C. (347° F.) for three hours.	...	...	194.2	241.3	...	276,500	343,600	5.0	7.8	627	...	...	...	...	...	(176)
Nickel-silicon-zirconium steel: C,0.34; Si,1.10; Mn,0.57; Ni, 3.05; Ti,0.06; Zr, 0.55.	Normalized at 860° C. (1,580° F.).	...	42.2	55.4	75.7	60,000	78,900	107,900	22.0	44.7	234	...	...	...	...	...	(176)
	Quenched in oil at 860° C.(1,580° F.); drawn at 175° C. (347° F.) for three hours.	...	74.5	153.3	163.2	106,000	218,000	232,200	6.5	36.5	351	...	...	...	...	...	(176)
C,0.37; Si,1.15; Mn,0.56; Ni, 3.05; Al,0.02; Ti, 0.11; Zr, 0.20.	Normalized at 820° C. (1,508° F.).	...	...	57.8	78.2	...	82,200	111,300	21.5	53.3	241	...	...	...	...	...	(176)
	Quenched in oil at 820° C.(1,508° F.); drawn at 175° C. (347° F.) for three hours.	...	91.3	162.2	176.9	130,000	230,900	251,700	4.5	30.3	532	...	...	...	...	...	(176)
Nickel-silicon-zirconium-cobalt steel: C,0.43; Si,1.56; Mn,1.08; Ni, 3.01; Zr,0.34; Co, 0.37.	Quenched in oil at 843° C.(1,550° F.); drawn at 288° C. (550° F.) for one hour.	...	123.0	188.6	228.6	175,000	268,300	325,400	8.5	19.8	534	...	...	...	...	...	(176)
Nickel-vanadium steel: [29] C,0.36; Ni,3.25; V, 0.45.	Oil tempered.....	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	(78)

[28] Quenched in oil at the temperature given for normalized specimens and drawn at 175° C. (347° F.) for three hours.
[29] Modulus of rupture in torsion, 71.6 kg/mm² (102,000 lb./in.²).

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm²			English lb./in.²					Hardness number.		Thermal properties.				Reference.
			Proportional limit.	Yield point.	Tensile strength.	Proportional limit.	Yield point.	Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	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
									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Rezistal:[30] C, 0.33; Mn, 0.76; Si, 4.51; Ni, 25.76; Cr, 15.16.	Bar (grade 4)		44.8		86.1	63,660		122,560	29.3	43.8	244	48					(107)
C, 0.33; Mn, 0.80; Si, 4.32; Ni, 25.18; Cr, 15.85.	Sheet 0.038 in. (0.96 mm), (grade 4).		107.3		142.8	152,590		203,150	26.7								(107)
Rezistal:[31] Grade 2-1	As rolled			75.4	103.2		107,300	146,900	25.5	40.1	302						(53)
	Quenched in oil from 1,320° C. (2,408° F.).			39.8	77.0		56,600	109,500	67.5	67.5	187						(53)
Grade 3-2	As rolled			60.2	83.0		85,700	118,000	33.0	48.2	228						(53)
	Quenched in oil from 1,040° C. (1,904° F.).			52.8	79.5		75,100	113,100	39.0	60.0	228						(53)
Grade 2-6	Quenched in air from 900° C. (1,652° F.).			56.0	91.5		79,600	130,200	33.5	28.3		50					(53)
	Quenched in oil from 900° C. (1,652° F.).			53.3	97.0		75,800	137,900	38.0	33.9		50					(53)
	Quenched in water from 900° C. (1,652° F.).			54.4	91.7		77,400	130,400	36.5	36.4		50					(53)
Grade 3-8	Quenched in water from 600° C. (1,112° F.).			78.5	89.2		111,600	126,900	25.0	37.9		55					(53)
	Quenched in water from 850° C. (1,562° F.).			69.3	92.3		98,500	131,300	31.0	37.9		47					(53)
	Quenched in water from 1,050° C. (1,922° F.).			55.3	84.9		78,700	120,700	45.0	45.7		40					(53)

	Quenched in water from 1,200° C. (2,192° F.).	...	...	40.7	69.9	...	57,900	99,400	60.0	51.1	...	38	...	...	...	(53)
	Cooled in air after one hour at 1,300°C.(2,372° F.).	...	...	37.9	69.8	...	53,900	99,200	43.5	43.6	...	...	...	...	...	(53)
Silicon steel:																
C,0.38; Si,0.46; Mn,0.52; Al, 0.45.	Normalized at 840° C. (1,544° F.).	...	30.2	...	63.0	43,000	...	89,600	26.3	50.2	163	...	...	...	...	(176)
	Heat treated [32]	...	29.5	...	78.2	42,000	...	111,200	9.5	30.6	...	28	...	...	...	(176)
C,0.24; Si,1.10; Mn,0.71; Al, 0.01.	Normalized at 900° C. (1,652° F.).	...	40.8	43.0	61.3	58,000	61,200	87,300	22.5	59.0	178	...	...	...	...	(176)
	Heat treated [32]	...	40.3	...	70.0	57,400	...	99,700	12.5	51.5	185	...	...	...	...	(176)
C,0.42; Si,1.50; Mn,0.86; Al, 0.01.	Normalized at 860° C. (1,580° F.).	...	55.5	60.4	86.1	79,000	85,900	122,500	20.0	51.5	241	...	...	...	...	(176)
	Heat treated [32]	...	96.2	...	182.2	137,000	...	259,400	4.5	15.9	418	...	...	...	...	(176)

[30] Rezistal was found to be fairly resistant to atmospheric corrosion, but the samples tested did not give as good results as 13 per cent chromium steel. Tests at high temperatures gave results somewhat higher than those obtained in high chromium, chromium-tungsten, or silicon-chromium steels.

Temperature.		Tensile strength.		Elongation in 2 in. (50.8 mm).
°C.	°F.	kg/mm²	lb./in.²	Per cent.
700	1,292	36.7	52,200	23
800	1,472	20.9	29,710	42
960	1,760	6.85	9,750	19.5

Compressive elastic limit, 57.4 kg/mm² (81,610 lb./in.²); Compressive strength, 91.6 kg/mm² (130,300 lb./in.²); Torsional elastic limit, 36.7 kg/mm² (52,150 lb./in.²); Modulus of rupture in torsion, 77.7 kg/mm² (110,560 lb./in.²); Impact value, 22.8 ft.-lb. (3.15 kgm).

Minimum diameter over which it can bend 180° without cracking—four thicknesses.

[31] Highly resistant to attack of all agencies. In oxidizing flame rezistal is only slightly stained after several hours at 1,093° C. (2,000° F.); may remain for days in tap water with practically no rust. Rezistal is tough and strong at all temperatures from −185 to +1,300° C. (−301 to +2,372° F.). When attacked by an oxyacetylene flame it takes 20 times as long to melt a hole as does ordinary steel. Established uses.—Rails, racks, trays in enameling furnaces for 871–982° C. (1,600–1,800° F.), valves and parts for internal-combustion engines, cooking utensils, vault plates and hinges that are to resist oxyacetylene flame, saws, and drills, rifle and shotgun barrels, cast cyanide pots, etc. Modulus of elasticity, 19,140 kg/mm² (27,200,000 lb./in.²) in tension and 8,220 kg/mm² (11,700,000 lb./in.²) in shear. For machining rezistal should be annealed at 800–850° C. (1,472–1,562° F.). Rezistal can not be cut successfully with an ordinary hack saw and requires high-speed friction saw or thin carborundum wheel. Rezistal can be welded with the oxyacetylene flame.

[32] Quenched in oil at the temperature given for normalized specimen and drawn at 175° C. (347° F.) for three hours.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties.								Hardness number.		Thermal properties.				Reference.
			Metric kg/mm²			English lb./in.²			Elongation in 50.8 mm or 2 inches.	Reduction of area.	Brinell.	Scleroscope.	Melting point.	Linear coefficient of expansion ×10⁶ (per 1 °C.).	Casting shrinkage.		
			Proportional limit.	Yield point.	Tensile strength.	Proportional limit.	Yield point.	Tensile strength.									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Titanium steel:[33] Ti, 0.5																	(98)
Tungsten steel:[34] C, 0.47; Mn, 0.38; S, 0.025; P, 0.01; Cr, 3.15; V, 0.72; W, 15.55.	Raw stock			59.6	77.3		84,800	110,000	24.0	54.0	207	35					(52)
Uranium steel: C, 0.37; Mn, 0.59; Si, 0.21; P, 0.022; S, 0.025; Ni, 3.51; U, 0.17.[35]	Untreated			35.1	66.1		50,000	94,000	22.0	46.7	194	29					(108)
	Quenched in oil at 1,400° F. (760° C.); drawn at 350° F. (177° C.).			101.3	190.5		144,000	271,000	9.3	29.2	541	64					(108)
	Quenched in oil at 1,400° F. (760° C.); drawn at 950° F. (510° C.).			92.1	97.7		131,000	139,000	17.9	59.7	302	44					(108)
C, 0.32; Mn, 0.66; Si, 0.23; P, 0.024; S, 0.028; U., 0.22.[36]	Untreated			16.5	46.4		23,400	66,000	31.0	60.0	129	22					(108)
	Quenched in water at 1,550° F. (843° C.); drawn at 350° F. (177° C.).			96.3	163.8		137,000	233,000	11.5	47.0	512	56					(108)
	Quenched in water at 1,550° F. (843° C.); drawn at 850° F. (454° C.).			72.4	89.3		103,000	127,000	18.7	65.6	286	45					(108)
Vanadium steel:[37] C, 0.22; Mn, 0.72; S, 0.039; P, 0.04; V, 0.12.	Quenched in oil at 1,500° F. (815° C.).			79.5	97.7		113,000	139,000	3.0			44					(52)
	Quenched in oil at 1,600° F. (871° C.).			118.1	137.3		168,000	195,300	4.5			55					(52)
	Quenched in oil at 1,700° F. (927° C.).			121.0	142.0		172,000	202,000	6.75			58					(52)

[33] Titanium removes O and N and prevents formation of blowholes in steel. It increases the density of the metal, tensile strength, elastic limit, reduction of area, transverse strength, and ductility; greatly improves resistance to shock, torsional and impact stresses. Resistance to wear was well shown in a nine-months test of rails. A titanium-treated rail lost 1.39 lb./yd. (0.689 kg/m) as against 7.03 lb./yd. (3.48 kg/m) lost by an ordinary rail. Still more illustrative is the increase in resistance to fatigue, as shown below. The composition of steel was: C, 0.25; Mn, 0.64; Si, 0.425; P, 0.04; S, 0.035.

Without titanium.			With titanium.		
Stress.		Number of revolutions.	Stress.		Number of revolutions (the same specimen).
kg/mm²	lb./in.²		kg/mm²	lb./in.²	
27.3	38,870	2,660,000 (broke)	27.3	38,870	4,052,000
			28.5	40,600	10,800,000
			29.8	42,400	1,919,000
			31.1	44,200	1,006,000 (broke)

[34] Used for high-speed cutting tools and exhaust valves; retains cutting properties at red heat.

[35] Charpy Impact Value.

Untreated.		Quenched in oil at 1,400° F. (760° C.) and drawn at 350° F. (177° C.).		Quenched in oil at 1,400° F. (760° C.) and drawn at 950° F. (510° C.).	
kgm	ft.-lb.	kgm	ft.-lb.	kgm	ft.-lb.
2.62	19.0	3.23	23.4	4.97	36.0

[36] Charpy Impact Value.

Untreated.		Quenched in water at 1,550° F. (843° C.) and drawn at 350° F. (177° C.).		Quenched in water at 1,550° F. (843° C.) and drawn at 850° F. (454° C.).	
kgm	ft.-lb.	kgm	ft.-lb.	kgm	ft.-lb.
1.50	10.8	3.83	27.8	7.12	51.7

[37] Especially good for sheet steel that has to be punched; very tough

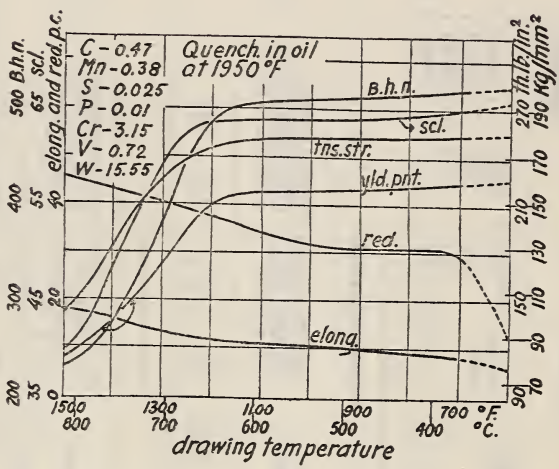

FIG. 32.—*Effect of drawing temperature on the tensile properties of tungsten steel.*

F. Grotts, Chem. and Met. Eng., 19; 1918.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Tensile properties. Metric kg/mm² Yield point.	Tensile properties. Metric kg/mm² Tensile strength.	Tensile properties. English lb./in.² Proportional limit.	Tensile properties. English lb./in.² Yield point.	Tensile properties. English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Thermal properties. Linear coefficient of expansion ×10⁶ (per 1 °C.).	Thermal properties. Casting shrinkage.		Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Zirconium steel:[88] C, 0.42; Mn, 1.00; Si, 1.50; Ni, 3.00; Zr, 0.34.			168.7		198.2	240,000		282,000			470						(141)
Lead:[39]																	
Pb	Rolled				2.1			2,990									(97)
	Annealed				1.8			2,560									(97)
Pb, commercial	Cast	11.35			1.25			1,780					[40] 327	[40] 29.24			(109)
	Wire, drawn soft				1.70			2,420									(109)
	Wire, drawn hard				2.20			3,130									(109)
Antimony (hard lead)[41]—																	
Pb; Sb	Sheet 0.035 in. (0.89 mm) thick.	10.71			3.89			5,530	14.8			3–4					(185)
	Sheet 0.042 in. (1.07 mm) thick.				3.82			5,440	15.2			3–4					(185)
	Sheet 0.050 in. (1.27 mm) thick.				4.16			5,910	19.0			3–4					(185)

[88] Iron-zirconium removes nitrogen and oxides from steel. Iron-zirconium alloys containing titanium and aluminum are highly resistant to chemical reagents, and are readily malleable. A typical analysis of some of these alloys: Zr 65; Fe, 26; Ti, 0.12; Al, 7.7.

[39] Compressive strength of rolled lead, 5.0 kg/mm² or 7,100 lb./in.² Modulus of elasticity, 1,500–1,700 kg/mm² (2,130,000–2,420,000 lb./in.²). Modulus of elasticity in shear, 550 kg/mm² (780,000 lb./in.²). According to Winkelman's Handbuch der Physik, I., 1, p. 557; 1908; modulus of elasticity of drawn lead, 1,727 kg/mm² (2,460,000 lb./in.²); modulus of elasticity of annealed lead, 1,803 kg/mm² (2,560,000 lb./in.²). Amagat gives for the Poisson's ratio, 0.427.

[40] Smithsonian Physical Tables, 7th edition; 1920.

[41] Note—

Thickness.		Erichsen test depth of cup.	Number of bendings before cracking; when bent over $r=0.05$ in. (1.97 mm) through an angle of 90° each way.*
mm	in.	mm	
0.88	0.035	9.96	5.6
1.07	.042	9.84	4.3
1.27	.050	9.66	2.9

*Mechanical properties are practically the same in both directions.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties.								Hardness number.		Thermal properties.				Reference.
			Metric kg/mm²			English lb./in.²			Elongation in 50.8 mm or 2 inches.	Reduction of area.	Brinell.	Scleroscope.	Melting point.	Linear coefficient of expansion ×10⁶ (per 1 °C.).	Casting shrinkage.		
			Proportional limit.	Yield point.	Tensile strength.	Proportional limit.	Yield point.	Tensile strength.									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Lead—Continued. Antimony (soft lead)[42]—									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Pb; Imp.	Sheet 0.033 in. (0.84 mm) thick along rolling.	11.32			1.91			2,720	38.4								(185)
	Sheet 0.033 in. (0.84 mm) thick across rolling.	11.32			1.98			2,815	36.8								(185)
Antimony— Pb, 95.5; Sb, 4.5.	Cast	10.5	2.81		4.5	4,000		6,400									(169)
Sb, 2.6; Pb, balance.	do				3.16			4,490	15.0	21.6							(55)
Sb, 3.9; Pb, balance.	do				3.71			5,270	19.0	25.0							(55)
Sb, 4.5; Pb, balance.	do				4.36			6,200	35.5	34.5							(55)
Sb, 5.0; Pb, balance.	do				4.42			6,290	28.5	27.3							(55)
Sb, 6.1; Pb, balance.	do				4.75			6,750	21.8	23.3							(55)
Sb, 6.4; Pb, balance.	do				4.99			7,100	21.8	20.8							(55)
Sb, 7.4; Pb, balance.	do				4.96			7,050	19.3	21.0							(55)
Sb, 8.1; Pb, balance.	do				5.24			7,450	21.5	22.1							(55)
Sb, 9.9; Pb, balance.	do				5.39			7,670	15.5	13.6							(55)
Sb, 12.6; Pb, balance.	do				5.17			7,350	11.0	10.6							(55)
Sb, 14.0; Pb, balance.	do				4.94			7,020	8.8	9.3							(55)
Sb, 19.6; Pb, balance.	do				4.40			6,250	1.8	1.5							(55)
Sb, 24.7; Pb, balance.	do				4.26			6,060	1.3	0.4							(55)

Barium (ulco metal)[43]— Pb, 98–99; Ba, Ca, balance.[44]					9.14			13,000	[45] 5	1							(56)
Barium (hardened lead)[46]— Pb, 97–98; Ba, Ca, balance.											[47] 31	[47] 13					(57)
Magnesium:																	
Pure	Cast	1.74			14.1			20,000	9				651	26.9			(58)
	Hot-rolled				24.6			35,000									(59)
Pure[48]					23.2			33,000									(77)
Pure[49]																	(75)

[42] Erichsen test.—Depth of cup, 9.76 mm; number of bendings (same conditions as for hard lead) before cracking, 11; number of bendings (same conditions as for hard lead) to complete rupture, 22; the last property practically the same in both directions.

[43] General appearance of lead; may be cast, drawn, rolled, or extruded; specific gravity and melting point identical with those of lead; has metallic ring of bell metal; none of the brittleness of antimonial lead; pronounced increase in hardness upon aging; aging accelerated by steam heat; excellent structure, free from blowholes, and has low coefficient of friction.

[44] American Machinist, Nov. 30, 1918.

[45] In 1 in. (25.4 mm).

[46] Alloy tested in bearings up to 6,000 lb./in.² (4.22 kg/mm²) pressure gave satisfactory results. Hardness of bearing alloys is fully maintained after extended periods of use. Decrease of hardness up to 200° C. (392° F.) was less than that of tin-base alloys.

[47] Brinell hardness at 500 kg (1,102 lb.) load; scleroscope, with magnifying hammer.

Bureau of Standards, comparative test:

Genuine Babbitt Metal.

Load.		r. p. m.	Total number of revolutions.	Final temperature.		Rise in temperature.		Friction.		Loss in weight.	
kg/mm²	lb./in.²			°C.	°F.	°C.	°F.	kg	lb.	g	gr
0.070	100	694	12,230	89	192	53	95	10.0	22	0.023	0.355
.141	200	706	16,510	102	216	58	104	13.2	29	.021	.324
.211	300	682	15,150	125	257	100	180	17.2	38	.013	.201
.281	400	603	6,600	139	282	94	164	35.8	79	*.054	.833
Ulco Metal.											
0.070	100	710	13,160	56	133	23	41	5.9	13	0.013	0.201
.141	200	715	18,870	69	156	33	59	8.2	18	.021	.324
.211	300	719	18,830	80	176	42	76	12.3	27	.013	.201
.281	400	711	17,310	81	178	43	77	10.4	23	.022	.339
.351	500	723	17,660	79	174	43	77	11.3	25	.014	.216
.422	600	692	14,960	84	183	45	81	10.9	24	.021	.324
.492	700	648	24,520	62	144	38	68	10.9	24	.020	.309
.562	800	365	12,870	53	127	20	36	10.4	23	.010	.154
.633	900	408	22,300	59	138	22	40	10.9	24	.015	.232
.703	1,000	405	23,200	66	151	36	65	10.0	22	†.014	.216

*Bearing seized and smoking. †Bearing still in good condition.

[48] Compressive strength 27.1 kg/mm² (38,500 lb./in.²).

[49] Modulus of elasticity, 4,260 kg/mm² (6,050,000 lb./in.²). Landolt–Börnstein tables (1912) give for modulus of elasticity 4,000 kg/mm² (5,680,000 lb./in.²) and for the modulus of elasticity in shear 1,180–1,700 kg/mm² (1,680,000–2,420,000 lb./in.²).

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties.								Hardness number.		Thermal properties.				Reference.
			Metric kg/mm²			English lb./in.²			Elongation in 50.8 mm or 2 inches.	Reduction of area.	Brinell.	Scleroscope.	Melting point.	Linear coefficient of expansion ×10⁶ (per 1 °C.).	Casting shrinkage.		
			Proportional limit.	Yield point.	Tensile strength.	Proportional limit.	Yield point.	Tensile strength.									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Magnesium	Cast, sand				10.2			14,500	5		[50] 40	18					(64)
	Forged				23.2			33,000									(64)
Magnesium:[51] Pure	Cast	1.74			14.1			20,000	8								(65)
	Rolled, bars				23.6			33,600									(65)
Dow metal— Mg, 92; Al, 8	Cast, sand	1.79			17.9			25,500	4		[50] 55	25					(64)
	Sand cast, heat treated.	1.79			21.8			31,000	7.5		[50] 50	23					(64)
Dow metal[52]			4.0		10.0	4,830		14,200	0	0							(186)
Zinc (electron metal).		1.77		9.9	23.2		13,780	32,800	12.0	18.0		20					(187)
Zinc (electron metal).[53]	Semihard	1.81		13.0	25.3		18,500	36,000	15.0	16.0		22					(188)
	Hard	1.83		14.6	33.7		20,800	48,000	5.0	7.0		27					(188)
Mg, 95; Zn, 5	Cast, sand				18.0			25,600	7.4		[50] 41	23					(64)
Mg, 95.18; Zn, 4.62; Cu, 0.20 (Spec. A).[54]		1.78		18.9	25.4		26,900	36,100	[55] 19.0		[56] 51						(69)
Mg, 95.34; Zn, 4.24; Cu, 0.42 (Spec. B).		1.79		12.0	28.3		17,000	40,300	[55] 19.0		[56] 51						(69)
Mg, 95.01; Zn, 4.37; Cu, 0.62 (Spec. C).		1.79		18.9	29.0		26,900	41,200	[55] 13.0		[56] 63						(69
Zinc (electron metal).[57]	Bars over 1.5 in. diam. (38.1 mm).				25–28			35,500–39,800	15–20	8–22							(212)
	Rods 0.3 in. diam. (7.6 mm).				27.2			38,700	18–22		[58] 47						(212)
	Hard, cold worked.				35.5			50,500	2–4		[58] 67						(212)
Manganese: Mn		7.42											1,230 (2,246° F.)				(138)
Molybdenum: Mo		9.01											2,535 (4,595° F.)				(138)

Nickel: Electrolytic— Ni, 99.5	Annealed				41.5			59,000	32.0				1,450 (2,642° F.)					(210)
	Rolled	8.6–8.9																(210)
Pure [59]— Ni, 99.0; Fe, Cu, C, Si, Mn, S.	Annealed	8.84		14.1– 21.1	42.2– 63.3		20,000– 30,000	60,000– 90,000	40–50	45–55			1,451 (2,644° F.)	[60]				(60)
Pure [61]	Cold, rolled			63.3– 77.3	70.3– 84.3		90,000– 110,000	100,000– 120,000	15–20	40–50								(60)
											[62] 80– 100	[62] 9–12						(61)
	Cast (deoxidized)			14.1– 21.1	35.1– 42.2		20,000– 30,000	50,000– 60,000	20–30									(172)
	Hot-rolled rods			14.1– 21.1	49.2– 56.2		20,000– 30,000	70,000– 80,000	40–50	50–70								(172)
	Sheet, hard-rolled			59.7– 73.8	63.3– 77.4		85,000– 105,000	90,000– 110,000	1–2	20–40								(172)
	Sheet, annealed			10.5– 17.6	42.2– 52.7		15,000– 25,000	60,000– 75,000	35–45	40–60								(172)
	Wire, hard-drawn			59.7– 73.8	63.3– 77.4		85,000– 105,000	90,000– 110,000										(172)
	Wire, annealed			14.1– 21.1	45.7– 52.7		20,000– 30,000	65,000– 75,000										(172)

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

[51] Brilliant white color; remains untarnished in a dry air, but in a moist atmosphere becomes covered with a thin white film of oxide; great affinity for oxygen; used largely for deoxidizing castings of copper, brass, nickel, silver, and aluminum; added to nonferrous castings to strengthen them; when cold is fairly malleable, especially after annealing at 400–425° C. (752–797° F.), when it can be rolled with ease.

[52] Modulus of elasticity, 4,260 kg/mm² (6,050,000 lb./in.²).

[53] Erichsen values.—Semihard, 4.52 mm; hard, 2.75 mm.

[54] The data refers to the German-made alloy; machining properties very satisfactory.

Compression tests on cylinders 0.31 in. (7.88 mm) in diameter and 0.31 in. (7.88 mm) long.

		Spec. A.	Spec. B.	Spec. C.
Load at compression of 0.5 per cent (yield point)	kg/mm²	4.7	9.5	13.2
	lb./in.²	6,720	13,450	18,820
Permanent reduction in length at load of 15.8 kg/mm² (22,400 lb./in.²)	per cent	3.9	2.0	1.0
Permanent reduction in length at load of 31.5 kg/mm² (44,800 lb./in.²)	do.	10.1	9.1	7.0
Crushing load (fracture occurred by shearing)	kg/mm²	36.3	35.2	37.7
	lb./in.²	51,500	50,000	53,600

[55] In 0.64 in. (16.27 mm.) $=4\sqrt{\text{area}}$.

[56] 1 mm ball, 10 kg (22 lb.) load, exterior surface.

[57] Impact value 0–1.0 kgm/cm² (0–46.6 ft.-lb./in.²); material is very plastic and at the proper temperature may be given any shape under press. Electron metal is attacked readily in moist air, but in dry places it may be used polished. While in touch with other metals, as iron, which have widely different expansion, it is necessary to protect it with paint.

[58] 10 mm ball, 250 kg (551 lb.) load.

[59] Hot shortness at 1,200° C. (2,192° F.); annealing range, 750–900° C. (1,382–1,652° F.).

[60] Coefficient of expansion $\times 10^6 = 12.8 + 0.0075\,t$.

[61] Modulus of elasticity, 21,100–23,200 kg/mm² (30,000,000–33,000,000 lb./in.²). Nickel is not corroded easily at ordinary temperatures. Exposed to oxidizing or sulphurizing atmospheres at 1,000–1,200° C. (1,832–2,192° F.), the grain boundaries are attacked and intercrystalline fracture takes place on working. Effect of impurities: (1) *Carbon.*—Up to the limit of solubility from 0.4 to 0.5 per cent improves hot working properties, but cold working properties are impaired. Carbon lowers melting point: (2) *Oxygen.*—The presence of oxygen destroys malleability, (3) *Manganese.*—Improves casting properties, increases strength, increases resistance to oxidation, (4) *Sulphur.*—Above 0.05 per cent impaires ductility, (5) *Iron.*—The amount present in nickel is usually less than 1.0 per cent and has no appreciable effect upon its properties, (6) *Cobalt.*—Soluble in all proportions and in small amounts is without appreciable effect on the properties of nickel, and (7) *Silicon.*—At a silicon content of 3 to 5 per cent the malleability is completely destroyed.

[62] These values may be raised by cold working to 250–350 Brinell and 40–45 Scleroscope.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Metric kg/mm² Yield point.	Metric kg/mm² Tensile strength.	English lb./in.² Proportional limit.	English lb./in.² Yield point.	English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Linear coefficient of expansion $\times 10^6$ (per 1 °C.).	Casting shrinkage.		Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Nickel—Contd. Pure—Contd.									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Ni, 98.5 [63]	Cast	8.30		16.7	26.7		23,800	38,000	5.7	6.1	[64] 76						(109)
Ni, 99.95	Wrought, annealed.	8.70	12.6		29.9	17,900		42,500	11.0								(109)
Ni, 98.5	Wrought, commercial.				45.7			65,000			[64] 83						(109)
	Rolled hard, commercial.				64.7			92,000	11.0								(109)
	Rolled, annealed, commercial.				53.4			76,000	35.0								(109)
	Drawn hard, 0.065 in. (1.65 mm) diameter.				109.0			155,000									(109)
Chromium (nichrome)[65]— Ni, Cr																	(62)
Iron, chromium, manganese (nichrome)— Ni, 60; Fe, 26; Cr, 12; Mn, 2.	Cast	8.15			35.1–38.7			50,000–55,000	1		179			12.1			(173)
	Wire	8.15			70.3			100,000						16.4			(173)
Chromium (illium)[66]— Ni, 60.65; Cr, 21.07; Cu, 6.42; Mo, 4.67; W, 2.13; Al, 1.09; Si, 1.04; Mn, 0.98; Fe, 0.76.					35.2			50,000									(9)
Copper, iron [67]— Ni, 71; Cu, 27; Fe, 2.	Drawn, hard				112.5			160,000									(79)
Copper (Monel metal)—																	

Ni, 67; Cu, 28; Fe, 3; Mn, 2.	Rolled, hot	8.95									[68] 162	27					(79)
	Rods to 1 in. (25.4 mm) diam.			44.4	66.6		63,100	94,600	40.0								(79)
	Rods 1–1¾ in. (25.4–44.4 mm) diam.			43.6	65.5		62,000	93,100	39.0								(79)
	Rods 1¾–2½ in. (44.4–63.5 mm) diam.			35.3	61.7		50,100	87,700	42.0								(79)
	Rods 2½–3½ in. (63.5–88.8 mm) diam.			30.8	60.0		43,800	85,300	44.0								(79)
	Rods over 3½ in. (88.8 mm) diam.			33.3	59.6		47,300	84,800	43.0								(79)
	Rectangles			39.6	60.2		56,400	85,600	42.0								(79)
	Hexagons			42.7	61.8		60,700	87,800	40.0								(79)
Copper, iron (Monel metal).[69]	Cast			21.1–28.1	45.7–56.2		30,000–40,000	65,000–80,000	25–35		[63] 100–120	15–25					(172)
	Cold-rolled			42.2–63.3	56.2–77.4		60,000–90,000	80,000–110,000	20–30		180–200						(172)
	Sheet, hard			63.3–77.4	70.3–84.4		90,000–110,000	100,000–120,000	1–2		180–200	40–50					(172)
	Sheet, annealed			17.6–24.6	45.7–52.7		25,000–35,000	65,000–75,000	35–45		[68] 100–120	15–25					(172)
	Wire, hard			63.3–77.4	70.3–84.4		90,000–110,000	100,000–120,000	1–2								(172)
	Wire, annealed			17.6–24.6	45.7–52.7		25,000–35,000	65,000–75,000	20–30								(172)
Copper (Monel metal)[70]— Ni, 67; Cu, 28; Fe, 2.5; Si, 1.5.	Cast, sand	8.83	26.1		50.9	37,100		72,300	34.0	32.0		21					(169)
Ni, min. 60; Cu, min. 23; Fe, max. 3.5; Mn, max. 3.5; Al, max. 0.5; C and Si, max. 2.0.	Cast			[71] 22.8	[71] 45.7		[71] 32,500	[71] 65,000	25								(208)

[63] Modulus of elasticity, cast, 20,300 kg/mm² (28,900,000 lb./in.²); modulus of elasticity, drawn hard, 23,900 kg/mm² (34,100,000 lb./in.²). Landolt Börnstein tables (1912) give for the modulus of elasticity in shear 7,800 kg/mm² (11,100,000 lb./in.²) and Poisson's ratio 0.30. Winkelman's Handbuch der Physik; 1908, 1, 1 gives for modulus of elasticity in shear 8,660 kg/mm² (12,300,000 lb./in.²).

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

[65] Used for heat-treatment boxes, pyrometer protection tubes, skimming ladles, etc. Nichrome boxes retain their strength and shape at high temperatures and do not warp or bulge. Owing to greater durability they may be of half thickness used for cast iron. Nichrome boxes may be quenched in water while hot (saving time). Was successfully tried for nozzles for injector burners and for pickling baskets. Can be readily machined. Tensile strength twice that of cast iron and about the same hardness.

[66] Was intended to replace platinum; highly resistant to the action of nitric and sulphuric acids; casting and drawing very difficult.

[67] Compressive proportional limit, 17.9–22.5 kg/mm² (25,500–32,000 lb./in.²).

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

[69] Compression: Proportional limit—Castings, 10.5–17.6 kg/mm² (15,000–25,000 lb./in.²); rods, 24.6–31.6 kg/mm² (35,000–45,000 lb./in.²). Yield point—Castings, 14.1–21.1 kg/mm² (20,000–30,000 lb./in.²); rods, 42.2–49.2 kg/mm² (60,000–70,000 lb./in.²). Shearing strength (rod, 1 in. or 50.8 mm), 38.6–42.9 kg/mm² (55,000–61,000 lb./in.²).

[70] Compressive proportional limit, 8.4–17.9 kg/mm² (12,000–25,500 lb./in.²).

[71] Minimum.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Metric kg/mm² Yield point.	Metric kg/mm² Tensile strength.	English lb./in.² Proportional limit.	English lb./in.² Yield point.	English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Linear coefficient of expansion ×10⁶ (per 1 °C.).	Casting shrinkage.	Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Nickel—Contd. Copper (Monel metal)—Con.									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Ni, min. 60; Cu, min. 23; Fe, max. 3.5; Mn, max. 3.5; Al, max. 0.5; C and Si, max. 0.8.[72]	Rolled, rods and bars up to 1 in. (25.4 mm).			28.1	56.2		40,000	80,000	30								(207)
	Rolled, rods and bars 1–2 in. (25.4–50.8 mm).			33.7	59.8		48,000	85,000	30								(207)
	Rolled, rods and bars 2–3½ in. (50.8–88.8 mm).			24.6	56.2		35,000	80,000	35								(207)
	Rolled, rods and bars over 3½ in. (88.8 mm) hexagons, rectangles.			28.1	56.2		40,000	80,000	32								(207)
Do.[73]	Sheets and plates.			21.1	45.6		30,000	65,000	15								(207)
Copper (Monel metal).[74]	Cast	8.87		26.2	50.8		37,200	72,300	34	32		20–23	1,360	13.75	20.8	0.25	(88)
Ni, 67; Cu, 29; Fe, 3; Mn, 1; Si, S, C, Co.[75]	Rolled		22.1	25.2–37.8	53.5–66.2	31,400	35,800–53,800	76,200–94,100	35–50	60–70	160–190						(89)
	Cast				31.5–39.4			44,800–56,000									(89)
Ni, 67; Cu, 29; Fe, 3; Mn, 1; Si, S, C, Co.[76]	Hot, rolled		24.6–34.4	30.7–43.0	62.6	35,000–49,000	43,700–61,200	88,800									(12)
Manganese— Mn, 3.00; Fe, 0.62; Si, 0.22; C, 0.06; S, 0.018; Ni, balance.	do		14.1	16.5	52.0	20,000	23,500	74,100	51	60							(61)
Mn, 5.06; Fe, 0.72; Si, 0.28; C, 0.06; S, 0.020; Ni, balance.	do		15.8	18.8	54.5	22,500	26,800	77,500	48	62							(61)
Mn, 9.24; Fe, 0.94; Si, 0.41; C, 0.10; S,	do		21.8	23.1	58.8	31,000	32,800	83,800	48	64							(61)

0.020; Ni, balance.																	
Tantalum [77]— Ni, Ta																	(127)
Tungsten, zirconium (cooperite).[78,79]																	(41)
Palladium:[80] Pure— Pd	Drawn, hard	12.1			27.4			39,000					[81] 1,549	[81] 11.76			(169)
Do.[82]	Wire																(38)
Platinum: Pt	Drawn, hard	21.5			37.3			53,000	18.0			24	[81] 1,755	[81] 8.99			(109)
	Drawn, annealed				24.6			35,000	50.0			13					(109)
Do.[83]	Rolled				34.0			48,300									(97)
	Annealed				24.0			34,100									(97)
Silver:[84] Pure— Ag, 100	Cast, in iron molds.	[81] 10.42–10.53	1.42	3.30	10.8	2,030	4,700	15,400	60	66.7	42	[85] 12	[81] 961	[81] 19.21			(123)
	Cast, sand		.74	2.38	10.8	1,050	3,380	15,300	41	37.7	34	[86] 8					(123)

[72] Cold-bend test through 180° angle, radius equal to diameter or thickness; shall stand hammering to a fine point.

[73] Cold-bend test through 120° angle, radius equal to thickness.

[74] Modulus of elasticity for hot-rolled rods, 15,500–16,200 kg/mm² (22,000,000–23,000,000 lb./in.²); compressive proportional limit for cast material, 8.4–18.0 kg/mm² (11,900–25,000 lb./in.²); compressive proportional limit for rolled material, 18.0–22.5 kg/mm² (25,600–32,000 lb./in.²); proportional limit in shear, 22.4 kg/mm² (31,800 lb./in.²); shearing strength, 55.5 kg/mm² (79,000 lb./in.²).

[75] Very little affected by heat treatment; can not be hardened, except by mechanical working. The strength does not fall rapidly with temperature; at 350° C. (662° F.) the strength is only 7.7 kg/mm² (11,000 lb./in.²) lower than at room temperature. Forging range 900–1,100° C. (1,652–2,012° F.). Above 1,100° C. (2,012° F.) it crumbles; immune from season cracking; not easy to work cold, better grades of high-speed steel ought to be used; considerable resistance to corrosion. High impact resistance; over 100 ft.-lb. (13.8 kgm) energy absorbed (Izod specimen). Influence of impurities: Carbon increases strength up to 0.3 per cent; excess of carbon, trouble in forging. Sulphur decidedly harmful. Yield point in torsion 18.9 kg/mm² (26,900 lb./in.²). Torsional strength 63.0 kg/mm² (89,600 lb./in.²).

[76] Modulus of elasticity, 17,850 kg/mm² (25,400,000 lb./in.²); modulus of elasticity in shear, 6,760 kg/mm² (9,600,000 lb./in.²); proportional limit in torsion, 14.1–20.4 kg/mm² (20,000–29,000 lb./in.²). Poisson's ratio 0.33. Fiber stress in fatigue test, lb./in.², $S=69{,}600\ N^{-0.0333}$ (where N is the number of alternations).

[77] Addition of 5–10 per cent of Ta to Ni increases considerably its resistance to the action of acids. Nickel alloy with 30 per cent tantalum may be boiled in aqua regia without alteration. It is hard, but can be rolled or drawn.

[78] Nonferrous material for cutting tools. Tools are cast to shape and ground. In tests at speed of 123 feet per minute lasted from 5 to 9 times longer than best standard high-speed steel.

[79] Its base, Ni; other components: W; Si; Mo; Al, and up to 15 per cent of Zr.

[80] Winkelman's Handbuch der Physik, 1908, 1, 1, gives for annealed Pd, modulus of elasticity, 9,710 kg/mm² (13,800,000 lb./in.²) and for modulus of elasticity in shear, 4,610 kg/mm² (6,550,000 lb./in.²).

[81] Smithsonian Physical Tables, 7th edition, 1920. Values are given for metal in general without reference to its condition.

[82] Modulus of elasticity, 12,900 kg/mm² (18,300,000 lb./in.²); modulus of elasticity in shear, 4,730 kg/mm² (6,720,000 lb./in.²). Landolt-Börnstein Tables (1912) give for Poisson ratio 0.39.

[83] Modulus of elasticity, 16,000–17,500 kg/mm² (22,700,000–24,900,000 lb./in.²); modulus of elasticity in shear, 6,000–7,000 kg/mm² (8,520,000–9,950,000 lb./in.²). Poisson's ratio 0.38. Winkelman's Handbuch der Physik, 1908, 1, 1, gives for: Modulus of elasticity of annealed Pt., 15,520 kg/mm² (22,100,000 lb./in.²); modulus of elasticity of drawn Pt., 17,190 kg/mm² (24,400,000 lb./in.²); modulus of elasticity in shear, 6,610 kg/mm² (9,400,000 lb./in.²).

[84] Modulus of elasticity, 6,000–8,000 kg/mm² (8,530,000–11,370,000 lb./in.²); modulus of elasticity in shear, 2,500–2,900 kg/mm² (3,550,000–4,125,000 lb./in.²). Poisson's ratio 0.37. Landolt-Börnstein Physikalisch-Chemische Tabellen, 1912.)

Compression Tests of Pure Silver.

Property.	Cast, in iron molds.		Cast, sand.	
	kg/mm²	lb./in.²	kg/mm²	lb./in.²
Yield point	1.93	2,740	2.36	3,360
Load at 5 per cent reduction of length	6.26	8,900	5.77	8,200
Load at 10 per cent reduction of length	11.5	16,300	10.2	14,450
Load at 20 per cent reduction of length	20.4	29,000	18.7	26,600
Load at 40 per cent reduction of length	35.2	50,100	33.8	48,100

[86] Magnifier hammer.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Metric kg/mm² Yield point.	Metric kg/mm² Tensile strength.	English lb./in.² Proportional limit.	English lb./in.² Yield point.	English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Linear coefficient of expansion ×10⁶ (per 1 °C.).	Casting shrinkage.	Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Silver:									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Ag	Rolled				29.0			41,200									(97)
	Annealed				16.0			22,800									(97)
Silver, copper [86] Standard—																	
Ag, 92.5; Cu, 7.5	Cast, in iron mold.	[87] 10.35	6.19	13.4	17.2	8,800	19,000	24,500	6.8	15.8	63	[88] 21					(123)
	Cast, sand		7.4	12.8	22.2	10,570	18,250	31,600	41	54.6	60	[88] 18					(123)
Cadmium (standard)[89]—																	
Ag, 92.5; Cu, 5.75; Cd, 1.75.	Cast, in iron mold.	[90] 10.35	2.48	8.9	13.3	3,530	12,700	18,900	9.0	21.4	74	[88] 23					(123)
	Cast, sand		3.58	9.9	20.7	5,090	14,100	29,500	40.0	49.7	73	[88] 22					(123)
Tantalum: [91]																	
Ta	Drawn, hard	12.8			93.0			132,300					2,250–2,300				(137)
Tellurium: [92]																	
Te	Wire, 0.36 mm or 0.0091 in. diameter.	[93] 6.25			1.15			1,635					[93] 452	[93] 16.75			(130)
Tin:																	
Sn	Rolled				2.5			3,550									(97)
	Annealed				1.7			2,420									(97)
Sn, 99.8 [94]	Cast	7.3	1.13		2.46	1,600		3,500					[95] 232	[95] 22.34			(109)
	Rolled				3.51–4.01			5,000 5,700									(109)
	Drawn, hard				7.03			10,000									(109)
Aluminum, zinc, cadmium—																	
Sn, 78; Al, 9; Zn, 8; Cd, 5.	Cast, chill				10.1			14,300	18.0	41.0							(169)
Antimony, copper, zinc (Brittania metal)—																	
Sn, 81; Sb, 16; Cu, 2; Zn, 1.																	(169)
Zinc, aluminum—																	
Sn, 86; Zn, 9; Al, 5.	Cast, chill				8.6			12,200	41.0	81.0							(169)

Zinc— Sn, 63; Zn, 18; Al, 13; Cu, 3; Sb, 2; Pb, 1 (aluminum solder).	Cast				10.2			14,500	1.9	1.5							(169)
Sn, 62; Zn, 15; Al, 11; Pb, 8; Cu, 3; Sb, 1.	do				9.1			13,000	1.6	1.3							(169)

[86] Charpy impact test (standard 10 by 10 mm specimen): Energy—Mold cast, 2.21 kgm (16.0 ft.-lb.); sand cast, 1.88 kgm (13.6 ft.-lb.).

Compression tests.

Property.		Cast in iron molds.	Cast in sand.
Yield point	kg/mm²	20.2	12.3
	lb./in.²	28,800	17,450
Load at 5 per cent reduction of length	kg/mm²	27.4	19.8
	lb./in.²	39,000	28,200
Load at 10 per cent reduction of length	kg/mm²	33.2	25.7
	lb./in.²	47,200	36,600
Load at 20 per cent reduction of length	kg/mm²	41.1	37.5
	lb./in.²	58,500	53,300
Load at 40 per cent reduction of length	kg/mm²	53.5	49.9
	lb./in.²	76,100	71,000

[87] Rolled after annealing.
[88] Magnifying hammer.
[89] Charpy impact test (standard 10 by 10 mm specimen): Energy— Mold cast, 2.74 kgm (19.8 ft.-lb.).; sand cast, 2.40 kgm (17.4 ft.-lb.).

Compression tests.

Property.		Cast in iron molds.	Cast in sand.
Yield point	kg/mm²	11.0	10.7
	lb./in.²	15,600	15,250
Load at 5 per cent reduction of length	kg/mm²	18.3	17.4
	lb./in.²	26,000	24,800
Load at 10 per cent reduction of length	kg/mm²	23.8	22.7
	lb./in.²	33,800	32,300
Load at 20 per cent reduction of length	kg/mm²	35.8	37.8
	lb./in.²	51,000	53,900
Load at 40 per cent reduction of length	kg/mm²	60.1	51.7
	lb./in.²	85,500	73,600

[90] Rolled after annealing.
[91] Modulus of elasticity, 19,000 kg/mm² (27,000,000 lb./in.²) (Landolt-Börnstein, Physikalisch-Chemische Tabellen, 1912). Pure tantalum can be hammered into thin sheets or drawn into fine wire. It has hardness of soft steel. At ordinary temperatures (below 300° C. or 572° F.) pure tantalum resists action of all acids except fluoric acid.
[92] Modulus of elasticity, 4,180 kg/mm² (5,950,000 lb./in.²); modulus of elasticity in shear, 1,570 kg/mm² (2,230,000 lb./in.²).
[93] Smithsonian Physical Tables, 7th edition; 1920.
[94] Compressive strength, cast, 4.22 kg/mm² (6,000 lb./in.²). Landolt-Börnstein Physikalisch-Chemische Tabellen, Berlin, 1912, give for: Modulus of elasticity, 4,000–5,500 kg/mm² (5,680,000–7,820,000 lb./in.²); modulus of elasticity in shear, 1,700 kg/mm² (2,420,000 lb./in.²).
[95] Smithsonian Physical Tables, 7th edition, 1920.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties. Metric kg/mm² Proportional limit.	Metric kg/mm² Yield point.	Metric kg/mm² Tensile strength.	English lb./in.² Proportional limit.	English lb./in.² Yield point.	English lb./in.² Tensile strength.	Elongation in 50.8 mm or 2 inches.	Reduction of area.	Hardness number. Brinell.	Hardness number. Scleroscope.	Thermal properties. Melting point.	Linear coefficient of expansion $\times 10^6$ (per 1°C.).	Casting shrinkage.	Casting shrinkage.	Reference.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Tin—Continued.									Per ct.	Per ct.			°C.		mm/m	in./ft.	
Antimony, copper (white metal bearing alloys).[96], [97]																	
Titanium: [98]																	
Ti		4.5											1,800–1,850 (3,272–3,362° F.)				(97)
Tungsten: [99]																	
W	Ingot sintered 0.20–0.25 in. (5.08–6.35 mm) diam.	18.0			12.7			18,000	0	0							(10)
	Rod swaged 0.026 in. (0.66 mm) diam.				151.0			215,000	4.0	28.0							(10)
	Drawn wire 0.00114 in. (0.029 mm) diam.				415.0			590,000		65.0							(10)
													3,540±30 (6,404° F. ±54)				(131)
														(1)			(132)

[96] Properties of White Metal Bearing Alloys*—Experimental Results.

Alloy No.	Formula. Sn	Formula. Sb	Formula. Cu	Formula. Pb	Pouring temperatures.	Pouring temperatures.	Specific gravity.	Permanent deformation at 21° C. (70° F.). At 454 kg=1,000 lb.	At 454 kg=1,000 lb.	At 2,268 kg=5,000 lb.	At 2,268 kg=5,000 lb.	At 4,536 kg=10,000 lb.	At 4,536 kg=10,000 lb.	Brinell hardness at 500 kg (1,102 lb.). At 21° C. (70° F.).	Brinell hardness at 500 kg (1,102 lb.). At 100° C. (212° F.).
	Per cent.	Per cent.	Per cent.	Per cent.	°C.	°F.		mm	in.	mm	in.	mm	in.		
	Tin base.														
1	91.0	4.5	4.5		440	824	7.34	0.000	0.0000	0.025	0.0010	0.380	0.0150	28.6	12.8
2†	89.0	7.5	3.5		432	808	7.39	.000	.0000	.038	.0015	.305	.0120	28.3	12.7

3	83.3	8.3	8.3	....	491	916	7.46	.025	.0010	.114	.0045	.178	.0070	34.4	13.7
4	75.0	12.0	3.0	10.0	360	680	7.52	.013	.0005	.064	.0025	.229	.0090	29.6	12.8
5	65.0	15.0	2.0	18.0	360	661	7.75	.025	.0010	.076	.0030	.229	.0090	29.6	11.8
	Lead base.														
6	20.0	15.0	1.5	63.5	337	638	9.33	.038	.0015	.127	.0050	.457	.0180	24.3	11.1
7	10.0	15.0	....	75.0	329	625	9.73	.025	.0010	.127	.0050	.583	.0230	24.1	11.7
8	5.0	15.0	....	80.0	329	625	10.04	.051	.0020	.229	.0090	1.575	.0620	20.9	10.3
9	5.0	10.0	....	85.0	324	616	10.24	.102	.0040	.305	.0120	2.130	.0840	19.5	8.6
10	2.0	15.0	....	83.0	329	625	10.07	.025	.0010	.254	.0100	3.910	.1540	17.0	8.9
11	....	15.0	....	85.0	329	625	10.28	.025	.0010	.254	.0100	3.020	.1190	17.0	9.9
12	....	10.0	....	90.0	334	634	10.67	.064	.0025	.432	.0170	7.240	.2850	14.3	6.4

*Babbitt metal, A. S. T. M., 18, 1, p. 491. Experimental permanent deformation values from compression tests on cylinders 31.8 mm (1¼ in.) diameter by 63.5 mm (2½ in.) long, tested at 21° C. (70° F.). (Set readings after removing loads.)

†U. S. Navy specification 46M2b (Cu, 3–4.5; Sn, 88–89.5; Sb, 7.0–8.0) covers manufacture of antifriction metal castings (composition W).

(Note.—For other bearing alloys see brass, lead (yellow brass); brass, lead-tin (red brass); bronze, phosphor, etc., under copper alloys.)

[97] Properties of antifriction bearing metals. P. W. Priestley, Met. Ind. (London), 18, p. 323; 1921. 1. Essential characteristics.—The most desirable alloy is one having hard grains embedded in soft material. The function of hard constituent—to resist wear and to provide surface with low coefficient of friction. The softer constituent permits uniform distribution of load and promotes efficient lubrication by leaving the particles of hard constituent in slight relief. Good bearing metal must have proper amount of both constituents.

2. Composition.—Typical composition of antifriction metals employed in construction of aircraft and automobile engines.

Alloy No.	Application.	Sn	Sb	Cu	Pb	Miscellaneous.	Alloy No.	Application.	Sn	Sb	Cu	Pb	Miscellaneous.
1	Aircraft, American	91.00	4.00	3.50	1.00	0.50	4	Aircraft, German	80.71	10.05	6.95	2.26	0.03
2	Aircraft, British	90.72	5.33	3.80	....	.15	5	Automobile, American	84.00	9.00	7.00	....	....
3	Aircraft, French	90.15	3.90	4.80	.27	.88	6	Automobile, British	86.00	10.50	3.25	....	.25

3. Influence of constituents.—(*a*) Antimony.—Increases hardness, wearing qualities, and brittleness. (*b*) Bismuth.—Traces of it may be introduced as a flux. (*c*) Copper.—Prevents segregation, increases hardness, but in quantities exceeding 5 per cent promotes brittleness. (*d*) Iron.—Increases hardness and brittleness; is considered undesirable. (*e*) Lead.—In small quantities (up to 3 per cent) is permissible. Lubricants containing excess of alkali will pit lead rich alloys. (*f*) Tin.—Improves wearing qualities. Tin-rich alloys are most successful under severe working conditions. (*g*) Nickel.—In quantities over 0.50 per cent removes liability to cracking without affecting hard wearing qualities. (*h*) Zinc.—Increases hardness and brittleness, creates a tendency to seize; considered undesirable. 4. Mechanical tests.— There is no direct relationship between the compressive strength, hardness, coefficient of friction, and durability factor. Mechanical tests are of little value. 5. Heat treatment.—Unnecessary in small bearings. It is advisable to heat large bearings to 150° C. (302° F.) and quench in water in order to eliminate the segregation of antimony-rich cuboids.

[98] For effect of Ti on strength and ductility of steels see Zeitschrift des Vereines der Deutschen Ingenieure, p. 897; 1908.

[99] Modulus of elasticity of drawn wire, 36,200 kg/mm² (51,400,000 lb./in.²), after Dodge. Ordinary annealing treatment makes W brittle and severe working below recrystallization or equiaxing temperature produces ductility. Tungsten rods which have been worked and recrystallized are stronger than sintered rods. The equiaxing temperatures of worked tungsten with a 5-minute exposure vary from 2,200° C. (3,992° F.) for a worked rod with 24 per cent reduction to 1,350° C. (2,462° F.) for a fine wire with 100 per cent reduction.

[1] Coefficient of expansion at 27° C. (81° F.)=0.00000444; coefficient of expansion at 1,027° C. (1,880° F.)=0.00000519; coefficient of expansion at 2,027° C. (3,680° F.)=0.00000726. Tungsten has the lowest known coefficient of expansion except diamond and molybdenum.

TABLE 1.—Tensile and Thermal Properties of Metals—Continued.

Material and composition.	Condition.	Specific gravity.	Tensile properties.								Hardness number.		Thermal properties.				Reference.
			Metric kg/mm²			English lb./in.²			Elongation in 50.8 mm or 2 inches.	Reduction of area.	Brinell.	Scleroscope.	Melting point.	Linear coefficient of expansion $\times 10^6$ (per 1 °C.).	Casting shrinkage.		
			Proportional limit.	Yield point.	Tensile strength.	Proportional limit.	Yield point.	Tensile strength.									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Tungsten—Contd.									Per ct.	Per ct.			°C.		mm/m	in./ft.	
W [2]	Wire 5 mm (0.197 in.) diam.				324.0			460,000									(44)
	Wire 1.2 mm (0.047 in.) diam.				408.0			580,000									(44)
	Rolled sheets				352.0			500,000									(44)
W [3]		19.3–21.4			322–427			458,000–607,000			[4] 4.5–8.0			4.3			(44)
Uranium: [5]																	
Ur		18.7											1,850				(116a)
Vanadium:																	
V		5.5											1,680				(97)
Zinc: [6]																	
Zn	Cast	7.09		3.4	3.8		4,900	5,400	0		39		419	26			(124)
	Rolled			6.3	16.4		8,950	23,300	33								(124)
	Annealed			7.5	15.7		10,700	22,400	38								(124)
Zn [7]																	(70)
Zn; Pb, 0.021–1.04; Cd, 0.03–0.91; Fe, 0.025.[8]	Rolled; tested parallel to direction of rolling.		0.5	8.0	21.4	710	11,400	30,400	27.2	43							(129)
	Rolled; tested perpendicular to direction of rolling.		.9	9.6	25.9	1,280	13,640	36,800	9.7	17							(129)
Zn [9]	Rolled, plate 0.019–0.222 in. (0.48–5.66 mm); parallel to direction of rolling.				18.3–10.0			26,000–14,200									(128)
	Rolled, plate 0.019–0.222 in. (0.48–5.66 mm); perpendicular to direction of rolling.				22.4–14.2			31,800–20,200									(128)
Zn, impur. Pb, Fe, Cd.[10]	Cast, coarse, crystalline.[11]	7.0			2.8			4,000			[12] 42	8					(96)

	Cast, fine, crystalline.[11]	...	...	...	8.4	...	...	12,000	...	...	[12] 48	10	...	...	...	...	(96)
	Rolled [11, 13]	...	2.04	...	19.0	2,900	...	27,000	...	...	...	...	...	...	...	...	(96)
	....do.[11, 14]	...	4.08	...	25.3	5,800	...	36,000	...	...	...	...	...	...	...	...	(96)
	Drawn, hard [15]	7.1	...	...	17.6	...	...	25,000	...	...	...	...	...	...	...	...	(96)
Zirconium: [16]																	
Zr	...	6.4	...	...	...	...	...	...	...	...	...	...	1,530	...	...	...	(54)

[2] Tungsten is not affected by air or water at temperatures below red heat.

[3] Modulus of elasticity, 42,200 kg/mm² (60,000,000 lb./in.²).

[4] Mohs' scale.

[5] Ur is a lustrous white metal; burns brilliantly at 170° C. (338° F.) though unattacked by air at normal temperatures. Metal decomposes in boiling water; struck with hard substance emits copious sparks. Chief use—in high-grade steels. Uranium steel is claimed to be superior to most other alloy steels. Ur hardens steel without imparting brittleness. In high-speed steel Ur tends to promote the formation of carbides upon which the property of "red-hardness" depends. (The Metal Industry, **20**, Jan. 6, 1922.)

[6] Bluish-white metal unaffected at ordinary temperatures in dry air, but tarnishes in damp air; annealing temperature 100° C. (212° F.).

[7] Effect of temperature on tensile properties of zinc.—Haines in 1911 found that at 80–90° C. (176–194° F.) impure metal became remarkably soft, as well as at 150° C. (302° F.). At 110° C. (230° F.) it was as hard as at 30° C. (86° F.) and more brittle. Pure zinc showed no changes at 100° C. (212° F.), but hardened at 200° C. (392° F.). Moore in 1915 made tensile tests of sheets from 1.0–0.006 in. (25.4–0.15 mm). No analysis given. Metal stronger across the grain, but more ductile with the grain than across it. Modulus of elasticity, 8,080 kg/mm² (11,500,000 lb./in.²). Miss Bingham in 1920: Pure zinc annealed. Tensile strength fell steadily from 16.9 kg/mm² (24,000 lb./in.²) at 10° C. (50° F.); sharp inflection at 180° C. (356° F.), marking rise of tensile strength. The elongation was at first 60 per cent; two maximums at 160° C. (320° F.) and 180° C. (356° F.). For quenched metal the elongation rose steadily from 30 per cent to 42 per cent at 100° C. (212° F.). At 180° C. (356° F.) there was a sudden fall from 33 to 19 per cent.

Effect of temperature on hardness of zinc.—Rose in 1912 had found the scleroscope hardness (magnifying hammer) of cast metal, 12.5; rolled, 36. On annealing the hardness was 32 at 50° C. (122° F.), 26 at 60° C. (140° F.), and then fell slowly to 23 at 100° C. (212° F.). Beyond 100° C. (212° F.) the effect was very small. Mathewson, Trewin, and Finkeldey, in 1919: (*a*) Scleroscope hardness of hard-rolled zinc, 28; softened with anneal at 75° C. (167° F.); completely softened (hardness 15) when annealed one hour at 100° C. (212° F.). Higher temperature had no further effect. (*b*) Medium hard rolled. Scleroscope hardness, 24; began to soften at 100° C. (212° F.), and was completely softened at 125° C. (257° F.) (hardness 14). (*c*) Annealing of soft and dead soft material gave only a slight drop from 15 to 14.

Results of the investigation, by D. H. Ingall.—(*a*) Absolute values for mechanical properties of rolled zinc are not obtainable, as material is variable; (*b*) rolled zinc is stronger across rolling. Pure-rolled zinc reduced by rolling 77–86 per cent has a tensile strength of 9.5 kg/mm² (13,500 lb./in.²) which rises to 21.1 kg/mm² (30,000 lb./in.²) with 96 per cent reduction by rolling; (*c*) ductility of pure-rolled zinc with 77–86 per cent reduction is 80 per cent along and 20 per cent across rolling. Beyond 88 per cent reduction the ductility rises sharply until at 96 per cent reduction material is quite ductile in either direction; and (*d*) annealing at 200° C. (392° F.) makes pure-rolled zinc weak and brittle.

[8] Modulus of elasticity: Parallel to direction of rolling, 9,030 kg/mm² (12,850,000 lb./in.²); perpendicular to direction of rolling, 10,200 kg/mm² (14,500,000 lb./in.²); Landolt-Börnstein tables (1912) give for the modulus of elasticity in shear, 4,000 kg/mm² (5,690,000 lb./in.²).

[9] Tensile strength depends to a great extent upon the rate of loading: In tests lasting 6 minutes the tensile strength was 20.5 kg/mm² (29,100 lb./in.²); in tests lasting 81 minutes the tensile strength was 16.4 kg/mm² (23,300 lb./in.²).

Effect of Temperature on Tensile Properties.

Temperature.		Tensile strength.		Elongation.	Temperature.		Tensile strength.		Elongation.
°C.	°F.	kg/mm²	lb./in.²	Per cent.	°C.	°F.	kg/mm²	lb./in.²	Per cent.
27	81	14.5	20,600	12.4	150	302	4.1	5,790	101.5
80	176	8.8	12,500	29.4	170	338	5.6	7,960	17.1
120	248	6.3	8,960	59.4	200	392	4.3	6,120	7.2

[10] Zinc either rolled or cast has no well-defined yield point and its elastic limit is very low. Zinc possesses a high degree of plasticity. Modulus of elasticity: Cast, 7,750 kg/mm² (11,025,000 lb./in.²); rolled, 8,450 kg/mm² (12,000,000 lb./in.²). Compression, load on cylinder 25.4 mm or 1 in. by 66.0 mm (2.6 in.) at 20 per cent deformation: Cast, free from Cd, 17.3 kg/mm² (24,500 lb./in.²); cast, with Cd, 0.26, 27.4 kg/mm² (39,000 lb./in.²). Proc. A. S. T. M., **13**, p. 688.) Modulus of rupture averages twice the corresponding tensile strength. Shearing strength, rolled, averages 13.6 kg/mm² (19,400 lb./in.²).

[11] Marks Mech. Eng. Handbook, p. 527; 1916.

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

[13] Tested with grain or direction of rolling.

[14] Tested across grain or direction of rolling.

[15] B. S. Circular No. 74, p. 317; 1918.

[16] Zirconium steel was proposed for armor plates and as self-hardening tool steel. Aluminum-zirconium has about the same properties as aluminum-titanium. Zr is used as a refractory in form of oxide-zirconia. Fused zirconia has a very low coefficient of expansion—0.00000084 per 1° C.—near that of quartz glass. Its mineralogical hardness is between that of corundum and quartz; specific gravity, 5.89; melting point, 2,950° C. (5,342° F.).

TABLE 16.—Correlation Between the Tensile Strength of Steel, and its Hardness.[1]

Steel.	Tensile strength in terms of Brinell hardness number.	Tensile strength in terms of scleroscope hardness.	Brinell hardness in terms of scleroscope hardness.	Steel.	Tensile strength in terms of Brinell hardness number.	Tensile strength in terms of scleroscope hardness.	Brinell hardness in terms of scleroscope hardness.
	th. lb./in.²	th. lb./in.²			th. lb./in.²	th. lb./in.²	
Carbon steel	0.73 Bhn.−28	4.4 Scl.−28	5.6 Scl.+14	Low chrome-nickel steel	0.68 Bhn.−22	3.7 Scl.−1	5.4 Scl.+33
Nickel steel	.71 Bhn.−32	3.5 Scl.−6	5.0 Scl.+48	High chrome-nickel steel	.71 Bhn.−33	3.7 Scl.−3	4.8 Scl.+58
Chrome-vanadium steel	.71 Bhn.−29	4.2 Scl.−21	5.5 Scl.+27				

[1] After R. Abbott, Proc. Am. Soc. Test. Mat., 15 (2); 1915.

TABLE 17.—Impact Properties of Some Metals.[1]

[Bureau of Standards results, 1923.]

Material and composition.	Energy absorbed.				Tensile properties.					
	Notch parallel to the plane of rolling.		Notch perpendicular to the plane of rolling.		Yield point.		Tensile strength.		Elongation in 2 in. (50.8 mm).	Reduction of area.
	kgm	ft.-lb.	kgm	ft.-lb.	kg/mm²	lb./in.²	kg/mm²	lb./in.²	Per ct.	Per ct.
Duralumin: Cu, 4.0; Si, 0.54; Fe, 0.58; Mn, 0.58; Mg, 0.60; Al, balance	1.47	10.60	1.06	7.64	29.6	42,200	42.9	61,100	15.8	17.6
Brass (hard): Cu, 65.23; Zn, 34.67; Pb, 0.07; Fe, 0.03	2.69	19.45	2.65	19.15	29.2	41,600	36.9	52,500	39.8	51.3
Nickel silver: Cu, 63.92; Ni, 18.09; Zn, 17.58; Mg, 0.24; Fe, 0.15; Pb, 0.02	2.32	16.82	2.31	16.74	41.3	58,800	45.5	64,800	18.5	35.8
Monel metal: Ni, 67.2; Cu, 27.5; Fe, 2.55; Mn, 2.27; C, 0.27; Si, 0.13; S, 0.014	12.89	93.35	10.41	75.30	28.2	40,200	62.1	88,400	47.3	62.0
Carbon steel (boiler plate): C, 0.25; Mn, 0.50; Si, 0.01; P, 0.007; S, 0.035	2.26	16.33	2.10	15.22	25.1	35,800	44.0	62,600	37.5	57.2
3½ per cent nickel steel: C, 0.44; Si, 0.24; Mn, 0.63; S, 0.027; P, 0.009; Ni, 3.50	3.48	25.15	3.52	25.48	56.2	80,000	85.0	121,000	19.8	49.6
Carbon tool steel: C, 1.00; Mn, 0.24; Si, 0.20; S, 0.025; P, 0.013	0.32	2.29	0.29	2.13	29.2	41,600	53.8	76,600	31.0	45.5
Chromium-tungsten tool steel: C, 0.88; Mn, 1.15; Si, 0.26; S, 0.007; P, 0.010; Cr, 0.50; W, 0.40	1.84	13.33	1.82	13.18	....	....	....	(2)	....	....

[1] The materials were as received from the mill. The specimens were 10 by 10 mm with 2 mm V-notch and were tested in an Izod machine of 120 ft.-lb. (16.6 kgm) capacity. They were cut in the direction of rolling.

[2] Bhn. = 175.

TABLE 18.—Impact Properties of Carbon Steel.

[F. C. Langenberg, Chem. and Met. Eng., November 16, 1921.]

[Chemical composition and Charpy values $\frac{\text{kgm}}{\text{ft.-lb.}}$ of heat-treated bar stock.]

Chemical Composition.						Heat Treatment.							
C	Mn	S	P	Si	Cr	Original.	V_1	V_2	V_3	V_4	V_5	V_6	V_7
0.14	0.45	0.035	0.018	0.131	....	6.28	3.88	5.27	6.52	6.63	6.85	6.69	7.27
						45.39	28.01	38.10	47.18	47.95	49.50	48.34	52.61
.18	.56	.043	.024	.132	....	5.74	4.26	4.94	6.39	6.22	6.17	6.49	6.98
						41.51	30.72	35.69	46.24	45.00	44.62	46.87	50.51
.32	.51	.027	.009	.128	....	3.18	2.11	1.51	2.61	2.66	2.75	3.09	3.64
						22.96	15.20	10.94	18.85	19.24	19.86	22.34	26.30
.46	.40	.050	.020	.144	....	3.17	1.11	....	1.94	1.93	1.92	2.17	2.30
						10.70	7.99	....	14.04	13.96	13.89	15.67	16.60
.49	.60	.028	.013	.127	....	1.76	1.43	....	2.22	2.01	1.98	2.42	2.66
						12.72	10.32	....	16.06	14.51	14.35	17.53	19.24
.57	.65	.028	.012	.167	....	1.16	1.10	....	1.74	1.50	1.55	1.66	1.94
						8.38	7.91	....	12.57	10.86	11.17	12.02	14.04
.71	.67	.025	.027	.147	....	.61	.34	....	....	.65	1.05	1.42	2.17
						4.42	2.48	....	....	4.73	7.60	10.32	15.67
.83	.55	.028	.018	.152	....	.18	.19	....	....	.47	.46	.60	.88
						1.31	1.39	....	....	3.42	3.33	4.34	6.36
1.01	.39	.029	.016	.160	....	.29	.20	....	....	.45	.44	.58	.61
						2.09	1.47	....	....	3.25	3.18	4.19	4.42
1.22	.34	.031	.025	.181	....	.19	.18	....	....	.34	.29	.36	.36
						1.39	1.31	....	....	2.48	2.09	2.63	2.63
1.39	.20	.029	.015	.191	....	.13	.12	....	....	.27	.18	.20	.22
						.93	.85	....	....	1.86	1.31	1.47	1.62
1.46	.20	.035	.011	.133	0.35	.11	.17	....	....	.27	.28	.28	.27
						.77	1.24	....	....	1.94	2.01	2.01	1.94

Heat treatments.—Original, as received; V_1, annealed just above Ac_3; V_2, hardened in water from just above Ac_3; V_3, hardened in oil from just above Ac_3; V_4, quenched in oil from just above Ac_3 and drawn at 375° C. (707° F.); V_5, quenched in oil from just above Ac_3 and drawn at 460° C. (860° F.); V_6, quenched in oil from just above Ac_3 and drawn at 560° C. (1,040° F.); V_7, quenched in oil from just above Ac_3 and drawn at 650° C. (1,202° F.).

TABLE 18.—Impact Properties of Carbon Steel—Continued.

Quenching Temperatures.

Carbon content.	°C.	°F.	Carbon content.	°C.	°F.	Carbon content.	°C.	°F.	Carbon content.	°C.	°F.
0.14	866	1,591	0.46	819	1,506	0.71	800	1,472	1.22	790	1,454
.18	858	1,576	.49	816	1,501	.83	795	1,463	1.39	790	1,454
.32	836	1,537	.57	809	1,488	1.01	790	1,454	1.46	790	1,454

TABLE 19.—Effect of Low Temperatures on Hardness and Impact Resistance of Metals.[1]

[L. Guillet and J. Cournot, Revue de Metallurgie, April, 1922.]

[Hardness tests were made with a 10 mm ball and 1,000 kg (2,204 lb.) load. For Ni, Cr steel the load was 3,000 kg (6,612 lb.) and for cobalt 500 kg (1,102 lb.); time, 10 sec. The impact tests were made in a Guillery rotary machine on Mesnager type of specimens.]

Metals and alloys tested.	Brinell hardness.				Impact resistance $\frac{\text{kgm}}{\text{ft.-lb.}}$			
	+20° C. (68° F.).	−20° C. (−4° F.).	−80° C. (−112° F.).	Liquid air.	+20° C. (68° F.).	−20° C. (−4° F.).	−80° C. (−112° F.).	Liquid air.
Electrolytic iron, annealed	80	77	77	269	21.2 153.3	17.5 126.5	2.5 18.1	1.9 13.7
Soft steel, annealed, C, 0.1	110	107	114	273	31.9 230.7	32.5 235.1	22.5 162.7	1.8 13.0
Medium steel, C, 0.33, annealed	176	174	190	286	13.1 94.8	11.2 81.0	10.0 72.3	3.7 26.8
Hard steel, C, 0.79, annealed	230	230	231	330	14.4 104.2	11.2 81.0	10.0 72.3	3.7 26.8
Cemented nickel steel, C, 0.06; Ni, 2.30; annealed.	130	132	135	230	31.2 225.8	31.2 225.8	23.1 167.1	3.1 22.4
Nickel-chromium steel, C, 0.11; Ni, 5.74; Cr, 1.74; annealed.	261	269	282	388	11.8 85.3	7.5 54.2	3.1 22.4	1.9 13.7
Nickel-chromium steel, C, 0.25; Ni, 4.25; Cr, 1.20; quenched in air.	460	466	444	578	11.2 81.0	10.0 72.3	11.2 81.0	10.0 72.3
Ferronickel (Ni, 36.8 p. c.), annealed	157	171	....	239	[2] 41.2 298.0	[2] 36.2 262.0	....	17.5 126.5
Ferronickel (Ni, 47.0 p. c.), annealed	184	192	....	238	32.5 235.1	29.4 212.6	....	29.4 212.6
Ferronickel (Ni, 57.4 p. c.), annealed	197	212	....	240	26.2 189.5	[2] 35.0 253.2	....	31.8 230.0
Ferronickel (Ni, 98.8 p. c.), annealed	98	103	....	120	[2] 47.5 343.5	[2] 46.2 334.2	....	[2] 40.6 293.6
Cobalt	174	....	....	222	....	....	....	....
Copper (pure), Cu, 99.9	51	52	53	66	[2] 20.6 149.0	[2] 18.7 135.3	[2] 20.6 149.0	[2] 20.1 145.4
Brass, Cu, 52.0; Zn, 42.5; Ni, 4.0; Pb, 1.3	118	114	118	148	8.1 58.6	7.5 54.2	8.8 63.6	6.9 49.9
Brass, Cu, 60.4; Zn, 39.3; Pb, 0.2	76	76	76	98	16.2 117.2	16.2 117.2	17.5 126.5	16.8 121.5
Aluminum, commercial, Si, 0.25; Fe, 0.06	24	25	24	53	11.2 81.0	10.6 76.7	11.2 81.0	13.1 94.8
Duralumin, Cu, 3.6; Mn, 0.5; Si, 0.6; Fe, 0.6; Mg, 0.5.	101	96	101	129	5.0 36.1	5.6 40.5	5.0 36.1	5.6 40.5
Aluminum-zinc (Zn, 15 p. c.)	55	47	48	76	11.2 81.0	11.2 81.0	10.0 72.3	9.3 67.3
Aluminum-zinc (Zn, 30 p. c.)	129	137	121	192	2.5 18.1	2.5 18.1	1.9 13.7	1.8 13.0
Aluminum-zinc-lead (Zn, 15.0; Pb, 1.5)	55	51	49	83	10.0 72.3	10.0 72.3	10.0 72.3	8.1 58.6

[1] For tensile strength and ductility at low temperatures of various metals and ferrous alloys see J. Dewar and R. Hadfield, Proc. Roy. Soc. of London, 74, p. 326; 1904–5. See also "Hardness of steels at low temperatures," by M. Robin, Revue de Metallurgie, p. 162; 1909.

[2] Specimen not broken.

TABLE 20.—Effect of Temperature on the Impact Resistance of Annealed Steels. (See fig. 60.)

[Proc. Interna. Assoc. for Testing Materials, 5th Congress, Vol. 3, 4.]

Chemical composition of tested steels.

Steel.	C	Si	Mn	S	P	Annealing treatment in air at temperature—	
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	°C.	°F.
Extra soft	0.218	1.26	0.24	0.041	0.013	850	1,562
Soft	.345	.20	.51	.048	.068	800	1,472
Half hard	.491	.44	.34	.044	.062	800	1,472
Martin (hard)	.725	.40	.33	.025	.013	750	1,382
Tool	1.224	.05	.04	.040	.023	700	1,292
2 per cent Ni	.085	.01	.15	.017	Ni=2.29	890	1,562
7 per cent Ni	.165	.13	.20	Ni=7.10	....	600	1,112
Nickel chrome	.105	.11	.34	Ni=4.38	Cr=0.85	750	1,382

TABLE 21.—Fatigue Properties of Manganese and Aluminum Bronze. (See fig. 14.)

[W. Corse and G. Comstock, Proc. A. S. T. M., vol. 16 (2), p. 117; 1916.]

Chemical Composition and Tensile Properties of Tested Samples.

Material.	Chemical composition.	Proportional limit.		Tensile strength.		Elongation in 50.8 mm or 2 in.	Reduction of area.
		kg/mm²	lb./in.²	kg/mm²	lb./in.²	Per cent.	Per cent.
Manganese bronze (cast).	Zn, 41.0; Fe, 1.0; Sn, 1.0; Mn, 0.5; Al, 0.5; Cu, balance.	20.5	29,200	61.4	87,400	25.0	25.2
Aluminum bronze (cast)	Al, 10.0; Fe, 1.0; Cu, balance....	14.3	20,400	54.0	76,900	30.5	27.6
Aluminum bronze (quenched at 850° C. or 1,562° F.; tempered at 630° C. or 1,116° F.).	Al, 10.0; Fe, 1.0; Cu, balance.....	30.4	43,300	62.2	88,500	13.0	14.2

XII. FATIGUE PROPERTIES OF STEEL.

SUMMARY.

A. [D. J. McAdam, jr., Chem. and Met. Eng., December 14, 1921.]

[See figures 33 to 35.]

1. The endurance stress for 100,000,000 cycles bears no definite relation to the corresponding proportional limit. The ratio is higher in annealed material than in quenched and tempered material. In ingot iron and annealed mild steels of lower carbon content the endurance stress for 100,000,000 cycles is above the proportional limit. In quenched and tempered steel it is often less than half the proportional limit.

2. The endurance stresses for 100,000,000 cycles have been found to bear a surprisingly uniform relation to the corresponding ultimate tensile stresses. In many kinds of material investigated this ratio varies from about 0.35 to 0.54, the highest value being found in ingot iron.

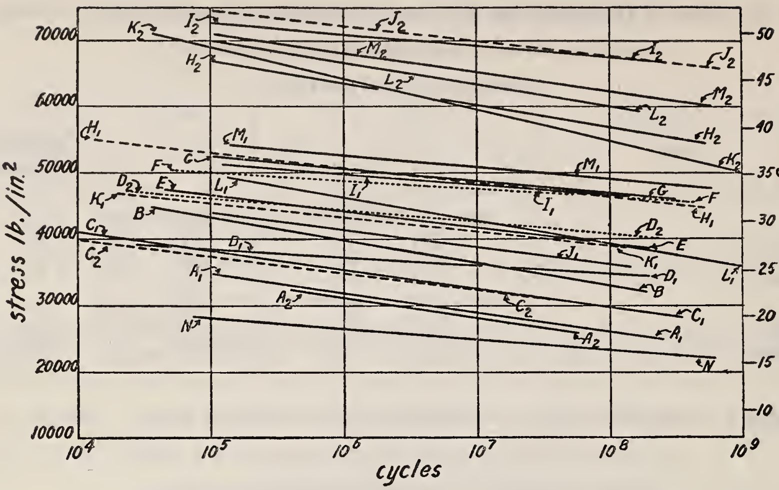

FIG. 33.—*Fatigue properties of carbon and alloy steels.*

D. J. McAdam, Chem. and Met. Eng., Dec. 14, 1921. For the chemical composition and heat treatment see Table 22. Tests were made in a White-Souther machine on tapered specimens.

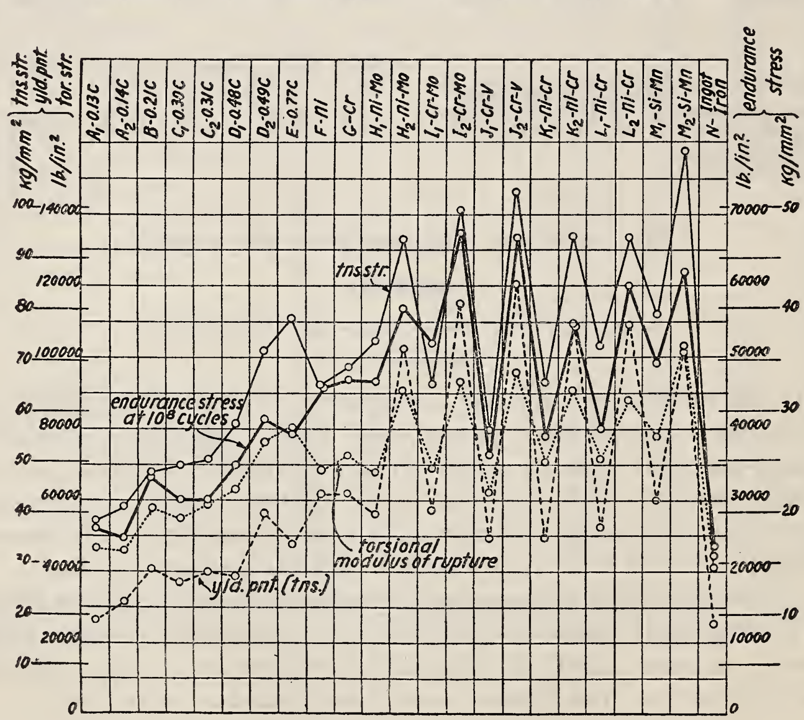

FIG. 34.—*Fatigue properties of carbon and alloy steels compared with other properties.*

D. J. McAdam, Chem. and Met. Eng., Dec. 14, 1921. For the chemical composition and heat treatment of steels see Table 22.

3. The ratio of endurance stress to Brinell hardness number, and the ratio of endurance stress to maximum torsional stress are nearly as uniform as the ratio of endurance stress to ultimate tensile stress.

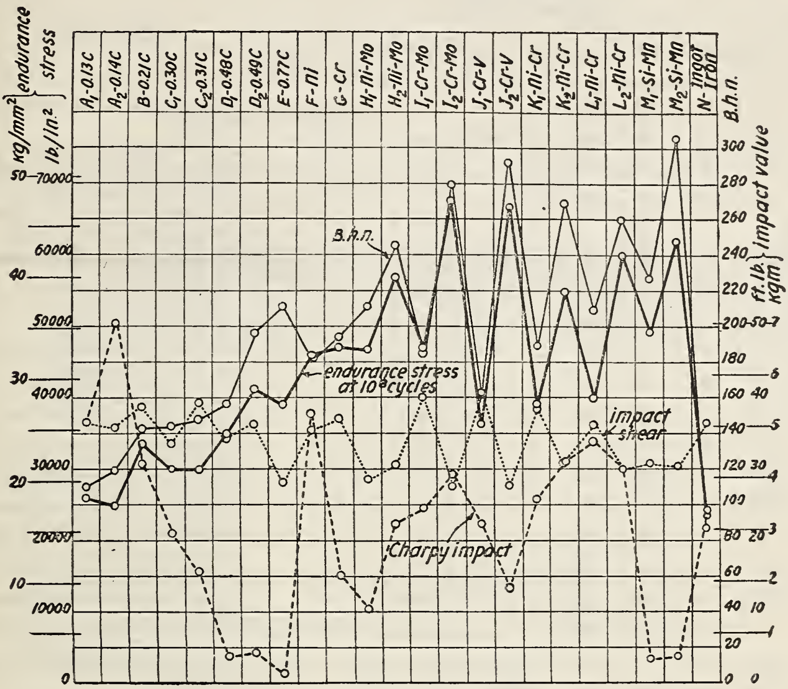

FIG. 35.—*Fatigue properties of carbon and alloy steels compared with other properties.*

D. J. McAdam, Chem. and Met. Eng., Dec. 14, 1921. For the chemical composition and heat treatment of steels see Table 22.

4. Until further evidence accumulates it may be stated that chemical composition has little effect on endurance properties other than its effect on tensile strength.

5. A comparison of impact test results with the results of endurance tests so far has shown no definite relationship.

TABLE 22.—Fatigue Properties of Carbon and Alloy Steels. (See figs. 33–35.)

[D. J. McAdam, Chemical and Metallurgical Engineering, December 14, 1921.]

Chemical Composition and Heat Treatment of Tested Steels.

Material.	Chemical composition.									Heat treatment.
	C	Mn	P	S	Si	Ni	Cr	V	Mo	
A_1	0.13	0.56	0.008	0.047	0.17					Annealed at 732° C. (1,350° F.).
A_2	.14	.53	.008	.056	.17				As, 0.010	As rolled.
B	.21	.82	.060	.080	.08	0.206	0.017			Do.
C_1	.29	.52	.010	.051	.17					Annealed at 649° C. (1,200° F.).
C_2	.31	.47	.013	.030	.16					Quenched in oil at 830° C. (1,525° F.) and annealed at 649° C. (1,200° F.).
D_1	.48	.60	.010	.038	.19					Annealed at 732° C. (1,350° F.).
D_2	.49	.63	.011	.036	.18					Quenched in oil at 871° C. (1,600° F.) and annealed at 621° C. (1,150° F.).
E	.77	.55	.037	.047	.18					Annealed at 732° C. (1,350° F.).
F	.29	.66	.005	.046	.14	3.70				To approximate proportional limit of 60,000 lb./in.² (42.2 kg/mm²).
G	.21	.59	.017	.017	.79	.13	13.31			To approximate proportional limit of 60,000 lb./in.² (42.2 kg/mm²).
H_1	.41	.45	.037	.020	.20	1.72			.13	To approximate proportional limit of 60,000 lb./in.² (42.2 kg/mm²).
H_2	.42	.47	.038	.020	.25	1.68			.12	To approximate proportional limit of 110,000 lb./in.² (77.4 kg/mm²).
I_1	.40	.52	.033	.024	.26		.95		.10	To approximate proportional limit of 60,000 lb./in.² (42.2 kg/mm²).
I_2	.42	.53	.032	.023	.25		1.04		.09	To approximate proportional limit of 110,000 lb./in.² (77.4 kg/mm²).
J_1	.24	.30	.046	.044	.29	1.73	1.16	0.23		To approximate proportional limit of 60,000 lb./in.² (42.2 kg/mm²).
J_2	.53	.50	.005	.038	.22		1.46	.23		To approximate proportional limit of 110,000 lb./in.² (77.4 kg/mm²).
K_1	.43	.63	.012	.038	.22	.47	1.10			To approximate proportional limit of 60,000 lb./in.² (42.2 kg/mm²).
K_2	.41	.64	.009	.033	.20	1.45	1.10			To approximate proportional limit of 110,000 lb./in.² (77.4 kg/mm²).
L_1	.33	.47	.007	.052	.18	3.18	.96			To approximate proportonal limit 60,000 lb./in.² (42.2 kg/mm²).
L_2	.33	.46	.006	.051	.19	3.16	.95			To approximate proportional limit of 110,000 lb./in.² (77.4 kg/mm²).
M_1	.55	.65	.024	.037	1.97					To approximate proportional limit of 60,000 lb./in.² (42.2 kg/mm²).
M_2	.51	.66	.029	.045	1.96					To approximate proportional limit of 110,000 lb./in.² (77.4 kg/mm²).
N	.023	.037	.002	.031	.005					As rolled.

B. [H. F. Moore, Ill. U. Eng. Exp. Sta. Bul. No. 124, p. 132; 1921.]

(See figs. 36 and 37.)

The following conclusions were drawn from the results obtained in the investigation:

1. For the metals tested under reversed stress there was observed a well-defined critical stress at which the relation between stress and the number of reversals necessary to cause failure changed markedly. Below this critical stress the metals withstood 100,000,000 reversals of stress and, so far as can be predicted from test results, would have withstood an indefinite number of such reversals. The name *endurance limit* has been given to this critical stress.

2. In the reconnaissance tests made in the field of ferrous metals no simple relation was found between the endurance limit and the "elastic limit," however determined. The ultimate tensile strength seemed to be a better index of the endurance limit under reversed stress than was the elastic limit. The Brinell hardness test seemed to furnish a still better

index of the endurance limit. The reason why the Brinell test and, to a less degree, the ultimate tensile strength seem to be better indices of the endurance limit than the elastic limit is not clear, and this result should be regarded as tentative. Elastic limits determined from compression tests and torsion tests gave no better index than did those from tension tests.

3. The single-blow impact tests (Charpy tests) and the repeated-impact tests did not furnish a reliable index for the endurance limit under reversed stress of the ferrous metals tested.

4. Accelerated or short-time tests of metals under repeated stress, using high stresses and consequent small numbers of repetitions to cause

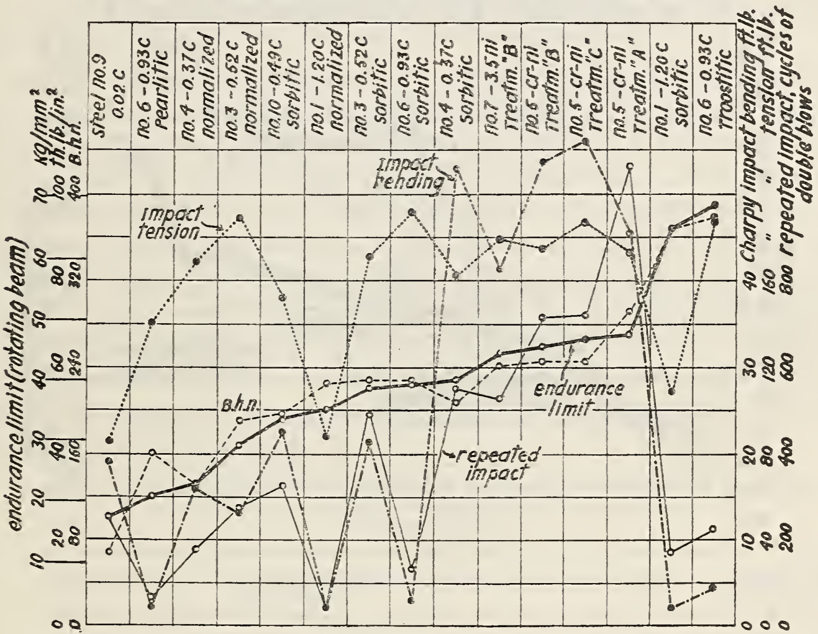

FIG. 36.—*Correlation between the endurance limit and other properties of steels.*

H. F. Moore, Ill. U. Eng. Exp. Sta. Bul., No. 124, 1921. Tests were made in a Farmer machine.

failure, are not reliable as indices of the ability of metal to withstand millions of repetitions of low stress.

5. The endurance limit for the ferrous metals tested could be predicted with a good degree of accuracy by the measurement of rise of temperature under reversed stress applied for a few minutes. This relation is explicable in view of the intercrystalline and intracrystalline slippage under repeated stress shown by the microscope. It is believed that this test, which is a development of a test proposed by C. E. Stromeyer, can be developed into a reliable commercial test of ferrous metals under repeated stress. Its applicability to nonferrous metals has not been investigated.

6. Abrupt changes of outline of specimens subjected to repeated stress greatly lowered their resistance. Cracks, nicks, and grooves caused in machine parts by wear, by accidental blows, by accidental heavy overload, or by improper heat treatment may cause such abrupt change of outline. Shoulders with short-radius fillets are a marked source of weakness.

7. Poor surface finish on specimens subjected to reversed stress was found to be a source of weakness. This weakness may be explained by

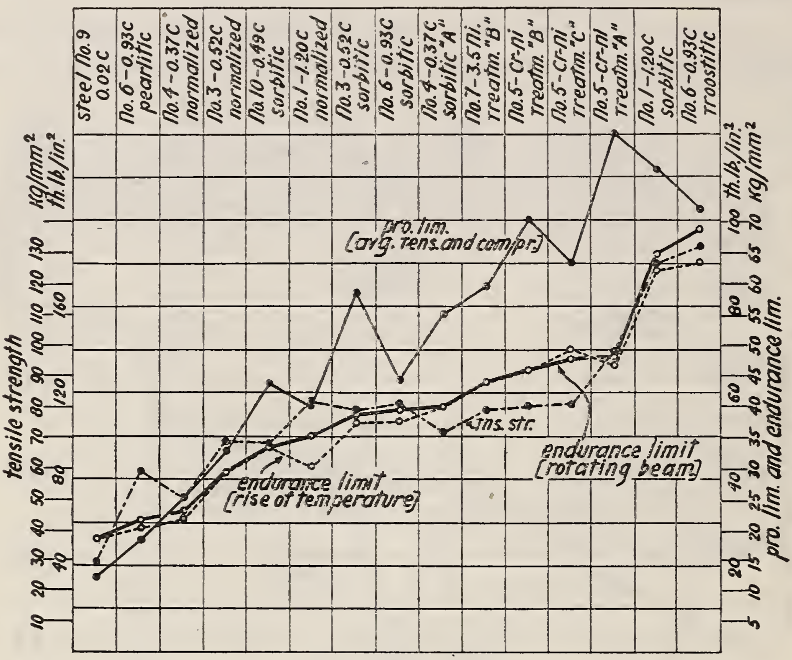

FIG. 37.—*Correlation between the endurance limit and the tensile properties of steels.*

H. F. Moore, Ill. U. Eng. Exp. Sta. Bul., No. 124, 1921. Tests were made in a Farmer machine.

the formation of cracks due to localized stress at the bottom of scratches or tool marks.

8. Stress above the endurance limits, due to either a heavy overload applied a few times or a light overload applied some thousands of times, was found to reduce somewhat the endurance limit of two ferrous metals tested.

9. In none of the ferrous metals tested did the endurance limit under completely reversed stress fall below 36 per cent of the tensile strength; for only one metal did it fall below 40 per cent, while for several metals it was more than 50 per cent. However, these metals were to a high degree free from inclusions or other internal defects; the specimens had no abrupt changes of outline and had a good surface finish.

10. It is well known that subjecting steel to a stress beyond the yield point raises the static elastic tensile strength to a marked degree. The effect is less marked on the endurance limit, although some increase was observed for 0.18 carbon steel with the surface polished after being stretched well beyond the yield point. Annealing of commercial cold-drawn screw stock was found to lower its endurance limit somewhat less than it did its static elastic strength.

11. The test results herein reported indicate the effectiveness of proper heat treatment in raising the endurance limit of the ferrous metals tested. Here, again, it should be noted that an increase in static elastic strength due to heat treatment is not a reliable index of increase of endurance limit under reversed stress.

12. The phenomenon known as "fatigue" of metals under repeated stress might better be called the "progressive failure" of metals. The most probable explanation seems to be that such failure is a progressive spread of microscopic fractures. A nucleus for damage may be a very small area of high, localized stress due to a groove, a scratch, or a crack; in other cases failure may be due to internal inclusions or irregularities of structure; it may be due to internal stress remaining after heat treatment; it may be due to a grain or group of grains unfavorably placed to resist stress; or failure may begin in the weaker grains of a metal whose structure consists of two or more kinds of grains; or it may, of course, begin in any portion of the metal which by accidental overload or otherwise is stressed to the yield point.

TABLE 23.—Effect of High Temperature on the Tensile Properties of Cast Iron.[1]

(See Tables 24 and 25.)

	Chemical composition of materials used.				Chemical composition of materials used.		
	A–1	A–2	A–3		A–1	A–2	A–3
Total carbon	3.286	3.144	2.845	S	0.110	0.110	0.155
Graphitic carbon	2.716	2.334	1.950	P	1.541	.868	1.036
Si	1.745	1.840	1.447	Mn	.155	.510	.460

[1] A. Campion and J. Donaldson, The Met. Ind., London, Aug. 11, 1922.

A—1 is used for stove plate and other light castings.

A—2 is a strong cast iron used for steam turbines and other marine work.

A—3 is a semisteel used for dies for tube drawing.

65516°—24——10

TABLE 24.—Effect of High Temperature on the Tensile Strength of Cast Iron.[1]

[For chemical composition, see Table 23.]

Temperature.		A-1				A-2				A-3			
		As cast.		Annealed.		As cast.		Annealed.		As cast.		Annealed.	
°C.	°F.	kg/mm²	lb./in.²	kg/mm²	lb./in.²	kg/mm²	lb./in.²	kg/mm²	lb./in.²	kg/mm²	lb./in.²	kg/mm²	lb./in.²
15	59	16.0	22,700	17.3	24,600	23.6	33,600	23.6	33,600	26.1	37,200	26.4	37,600
100	212	15.6	22,200	17.3	24,600	23.5	33,400	23.9	34,000	25.8	36,800	26.4	37,600
200	392	15.3	21,700	18.1	25,800	22.7	32,200	23.3	33,100	25.3	36,000	26.6	37,800
250	482	....	....	....	....	21.9	31,100	....	....	24.6	35,000	....	....
300	572	16.0	22,700	17.7	25,200	21.0	29,800	23.5	33,400	25.0	35,600	26.6	37,800
350	662	....	....	....	....	22.0	31,400	....	....	....	....	....	....
400	752	16.1	22,800	17.8	25,300	23.3	33,200	23.7	33,800	26.7	38,000	26.6	37,850
500	932	15.8	22,500	17.3	24,600	22.0	31,200	22.7	32,300	25.0	35,600	25.0	35,500
600	1,112	11.5	16,350	12.8	18,100	20.2	28,700	....	....	....	....	....	....
700	1,292	5.3	7,500	6.3	8,950	10.1	14,350	....	....	....	....	....	....
800	1,472	....	....	....	....	4.25	6,050	....	....	....	....	....	....

[1] The Met. Ind., London, Aug. 11, 1922.

TABLE 25.—Effect of Repeated Heating and Cooling on Tensile Strength of Cast Iron.[1]

[For chemical composition, see Table 23.]

Condition.	A-1		A-2		A-3	
	kg/mm²	lb./in.²	kg/mm²	lb./in.²	kg/mm²	lb./in.²
Original	16.1	22,800	23.6	33,600	26.1	37,200
After 25 heatings at 450° C. (842° F.)	15.3	21,800	21.2	30,200	23.4	33,200
After 25 heatings at 550° C. (1,022° F.)	....	....	20.5	29,100	22.0	31,300
After 55 heatings at 550° C. (1,022° F.)	11.8	16,800	....	....	....	....

[1] The Met. Ind., London, Aug. 11, 1922.

TABLE 26.—Effect of Temperature on Tensile Properties of Some Metals (see fig. 47).

Alloy.		Composition.						
No.	Name.	Sn	Pb	Cu	Fe	Zn	P	Al
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
1	Copper-tin bronze	12.46	0.06	87.02	0.30	0.20	....	....
2	....do	10.22	Trace.	89.50	.38	0	0.035	....
3	Brass	5.69	3.02	86.19	.20	5.03	....	....
4	Aluminum bronze	.03	.16	94.94	.14	....	....	4.90
5	....do	.48	.17	88.86	.75	.15	....	9.67
6	Cast manganese bronze	.51	Trace.	58.10	2.21	39.05	(Mn, 0.055)	....
7	U. S. Navy brass "S-C"	3.98	2.78	80.32	.24	12.80	....	....
8	U. S. Navy bronze "M"	7.72	1.22	86.92	.23	3.62	....	....
9	U. S. Navy gun bronze "G"	10.40	.39	87.60	.11	1.31	....	....
10	Cast Monel metal	.08	.13	27.11	5.46	(Mn, 2.33)	(Ni, 64.79)	(C, 0.32)
16	Rolled rod brass	.00	2.53	62.30	.15	34.84	....	....
18	Rolled Monel metal	....	....	27.22	2.38	(Mn, 1.56)	(Ni, 68.64)	(C, 0.025)
		Si	Mn	S	P	Graph C.	Comb C	C
11	Soft cast iron	2.57	0.60	0.103	0.73	3.31	0.17	....
12	Cast iron ("semisteel")	1.76	1.15	.103	.44	3.00	.47	....
13	Cupola malleable iron	.92	.51	.152	.183	2.96	Trace.	....
14	Cast steel	.22	.61	.068	.045	....	....	0.302
15	Cold-rolled shafting	.031	.80	.108	.079	....	....	.140
17	30 per cent nickel steel, rolled	.14	2.80	.017	.011	(Ni, 30.92)	....	.285

NOTE.—Analyses of materials used in tensile tests. Bregowsky and Spring, Proc. Internat. Assoc. for Testing Materials, 7 (1); 1912.

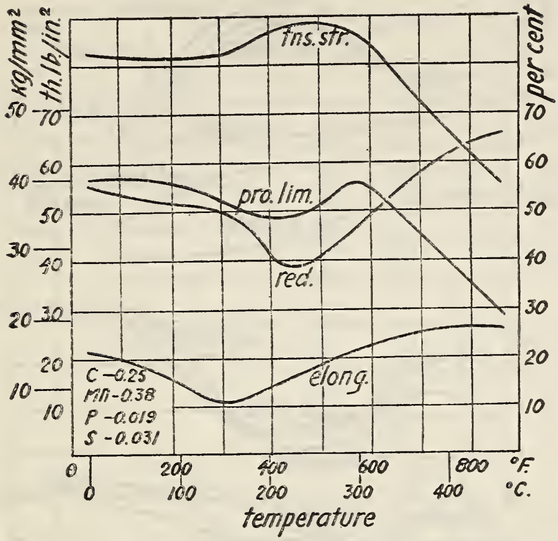

FIG. 38.—*Tensile properties of cold-rolled boiler plate at elevated temperatures.*

H. J. French, Chem. and Met. Eng., August 2, 1922.

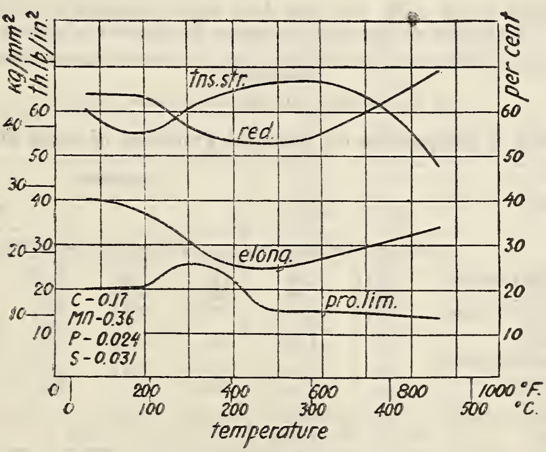

FIG. 39.—*Tensile properties of hot-rolled boiler plate at elevated temperatures.*

H. J. French, Chem. and Met. Eng., August 2, 1922.

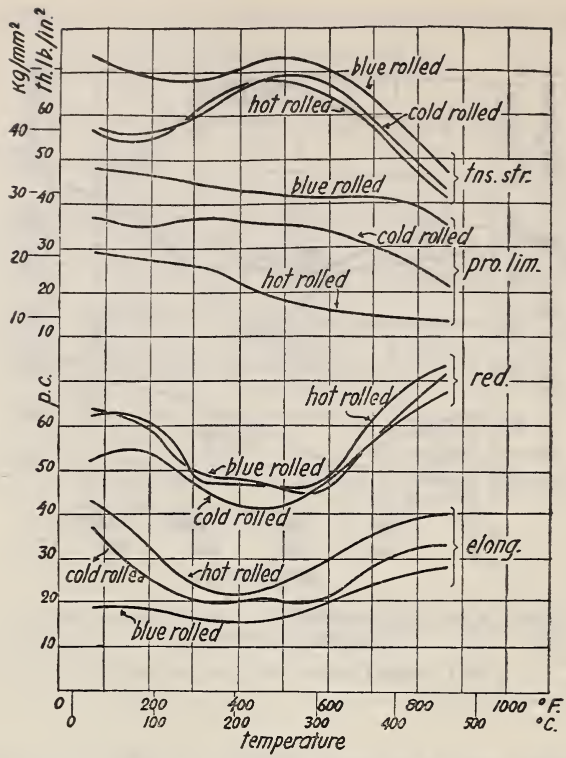

FIG. 40.—*Tensile properties of cold, hot, and blue rolled boiler plate at elevated temperatures as determined on specimens cut across the direction of rolling.*

Cold and blue rolled plates reduced 1/16 in. (1.6 mm) from ½ in. (12.7 mm) at room temperature and 300° C. (572° F.), respectively.

H. J. French, Chem. and Met. Eng., August 2, 1922.

TABLE 27.—Effect of Temperature on Torsional Properties of Some Metals (see fig. 48).

Alloy and name.	Composition.							
	Si	Mn	S	P	C	Ni	V	Cr
	Per cent.	Per cent.	Per cent	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
A. Cold-rolled shafting	0.011	0.73	0.117	0.198	0.093			
B. Cumberland cold-rolled shafting	.024	.50	.110	.101	.083			
C. O. H. machinery steel	.024	.49	.029	.013	.084			
D. 3½ per cent nickel-vanadium steel	.132	.45	.042	.032	.365	3.25	0.45	
E. 25 per cent nickel steel					.186	25.03		
F. 30 per cent nickel steel	.14	2.80	.017	.011	.275	30.92		
P. Medium Cumberland cold-rolled steel	.12	.51	.050	.013	.375			
N. Vanadium tool steel	.16	.32	.034	.014	.722		.145	0.49

Alloy and name.	Sn	Pb	Cu	Fe	Ni	Mn	C	Zn	P	Al
	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.
G. 1⅛″ rolled Monel metal		0.28	27.08	2.50	68.40	1.52	0.186			
M. ⅞″ rolled Monel metal			27.22	2.38	68.64	1.56	.225			
H. Rod brass	0.18	2.34	61.08	.42				35.72		
I. Tobin bronze	.80	0	59.86	.46				38.94	0.0015	
J. Elephant (phosphor) bronze	3.87	0	95.52	.16				0	.307	
K. Delta metal	.76	.56	56.56	2.40				39.36	.004	
L. Parsons' manganese bronze	.64	0	59.58	1.22				38.08		0.34

NOTE.—Analyses of materials used in torsional tests. Bregowsky and Spring, Proc. Internat. Assoc. for Testing Materials, 7 (1); 1912.

TABLE 28.—Effect of Temperature on the Tensile Properties of Some Metals.[1]

Metal.	Temperature.		Tensile strength.		Elongation.	Reduction of area.
	°C.	°F.	kg/mm²	lb./in.²	Per cent.	Per cent.
Cadmium, annealed at 100° C. (212 °F.)	20	68	6.4	9,100	17	49
	130	266	2.45	3,480	34	51
	237	459	.55	780	45	44
Copper, annealed at 600° C. (1,112° F.)[2]	20	68	22.8	32,400	32	67
	160	320	18.4	26,200	32	71
	300	572	13.2	18,750	30	50
	410	770	8.5	12,100	19	24
	555	1,031	4.85	6,900	14	19
	650	1,202	3.3	4,700	15	20
	793	1,460	1.9	2,700	14	34
	970	1,778	.8	1,140	6	15
Low carbon steel, annealed at 900° C. (1,652° F.)	20	68	33.4	47,500	21	68
	225	437	43.0	61,200	4	57
	275	527	44.5	63,300	7	51
	335	635	37.1	52,800	18	61
	407	764	27.0	38,400	21	68
	617	1,142	7.6	10,800	45	95
	807	1,484	2.3	3,270	39	89
	835	1,535	2.2	3,130	39	88
	1,010	1,850	2.9	4,120	....	....
	1,100	2,012	2.7	3,840	....	....
	1,200	2,192	1.3	1,850	....	....
Medium carbon steel, annealed at 700° C. (1,292° F.)	20	68	45.0	64,000	16	63
	250	482	57.2	81,300	5	43
	330	626	52.6	74,700	9	54
	412	774	44.5	63,300	19	55
	485	905	27.8	39,500	20	62
	617	1,142	15.0	21,300	32	80
	722	1,332	7.0	9,940	35	63
Lead, annealed at 100° C. (212° F.)	20	68	1.35	1,920	31	100
	82	180	.8	1,140	24	100
	150	302	.5	710	33	100
	195	383	.4	570	20	100
	265	509	.2	280	20	100
Magnesium, annealed at 350° C. (662° F.)	20	68	17.0	24,200	0	2
	83	181	13.4	19,050	10	13
	175	347	6.75	9,600	35	45
	273	523	2.95	4,190	46	76
	355	671	1.6	2,270	50	87
	550	1,022	.3	430	40	100
Nickel, annealed at 900° C. (1,652° F.)	20	68	49.3	70,000	26	72
	195	383	44.8	63,600	26	66
	300	572	44.8	63,600	31	67
	455	851	30.2	42,900	20	31
	593	1,100	20.6	29,300	16	25
	800	1,472	9.2	13,100	11	18
	1,000	1,832	4.0	5,690	11	15
	1,100	2,012	2.5	3,550	11	24
Tin, annealed at 50° C. (122° F.)	20	68	27.5	39,100	40	74
	53	127	17.5	24,900	45	72
	100	212	10.5	14,900	45	82
	153	307	6.5	9,240	41	97
	180	356	4.5	6,400	10	12
	297	405	2.5	3,550	0	0
Zinc, annealed at 200° C. (392° F.)	20	68	11.3	16,050	5	7
	112	234	7.25	10,300	8	15
	150	302	5.0	7,100	7	10
	247	477	2.25	3,200	6	11
	330	626	1.25	1,780	8	15
	405	761	.03	40	2	2

[1] P. Ludwik, Zeitschrift des Vereines der Deutscher Ingenieure, p. 657, Aug. 14, 1915.
[2] The rate of loading not given.

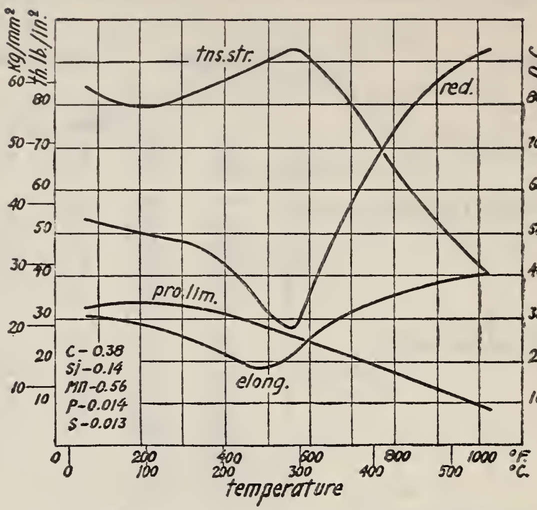

Fig. 41.—*Tensile properties at elevated temperatures of 0.38 per cent carbon steel.*

H. J. French, B. S. Tech. Paper No. 205; 1921.

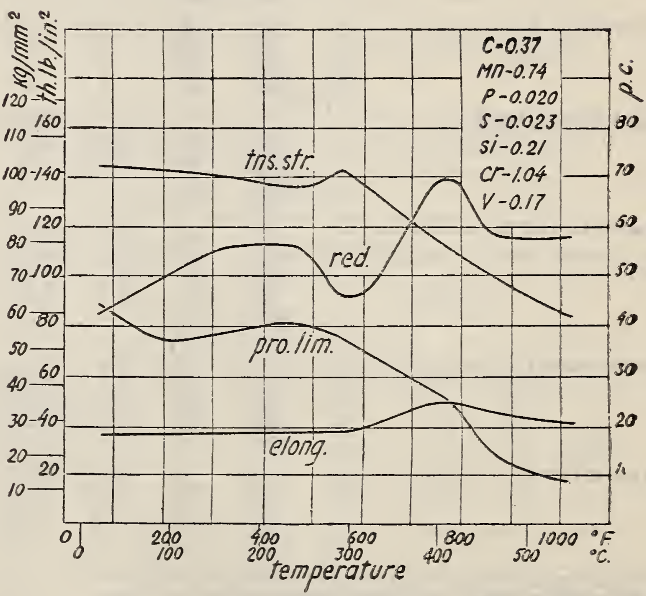

Fig. 42.—*Tensile properties at elevated temperatures of chromium-vanadium, steel containing 1 per cent chromium, 0.2 per cent vanadium, and 0.37 per cent carbon.*

H. J. French, B. S. Tech. Paper No. 205; 1921.

TABLE 29.—Effect of Temperature on the Tensile Strength of High-Speed Steel.[1]

Temperature.		Tensile strength.				Temperature.		Tensile strength.			
		Grade A.		Grade B.				Grade A.		Grade B.	
°C.	°F.	C, 0.63; Cr, 3.55; V, 0.97; W, 17.04.		C, 0.65; Cr, 3.33; V, 1.78; W, 13.85.		°C.	°F.	C, 0.63; Cr, 3.55; V, 0.97; W, 17.04.		C, 0.65; Cr, 3.33; V, 1.78; W, 13.85.	
		kg/mm²	lb./in.²	kg/mm²	lb./in.²			kg/mm²	lb./in.²	kg/mm²	lb./in².
38	100	171.2	243,500	151.1	215,000	538	1,000	168.7	240,000	156.8	223,000
204	400	180.3	256,500	....	....	593	1,100	154.7	220,000	140.6	200,000
316	600	202.0	287,500	191.9	273,000	649	1,200	130.1	185,000	112.5	160,000
427	800	200.4	285,000	182.9	260,000						

[1] Met. Ind., London, Apr. 14, 1922.

TABLE 30.—Flow of Steels Under Constant Load at High Temperatures.[1]

[For Chemical Composition and Heat Treatment of Tested Steels, see Table 31.]

Type of steel.	Temperature range.		Actual duration of test before fracture or withdrawal.	Estimated time at load of 13.4 kg/mm² or 19,000 lb./in. causing fracture.	Elongation on middle 50.8 mm or 2 inches.	Reduction of area.
	°C.	°F.	Hours.	Hours.	Per cent.	Per cent.
0.30 per cent carbon	500–550	932–1,022	1,739 withdrawn	[2] 3,400	....	....
	550–600	1,022–1,112	956 broken	956	30.0	85
	600–650	1,112–1,202	28 broken	28	29.0	88
	700	1,292	....	3 min.	32.5	92
	775	1,427	....	[2] 6 sec.	....	....
0.45 per cent carbon	500–550	932–1,022	1,405 withdrawn	[2] 2,600	....	....
	550–600	1,022–1,112	195 broken	195	32.0	84
	600–650	1,112–1,202	26 broken	26	32.0	84
	680	1,256	....	3 min.	33.0	90
	775	1,427	....	[2] 6 sec.	....	....
Nickel-chromium	500–550	932–1,022	701 broken	701	40.0	85
	550–600	1,022–1,112	88 broken	88	41.0	88
	600–650	1,112–1,202	8 broken	8	38.0	91
	685	1,265	....	3 min.	40.0	94
	805	1,481	....	[2] 6 sec.	....	....
14.7 per cent chromium	500–550	932–1,022	1,740 withdrawn	[2] 10,000	....	....
	550–600	1,022–1,112	1,728 broken	1,728	34.0	84
	600–650	1,112–1,202	79 broken	79	37.0	85
	735	1,355	....	3 min.	36.0	91
	800	1,472	....	[2] 6 sec.	....	....
High-speed	500–550	932–1,022	1,717 withdrawn	[2] 81,000	....	....
	550–600	1,022–1,112	2,002 withdrawn	[2] 25,000	....	....
	600–650	1,112–1,202	380 withdrawn	[2] 4,500	....	....
	650–700	1,202–1,292	564 broken	564	19.0	47
	700–750	1,292–1,382	21 broken	21	24.0	60
	815	1,499	....	3 min.	32.0	82
	955	1,751	....	[2] 6 sec.	....	....
Nickel-chromium alloy (as cast)	500–550	932–1,022	521 withdrawn	....	....	....
	550–600	1,022–1,112	3,604 withdrawn	[2] 108,120	....	....
	600–650	1,112–1,202	6,041 broken	6,041	17.5	40
	650–700	1,202–1,292	901 broken	901	14.5	23
	700–750	1,292–1,382	273 broken	273	27.0	51
	895	1,643	....	3 min.	24.5	44
	925	1,697	....	1 min.	25.0	47
	965	1.769	....	[2] 6 sec.	....	....

[1] J. H. S. Dickenson, Eng., Sept. 15, 1922. [2] Estimated time.

TABLE 31.—Flow of Steels Under Constant Load at High Temperatures. See Table 30.[1]

[Chemical Composition and Heat Treatment of Tested Steels.]

Class of steel.	Diameter of bar.	Heat treatment before machining.	Chemical composition.								
			C	Si	Mn	S	P	Ni	Cr	W	V
	Inches.										
0.30 per cent carbon.	$\frac{7}{8}$ (22.2 mm)	Oil hardened, 850° C. (1,562° F.); tempered, 575° C. (1,067° F.).	0.30	0.12	0.54	0.027	0.038	0.51	0.14	....	......
0.45 per cent carbon.	1 (25.4 mm)	Water hardened, 850° C. (1,562° F.); tempered, 600° C. (1,112° F.).	.45	.37	.79	.022	.024	....	.02	....	......
Nickel-chromium..	$\frac{3}{4}$ (19.05 mm)	Oil hardened, 830° C. (1,526° F.); tempered, 600° C. (1,112° F.).	.25	.11	.36	.031	.026	3.63	.55	....	......
14.7 per cent chromium.	$\frac{7}{8}$ (22.2 mm)	Oil hardened, 925° C. (1,697° F.); tempered, 650° C. (1,202° F.).	.26	.59	.17	.066	.016	.39	14.68	....	......
High-speed........	$\frac{13}{16}$ (20.6 mm)	Annealed, 800° C. (1,472° F.).	.60	.28	.23	.044	.029	....	3.49	14.09	0.72
Nickel-chromium alloy (cast).	....	....	.54	.73	.10	.032	.030	69.90	15.50	....	......

[1] J. H. S. Dickenson, Eng., Sept. 15, 1922.

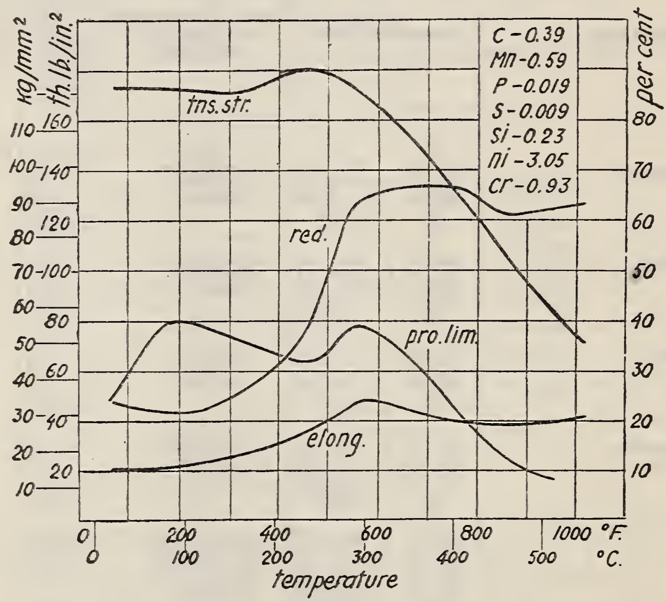

FIG. 43.—*Tensile properties at elevated temperatures of nickel-chromium steel containing 3 per cent nickel, 1 per cent chromium, and 0.39 per cent carbon.*

H. J. French, B. S. Tech. Paper No. 205; 1921.

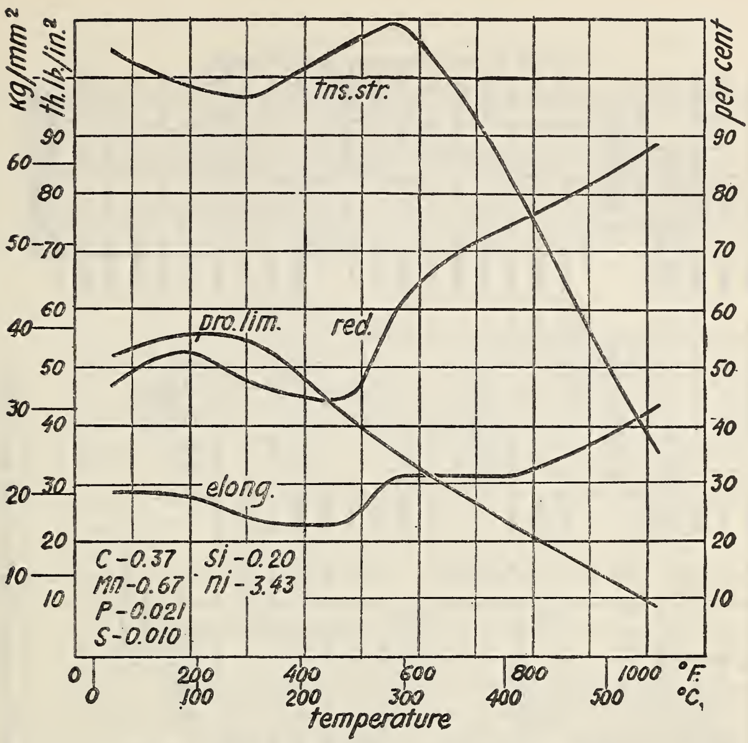

FIG. 44.—*Tensile properties at elevated temperatures of 3½ per cent nickel steel containing 0.37 per cent carbon.*

H. J. French, B. S. Tech. Paper No. 205; 1921.

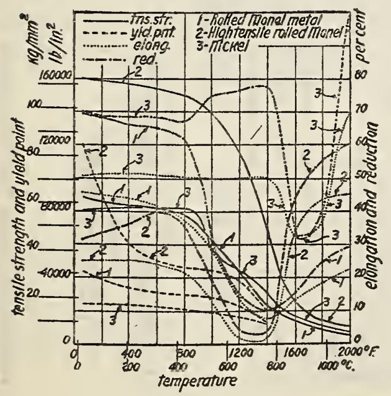

FIG. 45.—*Tensile properties of Monel metal and nickel at high temperatures.*

Communicated by P. Merica of the International Nickel Co., 1922.

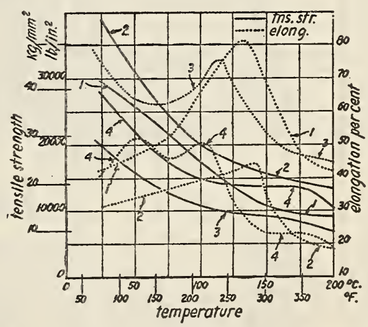

FIG. 46.—*Variation of tensile properties of rolled zinc with temperature.*

C. Mathewson, C. Trewin, and W. Finkeldey, Trans. Am. Inst. Min. Met. Eng., **64**, p. 305; 1920.

1. With grain } Common zinc with 0.37 Pb,
2. Across grain } 0.016 Fe, 0.04 Cd.
3. With grain } Pure zinc with 0.065 Pb,
4. Across grain } 0.018 Fe.

Thickness of specimens was 1.4 mm or 0.055 in. Scleroscope hardness of common zinc, 27 and that of pure zinc, 23.

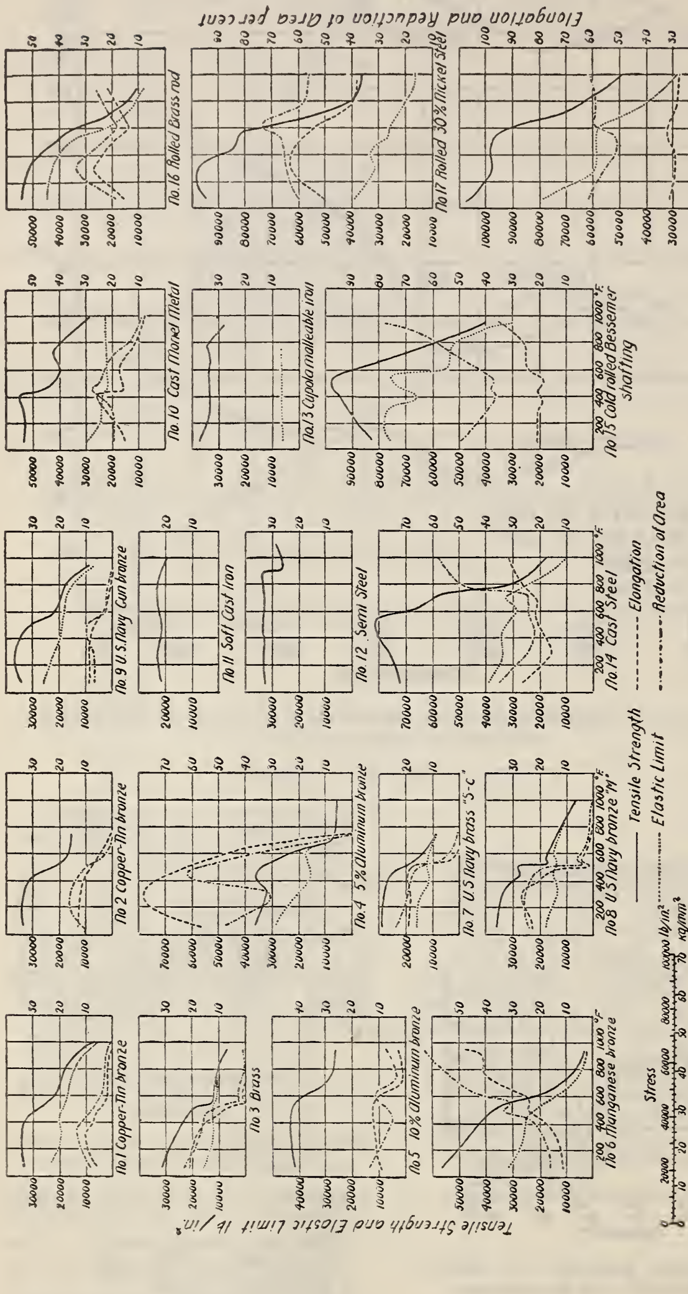

FIG. 47.—*Effect of temperature on tensile properties of some metals.*

Bregowsky and Spring, Proc. 6th congress of the International Association for Testing Materials, VII, 1; 1912. For chemical composition of tested metals see Table 26.

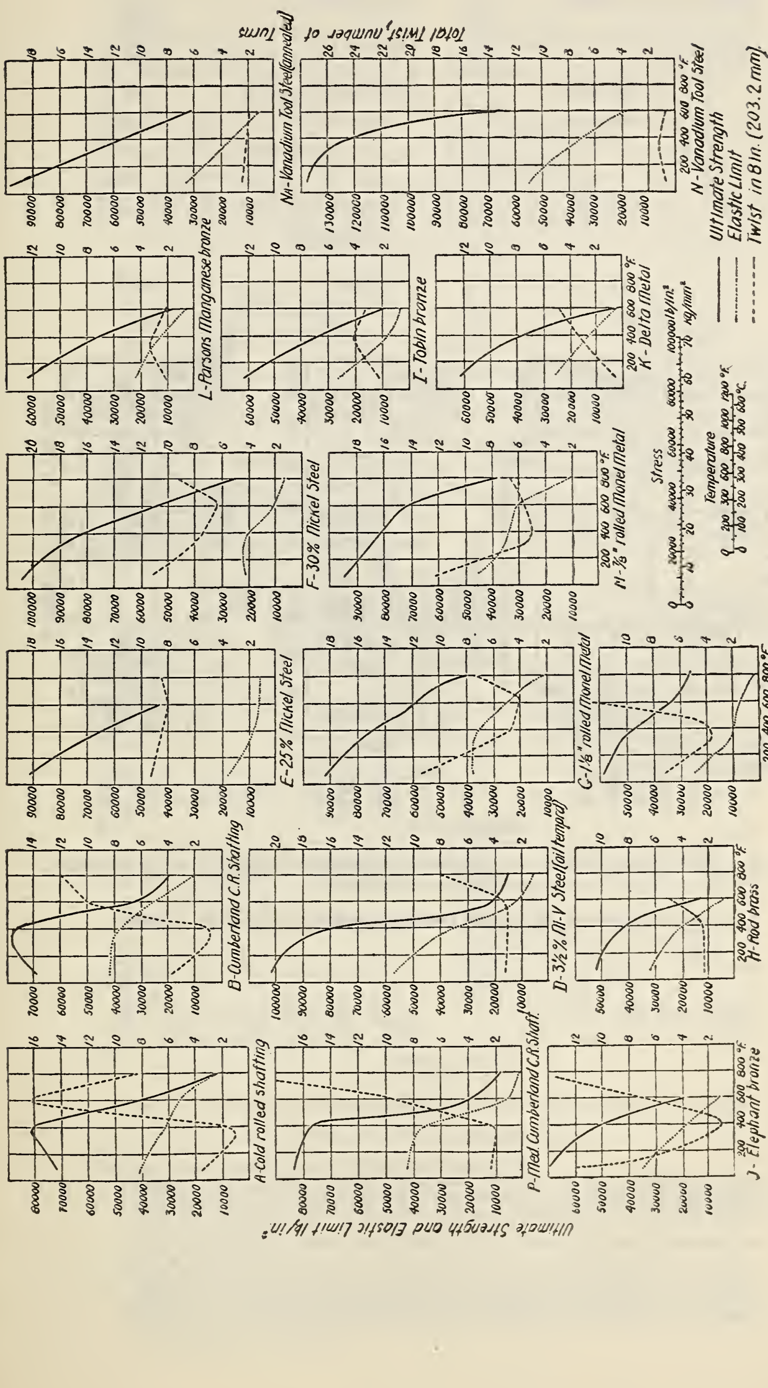

FIG. 48.—*Effect of temperature on torsional properties of some metals.*

Bregowsky and Spring, Proc. 6th congress of the International Association for Testing Materials, VII, 1; 1912. For chemical composition of tested metals see Table 26.

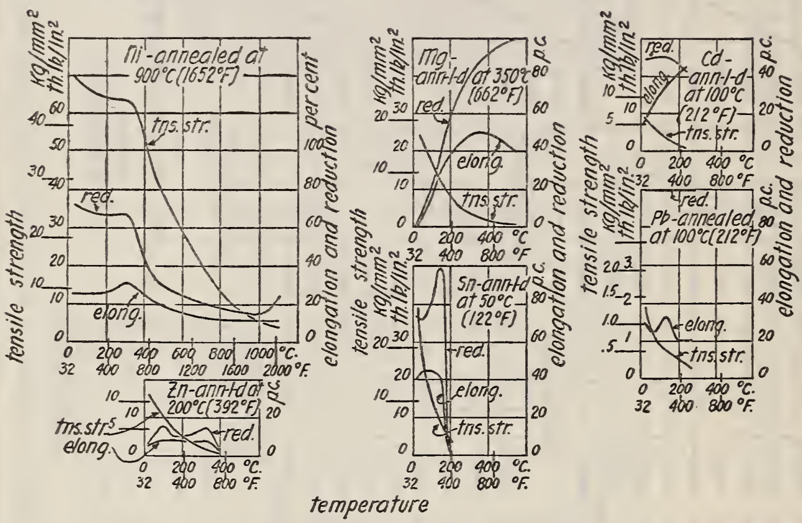

FIG. 49.—*Effect of temperature on the tensile properties of nickel, zinc, magnesium, tin, cadmium, and lead.*

P. Ludwik, Zeitschrift des Vereines Deutscher Ingenieure, p. 657, Aug. 14, 1915.

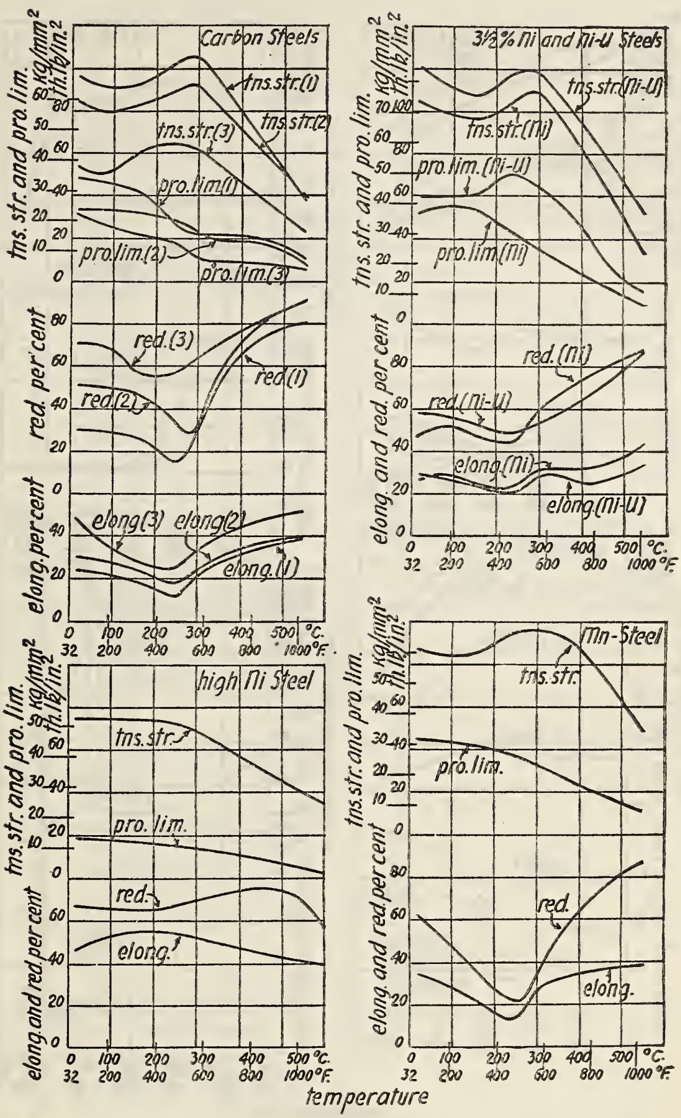

FIG. 50.—*Effect of high temperature on the tensile properties of steels.*

H. J. French, B. S. Tech. Paper No. 219; 1922.

Chemical composition and heat treatment of tested steels:

Carbon: (1) C, 0.59; Mn, 0.40; Si, 0.05; p, 0.017; S, 0.027; Cr, 0.05. Cooled in air from 850° C. (1,562° F.). (2) C, 0.38; Mn, 0.55; Si, 0.14; P, 0.014; S, 0.013. Cooled in air from 850° C. (1,562° F.). (3) C, 0.18; Mn, 0.43; P, 0.017; S, 0.035. Cooled in air from 900° C. (1,652° F.).

3½ per cent Ni: C, 0.37; Mn, 0.67; Si, 0.20; P, 0.021; S, 0.010; Ni, 3.43 Air cooled from 800° C. (1,472° F.).

Nickel-uranium: C, 0.43; Mn, 0.50; Si, 0.50; P, 0.007; S, 0.010; Ni, 2.79; U, 0.35. Quenched in water from 800° C. (1,472° F.) and cooled in air from 600° C (1,112° F.).

High Ni: C, 0.20; Mn, 0.80; Si, 0.15; Ni, 28.6. Cooled in air from 800° C. (1,472° F.).

Manganese: C, 0.28; Mn, 1.26; Si, 0.12; P, 0.07; S, 0.047; Ni, 0.12; Cr, 0.05. Cooled in air from 850° C. (1,562° F.).

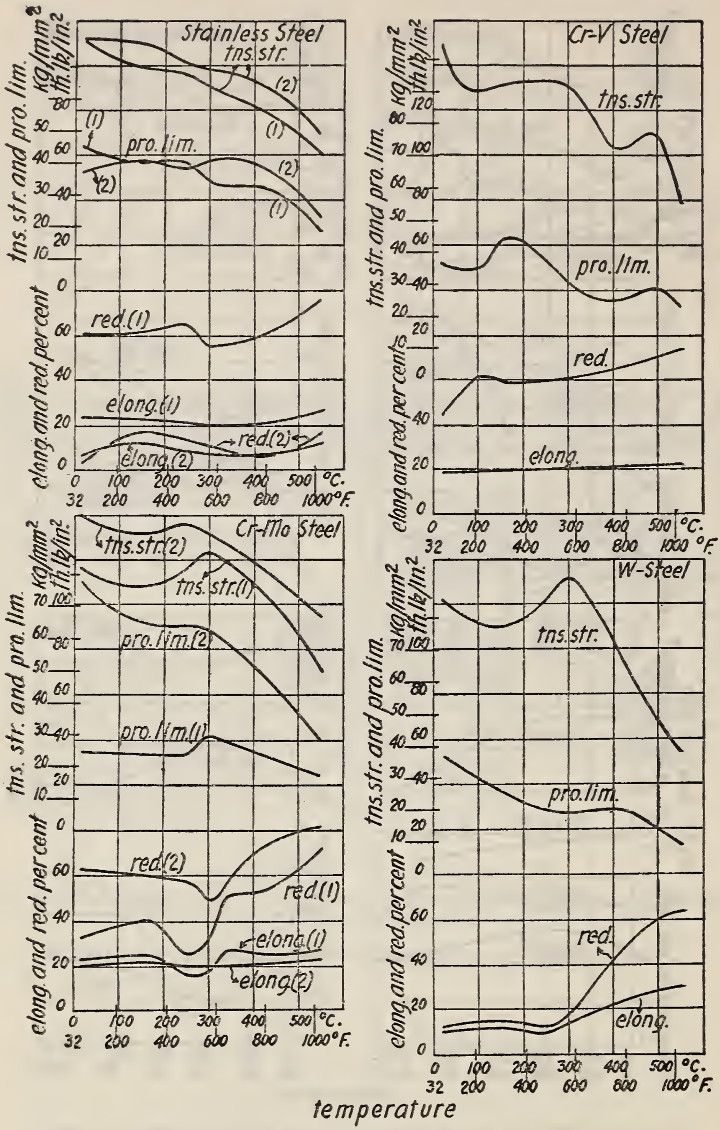

FIG. 51.—*Effect of high temperature on the tensile properties of steels.*

H. J. French, B. S. Tech. Paper No. 219; 1922.

Chemical composition and heat treatment of tested steels:

Stainless: C, 0.31; Mn, 0.24; Si, 0.054; P, 0.020; S, 0.020; Cr, 12.75. (1) Quenched in oil from 955° C. (1,751° F.) and cooled in air from 675° C. (1,247° F.). (2) Quenched in oil from 1,150° C. (2,102° F.) and cooled in air from 675° C. (1,247° F.).

Chromium Vanadium (die steel): C, 0.38; Mn, 0.56; Si, 0.16; P, 0.011; S, 0.014; Cr. 1.98; V, 0.18. Cooled in air from 800° C. (1,472° F.).

Chromium-molybedenum: C, 0.27; Mn, 0.62; Si, 0.26; P, 0.018; S, 0.008; Cr, 0.99; Mo, 0.41; Ni, 0.08. (1) Cooled in air from 815° C. (1,499° F.). (2) Queched in oil from 845° C. (1,553° F.) and cooled in air from 600° C. (1,112° F.).

Tungsten: C, 0.95; Si, 0.26; W, 1.17. Cooled in air from 815° C. (1,499° F.).

TABLE 32.—Tensile Strength of Steels at Elevated Temperatures Under Rapidly (1–2 min.) Applied Load.[1]

[For Chemical Composition and Heat Treatment of Tested Steels see Table 31.]

Temperature.		0.30 per cent carbon.			0.45 per cent carbon.[2]			Nickel-chromium.			14.7 per cent chromium.			High-speed.		
		Tensile strength.		Reduction of area.	Tensile strength.		Reduction of area.	Tensile strength.		Reduction of area.	Tensile strength.		Reduction of area.	Tensile strength.		Reduction of area.
°C.	°F.	kg/mm²	lb./in.²	Per cent.	kg/mm²	lb./in.²	Per cent.	kg/mm²	lb./in.²	Per cent.	kg/mm²	lb./in.²	Per cent.	kg/mm²	lb./in.²	Per cent.
Room temperature....		68.0	96,800	64.8	80.4	114,400	64.8	83.1	118,200	66.8	85.0	121,000	57.0	86.1	122,500	15.0
100	212	63.6	90,500	59.2	74.0	105,200	59.2	80.6	114,700	64.8	78.5	111,800	54.6	86.6	123,200	23.0
200	392	65.8	93,500	55.8	74.9	106,600	60.4	80.3	114,300	62.6	74.3	105,800	58.1	82.5	117,400	21.4
300	572	71.8	102,200	51.0	77.5	110,200	53.4	82.5	117,400	55.2	73.6	104,800	57.0	83.1	118,200	32.0
400	752	64.1	91,300	67.8	73.6	104,800	69.9	74.0	105,300	68.8	70.0	99,500	52.2	70.9	100,800	27.6
500	932	43.5	61,800	79.4	52.2	74,400	83.4	56.7	80,600	82.7	59.8	85,100	64.4	58.9	83,800	32.0
600	1,112	32.8	46,600	86.1	38.4	54,700	84.1	36.5	52,000	88.6	43.5	61,800	70.7	42.7	60,700	58.1
700	1,292	19.8	28,200	92.8	16.4	23,300	92.0	21.1	30,000	88.6	27.4	39,000	84.1	36.2	51,500	62.6
800	1,472	11.3	16,100	99.0	12.9	18,400	93.4	13.9	19,700	96.2	13.9	19,700	93.4	21.4	30,500	65.4
900	1,652	8.0	11,400	99.6	6.9	9,850	95.2	8.5	12,100	95.4	10.1	14,300	91.4	16.4	23,300	75.3
1,000	1,832	6.3	8,960	99.8	5.4	7,610	98.8	5.7	8,060	99.9	9.6	13,700	91.4	11.3	16,100	80.3

[1] J. H. S. Dickenson, Eng., Sept. 15, 1922.

[2] Oil hardened 870° C. (1,598° F.), tempered 600° C. (1,112° F.).

TABLE 33.—Tensile Properties of Molybdenum Wire at High Temperatures.[1]

Condition.	Temperature.		Tensile strength.		Elongation in 50.8 mm (2 in.).	Reduction of area.
	°C	°F.	kg/mm²	lb./in.²	Per cent.	Per cent.
Treated to develop extremely large grains	−185	−301	68.5	97,500	0.0	0.0
	25	77	29.9	42,500	3.15	.0
	100	212	24.6	35,000	4.30	.0
	200	392	19.7	28,000	8.70	.0
	300	572	21.8	31,000	10.20	100
	400	752	19.3	27,500	6.25	100
	500	932	19.0	27,000	3.10	100
	600	1,112	19.7	28,000	2.35	100
	700	1,292	21.1	30,000	3.15	100
	900	1,652	20.7	29,500	3.10	100
Treated to develop very small grains	−185	−301	105.9	150,500	.40	0.0
	−50	−58	105.5	150,000	11.75	55
	25	77	88.0	125,000	20.00	66
	100	212	80.2	114,000	17.30	68
	200	392	73.9	105,000	14.00	78
	300	572	66.8	95,000	9.40	85
	400	752	61.8	88,000	7.00	86
	500	932	56.2	80,000	6.25	89
	600	1,112	55.5	79,000	2.35	90
	700	1,292	53.8	76,500	2.35	93
	900	1,652	49.9	71,000	1.80	93
Swaged and drawn hot at 1,300 to 1,000° C. (2,372 to 1,832° F.) from 0.125 to 0.025 in. (3.33 to 0.66 mm).	−185	−301	147.8	210,000	0.0	0.0
	25	77	104.0	148,000	4.70	68
	100	212	92.2	131,000	1.55	71
	200	392	84.4	120,000	.80	75
	300	572	73.2	104,000	.80	79
	400	752	70.3	100,000	.80	87
	500	932	68.9	98,000	Less than .5	89
	600	1,112	67.5	96,000	Less than .5	88
	700	1,292	56.2	80,000	Less than .5	89
	900	1,652	54.8	[2] 78,000	Less than .5	88

[1] W. P. Sykes, Trans. Am. Inst. Min. and Metal. Eng., **64**, p. 780; 1920.
[2] Rapid loading.

TABLE 34.—Tensile Properties of Nickel Wire at High Temperatures.[1]

Condition.	Temperature.		Tensile strength.		Elongation in 50.8 mm (2 in.).	Reduction of area.
	°C.	°F.	kg/mm²	lb./in.²	Per cent.	Per cent.
Drawn cold from 0.040 to 0.025 in. (1.02 to 0.64 mm)	−185	−301	102.0	145,000	3.15	60
	25	77	87.2	124,000	1.06	70
	100	212	85.8	122,000	.8	65
	200	392	81.6	116,000	.0	60
	300	572	78.0	111,000	.0	75
	400	752	67.5	96,000	.8	73
	500	932	59.7	85,000	.8	69
	600	1,112	58.3	83,000	.8	65
	700	1,292	14.1	20,000	20.3	50
	800	1,472	12.0	17,000	20.5	45
Drawn at 400° C. (752° F.) from 0.040 to 0.025 in. (1.02 to 0.64 mm).	−185	−301	91.0	129,500	3.98	50
	25	77	77.4	110,000	3.12	73
	100	212	73.2	104,000	2.35	73
	200	392	68.9	98,000	2.35	73
	300	572	60.4	86,000	1.55	68
	400	752	54.1	77,000	1.60	63
	500	932	48.5	69,000	1.60	73
	600	1,112	40.8	58,000	1.60	68
	700	1,292	12.7	18,000	13.0	47
	800	1,472	7.7	11,000	18.0	48
Drawn cold from 0.095 to 0.025 in. (2.41 to 0.64 mm)	−185	−301	109.0	155,000	3.12	54
	25	77	93.5	133,000	1.06	58
	100	212	90.7	129,000	.80	52
	200	392	85.1	121,000	.0	52
	300	572	83.7	119,000	.0	58
	400	752	75.2	107,000	.0	56
	500	932	61.2	87,000	.80	63
	600	1,112	58.4	83,000	.80	55
	700	1,292	15.5	22,000	18.5	82
	800	1,472	9.1	13,000	15.5	65
	900	1,652	6.0	8,500	20.0	....
Drawn cold from 0.095 to 0.025 in. (2.41 to 0.64 mm) and annealed at 800° C. (1,472° F.).	−185	−301	59.0	84,000	22.0	[2] 58
	25	77	42.2	60,000	22.0	75
	100	212	39.3	56,000	20.3	73
	200	392	35.1	50,000	15.5	68
	300	572	35.1	50,000	17.5	75
	400	752	30.2	43,000	17.25	75
	500	932	23.9	34,000	19.5	75
	600	1,112	17.6	25,000	15.5	65
	700	1,292	12.0	17,000	15.5	60
	800	1,472	9.1	13,000	15.5	45
	900	1,652	6.3	9,000	15.5	39
	1,000	1,832	4.9	7,000	26.5	48

[1] W. P. Sykes, Trans. Am. Inst. Min. and Metal. Eng., 64, p. 780; 1920. [2] Rapid loading.

TABLE 35.—Compression Tests of Some Steels at High Temperature.[1]

[See Figs. 52 to 57.]

CHEMICAL ANALYSIS OF TESTED STEELS.[2]

Steel.	Chemical composition.						
	C	Mn	P	S	Si	Cr	Ni
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
A	0.07	0.43	0.069	0.052	0.008	....	....
B	.10	.37	.012	.051	.009	....	....
C	.32	.53	.013	.037	.015	....	....
D	.95	.20	.014	.011	.250	....	....
E	.33	.59	.010	.046	.144	0.51	1.14
F	.31	.50	.032	.029	.17	.94	2.89

[1] Results obtained by H. J. French, unpublished data of the Bureau of Standards; 1923.
[2] The specimens were 0.75 in. (19.05 mm) in diameter and 3.25 in. (82.55 mm) long. The speed of the testing machine was about 0.07 in. (1.78 mm) per minute.

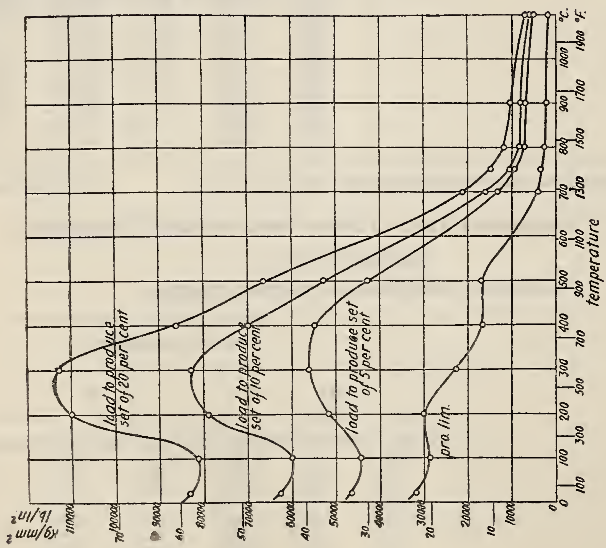

FIG. 52.—*Compression tests of wrought iron at elevated temperatures.*

Results obtained by H. J. French, unpublished data of the Bureau of Standards, 1923. For chemical composition see Table 35, material A.

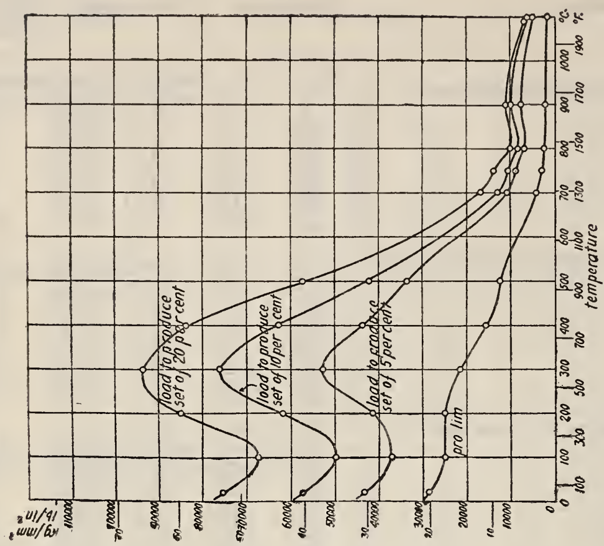

FIG. 53.—*Compression tests of 0.10 per cent carbon steel at elevated temperature.*

Results obtained by H. J. French, unpublished data of the Bureau of Standards, 1923. For chemical composition see Table 35, material B.

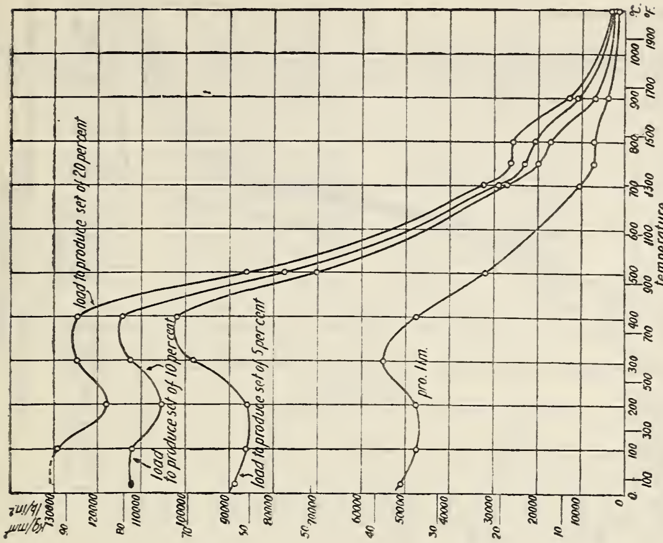

FIG. 55.—*Compression tests of 0.95 per cent carbon steel at elevated temperature.*

Results obtained by H. J. French, unpublished data of the Bureau of Standards, 1923. For chemical composition see Table 35, material D.

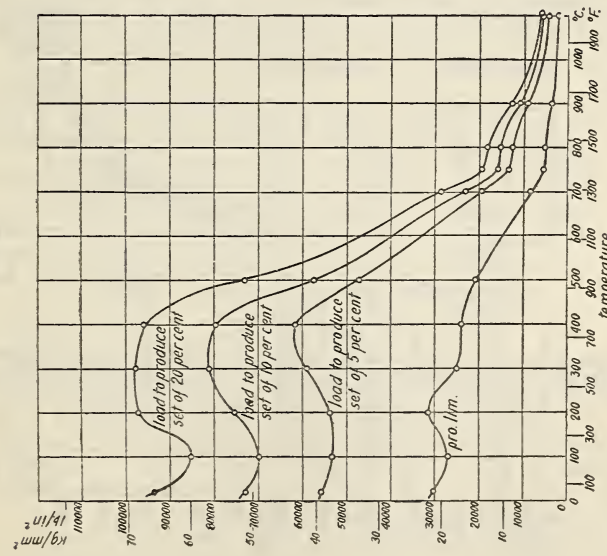

FIG. 54.—*Compression tests of 0.32 per cent carbon steel at elevated temperature.*

Results obtained by H. J. French, unpublished data of the Bureau of Standards, 1923. For chemical composition see Table 35, material C.

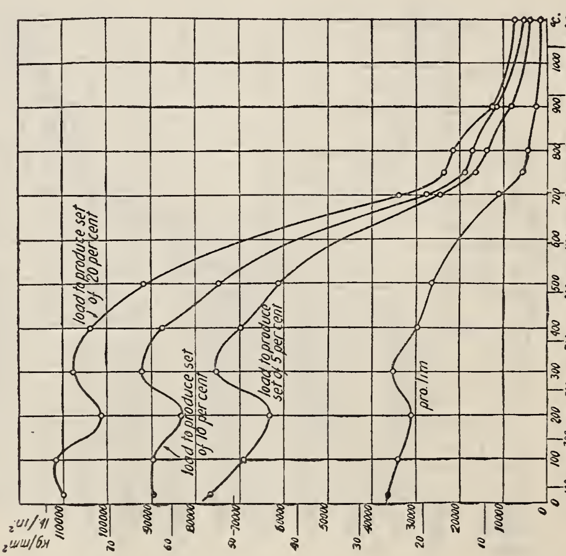

FIG. 56.—*Compression tests of chrome-nickel steel at elevated temperature.*

Results obtained by H. J. French, unpublished data of the Bureau of Standards, 1923. For chemical composition see Table 35, material E.

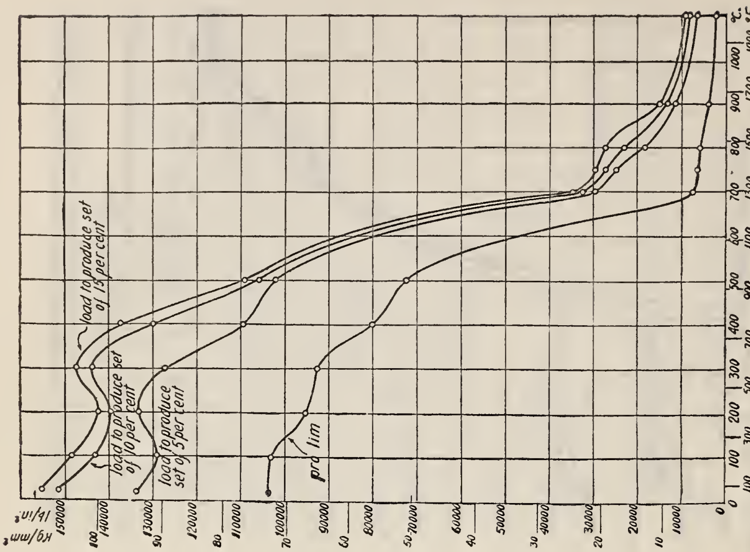

FIG. 57.—*Compression tests of chrome-nickel steel at elevated temperature.*

Results obtained by H. J. French, unpublished data of the Bureau of Standards, 1923. For chemical composition see Table 35, material F.

TABLE 36.—Compression Tests of White Metal Bearing Alloys at Elevated Temperatures.[1]

[For chemical composition of tested alloys, see Table 37.]

Alloy No.	25° C. (77° F.).			50° C. (122° F.).			75° C. (167° F.).			100° C. (212° F.).		
	Yield point, kg/mm², lb./in.².	Ultimate strength, kg/mm², lb./in.².	Brinell hardness.	Yield point, kg/mm², lb./in.².	Ultimate strength, kg/mm², lb./in.².	Brinell hardness.	Yield point, kg/mm², lb./in.².	Ultimate strength, kg/mm², lb./in.².	Brinell hardness.	Yield point, kg/mm², lb./in.².	Ultimate strength, kg/mm², lb./in.².	Brinell hardness.
1	3.1 4,400	9.04 12,850	17	2.67 3,800	7.32 10,400	14	2.22 3,150	5.94 8,450	11	1.86 2,650	4.89 6,950	8
2	4.4 6,250	10.67 15,175	22	3.41 4,850	8.34 11,850	....	2.81 4,000	6.61 9,400	....	2.00 2,850	4.87 6,825	....
3	4.04 5,750	11.55 16,425	22	3.51 5,000	8.56 12,175	18	2.99 4,250	7.10 10,100	15	2.36 3,350	5.43 7,725	11
4	3.3 4,700	9.64 13,700	22	2.57 3,650	7.07 10,050	16	2.04 2,900	5.52 7,850	11	1.51 2,150	4.25 6,050	8
5	2.64 3,750	10.56 15,000	20	1.86 2,650	7.93 11,275	17	1.58 2,250	5.55 7,900	11	1.09 1,550	3.36 4,770	8

[1] J. R. Freeman, jr., and R. W. Woodward, U. S. Bureau of Standards Technologic Paper No. 188; 1921.

TABLE 37.—Chemical Composition of White Metal Bearing Alloys.

[See Table 36.]

Alloy No.	1	2	3	4	5
Copper ... per cent.	4.56	3.51	5.65	2.90	None.
Antimony ... do.	4.52	7.57	6.90	10.50	10.03
Tin ... do.	Balance.	Balance.	Balance.	Balance.	Balance.
Lead ... do.	None.	None.	0.09	25.05	84.95
Iron [1] ... do.	....	....	....	....	....

[1] Less than 0.05.

TABLE 38.—Tensile Properties of Some Bearing Alloys at Elevated Temperature.[1]

Alloy.				Temperature.		Proportional limit.		Tensile strength.		Elongation in 2 in. (50.8 mm).	Reduction of area.
Cu	Sn	Pb	Zn	°C.	°F.	kg/mm²	lb./in.²	kg/mm²	lb./in.²	Per cent.	Per cent.
85	5	5	5	Room temperature.		14.1	20,000	26.8	38,100	36	32.0
				100	212	12.2	17,400	23.7	33,700	24	24.5
70	5	20	5	Room temperature.		14.1	20,100	22.7	32,300	20	17.0
				100	212	12.4	17,600	20.5	29,200	19	19.5

[1] G. H. Clamer, Am. Inst. Met. Trans., 9, p. 241; 1915.

TABLE 39.—Elasticity at High Temperatures.[1]

[See Figs. 58 and 59.]

[Determinations of the modulus of elasticity in shear at temperatures approaching melting point have been made on a wire suspended in a cylinder evacuated to a pressure of only 1.3 mm (to avoid oxidation). The diameter of wire was about 1.5 mm or 0.059 in. and its length about 380 mm or 15 in. The wire was heated by electric current passing through it.]

CHEMICAL COMPOSITION OF TESTED ALLOYS.

Name.	Cu	Al	Zn	Mn	Ni	Sn	Mg
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Brass	60.0	....	40.0	....	....	....	....
Red brass	85.0	....	15.0	....	....	....	....
Nickel silver [2]	....	....	....	....	....	....	....
Manganin	84.0	....	....	12.0	4.0	....	....
Phosphor bronze	93.0	....	....	....	....	7.0	....
Duralumin	4.2	94.7	....	.6	....	....	0.5

[1] K. Koch und C. Danneker, Annalen der Physik, 47, p. 197; 1915.

[2] Was not determined.

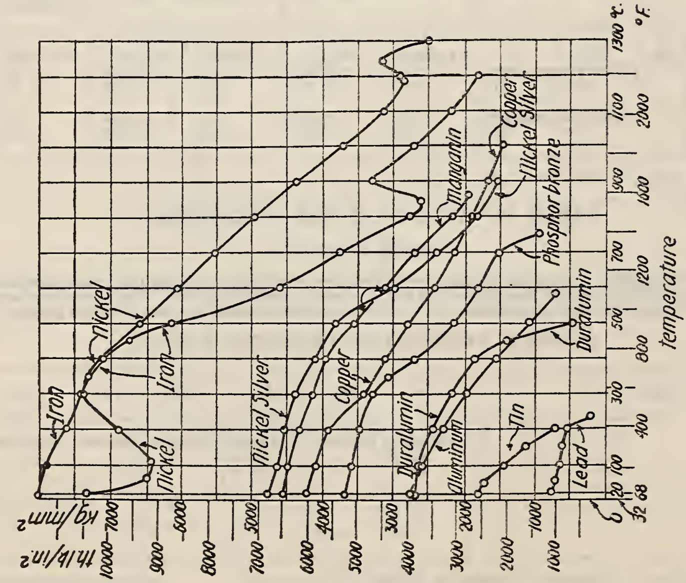

FIG. 58.—Effect of temperature on the modulus of elasticity in shear.

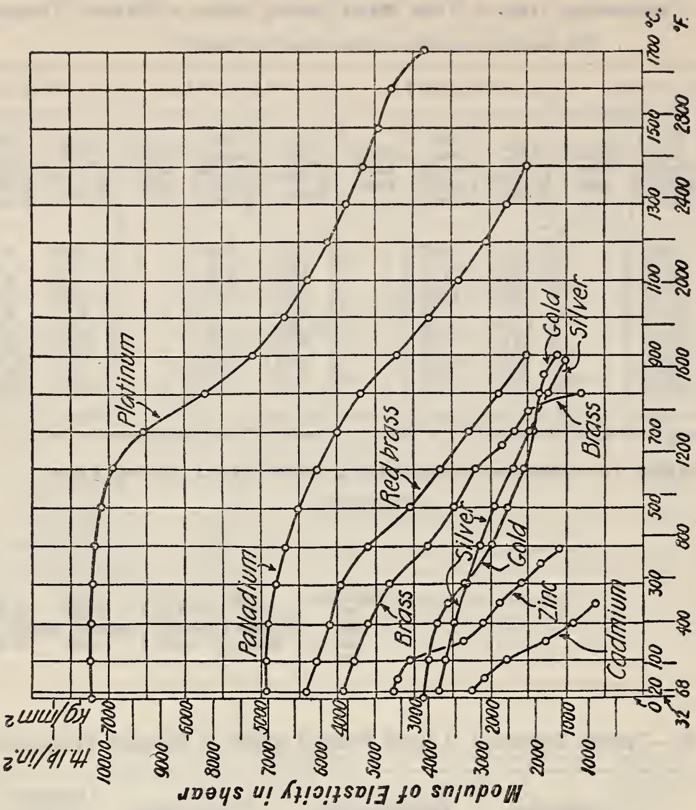

FIG. 59.—Effect of temperature on the modulus of elasticity in shear.

K. Koch and C. Danneker, Annalen der Physik, 47; 1915. For chemical composition of tested metals see Table 39.

TABLE 40.—Elasticity at Low Temperatures.[1]

[Modulus of elasticity was determined at temperatures from that of liquid air to 100° C. (212° F.).]

Metal.	Melting point, absolute degrees Centigrade.	Ratio of Young's modulus at zero absolute to that of zero Centigrade.	Metal.	Melting point, absolute degrees Centigrade.	Ratio of Young's modulus at zero absolute to that of zero Centigrade.
Rhodium	2,270	1.18	Magnesium	903	1.57
Platinum	2,045	1.27	Aluminum	870	1.44
Iron	1,870	1.27	Zinc	690	2.00
Palladium	1,770	1.27	Lead	595	1.80
Nickel	1,720	1.12	Cadmium	585	2.50
Copper	1,324	1.37	Bismuth	530	1.85
Gold	1,315	1.32	Tin	500	2.22
Silver	1,224	1.37			

[1] A. Mallock, Proc. Roy. Soc. of London, 95, A, p. 429; 1919.

Note.—Modulus itself does not bear any simple relation to the melting point, but there is some relation between the variation of the modulus with temperature and the melting point.

TABLE 41.—Effect of Temperature on Modulus of Elasticity of Annealed Metals.[1]

Material.	15° C. (59° F.).		100° C. (212° F.).		200° C. (392° F.).	
	kg/mm²	lb./in.²	kg/mm²	lb./in.²	kg/mm²	lb./in.²
Copper	10,519	14,950,000	9,827	14,000,000	7,862	11,200,000
Gold	5,584	7,925,000	5,408	7,680,000	5,482	7,790,000
Lead	1,727	2,450,000	1,630	2,320,000	....	....
Platinum	15,518	22,100,000	14,178	20,150,000	12,964	18,400,000
Silver	7,140	10,150,000	7,274	10,350,000	6,374	9,050,000
Iron	20,794	29,550,000	21,877	31,100,000	17,700	25,200,000
Cast steel	19,561	27,800,000	19,014	27,000,000	17,926	25,500,000

[1] Winkelman, Handbuch der Physik, 1, 1, p. 564; 1908.

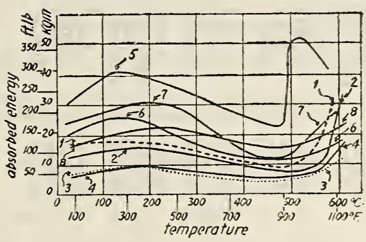

FIG. 60.—*Effect of temperature on the impact resistance of annealed steels.*

Proc. Internat. Association for Testing Materials, 5th Congress, III—4. The test pieces were of Mesnager type, 10 by 10 by 60 mm with notches 2 mm wide and 2 mm deep with round bottom. For chemical composition of tested steels see Table 20.

TABLE 42.—Effect of Annealing Temperature on Elastic Properties of Cold-Rolled Brass Tube.[1]

Property.	Material.[2]		Annealing temperature, °C.								
			Un-annealed.	100 (212° F.).	215 (419° F.).	310 (590° F.).	410 (770° F.).	520 (968° F.).	610 (1,130° F.).	710 (1,310° F.).	800 (1,472° F.).
Modulus of elasticity in tension.	Hard	kg/mm²	10,680	10,835	10,970	11,000	11,550	11 500	11,270	11,270	12,400
		lb./in.²	15,170,000	15,400,000	15,630,000	15,650,000	16,430,000	16,350,000	16,020 000	16,020,000	17,650,000
	Half hard	kg/mm²	11,850	12,010	11,810	12,300	11,910	12.000	11 910	12,250	12,120
		lb./in.²	16,860,000	17,090,000	16,810,000	17,500,000	16,950,000	17,070,000	16,950,000	17,420,000	17,250,000
Modulus of elasticity in compression.	Hard	kg/mm²	10,120	10,020	9,910	10,500	10,640	10,600	9,960	9,540	....
		lb./in.²	14,400,000	14,250,000	14,100,000	14,940,000	15,130,000	15,080,000	14,170,000	13,570,000	....
	Half hard	kg/mm²	10,510	11,490	11,200	11,300	11,410	9,990	10,330	10,960	....
		lb./in.²	14,950,000	16,330,000	15,940,000	16,070,000	16,230,000	14,210,000	14,680,000	15,600,000	....
Compressive elastic limit	Hard	kg/mm²	23.9	20.9	33.3	23.4	13.5	15.5	8.9	....	....
		lb./in.²	34,000	29,600	47,400	33,200	19,200	22,100	12,650	....	....
	Half hard	kg/mm²	18.9	17.8	24.5	24.9	14.2	8.7	7.2	4.4	....
		lb./in.²	26,900	25,300	34,800	35,500	20,200	12,300	10,300	6,180	....
Compressive strength	Hard	kg/mm²	39.2	38.1	47.0	39.7	18.2	17.2	11.8	8.3	....
		lb./in.²	55,700	54,300	66,800	56,500	25,900	24,400	16,750	11,900	....
	Half hard	kg/mm²	28.2	28.7	36.7	34.1	25.2	15.7	11.5	9.7	....
		lb./in.²	40,200	40,800	52,300	48,400	35,900	22,400	16,350	13,750	....
Modulus of elasticity in shear	Hard	kg/mm²	3,810	3,880	3,950	3,950	4,180	4,240	4,100	4,100	4,420
		lb./in.²	5,420,000	5,530,000	5,620,000	5,620,000	5,940,000	6,030,000	5,840,000	5,840,000	6,290,000
	Half hard	kg/mm²	3,870	3,870	3,980	3,970	3,870	4,120	4,080	4,210	4,720
		lb./in.²	5,500,000	5,500,000	5,660,000	5,650,000	5,500,000	5,860,000	5,810,000	5,990,000	6,720,000
Shearing strength	Hard	kg/mm²	36.7	35.9	34.4	30.2	16.6	16.2	14.0	10.5	6.4
		lb./in.²	52,200	51,100	49,000	43,000	23,700	23,100	19,900	15,000	9,180
	Half hard	kg/mm²	22.2	22.1	23.6	20.9	18.3	13.1	11.3	10.3	6.4
		lb./in.²	31,600	31,400	33,600	29,800	26,000	18,600	16,100	14,600	9,180

[1] F. C. Lea, V. A. Collins, and E. A. F. Reave, Jour. Inst. of Metals, 29, p. 217; 1923.

[2] The chemical composition of tested materials:

	Cu	Zn	Fe
hard	67.08	32.45	0.44.
half hard	73.85	25.90	0.25.

XIII. MANILA ROPE.

TABLE 43.—Weight and Strength of Manila Rope—Specification Values.

[From U. S. Government standard specifications adopted Apr. 4, 1918, and formulated jointly by cordage manufacturers and Government representatives. Rope to be made of manila or Abaca fiber, with no fiber of grade lower than U. S. Government grade (1) to be three-strand[1] medium laid, with maximum weights and minimum strengths shown in the table below, lubricant content to be not less than 8 nor more than 12 per cent of the weight of the rope as sold.]

Approximate diameter.		Circumference.		Maximum net weight.		Minimum breaking strength.	
mm	in.	mm	in.	kg/m	lb./ft.	kg	lb.
6.3	1/4	19.1	3/4	0.029	0.0196	317	700
7.9	5/16	25.4	1	.042	.0286	544	1,200
9.5	3/8	28.6	1 1/8	.061	.0408	657	1,450
11.1	7/16	31.8	1 1/4	.080	.0539	793	1,750
11.9	15/32	34.9	1 3/8	.095	.0637	952	2,100
12.7	1/2	38.1	1 1/2	.109	.0735	1,110	2,450
14.3	9/16	44.5	1 3/4	.153	.1029	1,430	3,150
15.9	5/8	50.8	2	.195	.1307	1,810	4,000
19.1	3/4	57.2	2 1/4	.241	.1617	2,220	4,900
20.6	13/16	63.5	2 1/2	.284	.1911	2,680	5,900
22.2	7/8	69.8	2 3/4	.328	.2205	3,170	7,000
25.4	1	76.2	3	.394	.2645	3,720	8,200
27.0	1 1/16	82.6	3 1/4	.459	.3087	4,310	9,500
28.6	1 1/8	88.9	3 1/2	.525	.3528	4,990	11,000
31.8	1 1/4	95.2	3 3/4	.612	.4115	5,670	12,500
33.3	1 5/16	101.6	4	.700	.4703	6,440	14,200
34.9	1 3/8	108.0	4 1/4	.787	.5290	7,260	16,000
38.1	1 1/2	114.3	4 1/2	.875	.5879	7,940	17,500
39.7	1 9/16	120.7	4 3/4	.984	.6615	8,840	19,500
41.2	1 5/8	127.0	5	1.094	.7348	9,750	21,500
44.5	1 3/4	139.7	5 1/2	1.312	.8818	11,550	25,500
50.8	2	152.4	6	1.576	1.059	13,610	30,000
52.4	2 1/16	165.1	6 1/2	1.823	1.225	15,420	34,000
57.2	2 1/4	177.8	7	2.144	1.441	17,460	38,500
63.5	2 1/2	190.5	7 1/2	2.450	1.646	19,730	43,500
66.7	2 5/8	203.2	8	2.799	1.881	22,220	49,000
73.0	2 7/8	215.9	8 1/2	3.136	2.107	24,940	55,000
76.2	3	228.6	9	3.543	2.381	27,670	61,000
79.4	3 1/8	241.3	9 1/2	3.936	2.645	30,390	67,000
82.5	3 1/4	254.0	10	4.375	2.940	33,110	73,000

[1] Four-strand medium-laid rope, when ordered, may run up to 7 per cent heavier than three-strand rope of the same size, and must show 95 per cent of the strength required for three-strand rope of the same size.

TABLE 44.—Strength of Manila Rope.

[Experimental formula derived from the tests $L=5,000\ d\ (d+1)$, where L is breaking load in pounds; d—diameter of rope in inches. (U. S. Bureau of Standards Tech. Paper No. 198; 1921.)]

Diameter.		Number of tests.	Observed breaking load.						Government standard specifications, breaking load.	
			Maximum.		Minimum.		Average.			
cm	in.		kg	lb.	kg	lb.	kg	lb.	kg	lb.
1.27	1/2	23	1,777	3,920	1,043	2,300	1,474	3,250	1,111	2,450
1.59	5/8	17	2,971	6,550	1,928	4,250	2,404	5,300	1,814	4,000
1.91	3/4	14	3,183	7,020	2,350	5,180	2,881	6,350	2,223	4,900
2.06	13/16	26	3,959	8,730	2,654	5,850	3,220	7,100	2,676	5,900
2.54	1	72	5,761	12,700	3,538	7,800	4,432	9,770	3,720	8,200
2.86	1 1/8	9	5,851	12,900	3,946	8,700	5,207	11,480	4,990	11,000
3.17	1 1/4	76	7,983	17,600	4,727	10,420	6,192	13,650	5,670	12,500
3.81	1 1/2	48	11,249	24,800	6,023	13,280	8,364	18,440	7,938	17,500
4.12	1 5/8	14	11,435	25,210	7,444	16,410	9,902	21,830	9,752	21,500
4.44	1 3/4	14	14,120	31,130	9,072	20,000	11,078	24,400	11,567	25,500
5.08	2	5	12,338	27,200	10,496	23,140	11,857	26,140	13,608	30,000
6.35	2 1/2	8	24,812	54,700	14,651	32,300	19,958	44,000	19,732	43,500
7.62	3	22	33,566	74,000	20,412	45,000	26,898	59,300	27,670	61,000
8.88	3 1/2	17	47,628	105,000	26,354	58,100	38,919	85,800	....	....
10.16	4	2	52,482	115,700	39,690	87,500	46,086	101,600	....	....
11.43	4 1/2	1	49,896	110,000	....	....	49,896	110,000	....	....

XIV. WOOD.

The data on mechanical and physical properties of wooas grown in the United States given in the tables below have been taken from Bulletin 556, Forest Service, U. S. Department of Agriculture, and are based upon about 130,000 tests.

The strength of green material should be made the basis of stresses. The bulletin recommends the following method of utilizing its data for green material. (Table 45.)

1. STATIC BENDING.

(*a*) For carefully selected structural timbers (with all exceptionally light pieces excluded) subjected to bending in dry, interior construction and where only small deflections are allowable safe working stresses are about one-fifth the modulus of rupture values given for green material. (Table 45.) (*b*) The values for modulus of elasticity are derived from the static bending test but are applicable to both beams and columns. Various factors tend to produce unequal local stresses which in their turn lead to deflections greater than those calculated from the average moduli of elasticity. For this reason it is good practice in the design of structures to use values for moduli of elasticity about one-half those given in Table 45.

2. COMPRESSION PARALLEL TO GRAIN.

A safe working stress for carefully selected structural timbers used as columns and in dry, interior construction (all exceptionally light pieces excluded) is about one-third the crushing strength as given in the table for tests on green materials. (Table 45.)

If the column is longer than about 10 times its least dimension, some formula should be used which will take care of the increased stress caused by eccentric loading or by the bending of the column.

3. COMPRESSION PERPENDICULAR TO GRAIN.

Two-thirds of the fiber stress at elastic limit, as given in the table for tests on green material may be used as a safe stress in dry, interior construction.

4. SHEARING STRENGTH PARALLEL TO GRAIN.

Only about one-eighth of the values given in the table for green material should be used as allowable stress in horizontal shear in beams. For small details in timbers unaffected by shakes or checks the allowable stress may be taken as one-fourth the value listed for green timber.

5. TENSION PERPENDICULAR TO GRAIN.

The allowable stress should be one-fifth the values given in Table 45.

Table 46 should be considered as supplementary to Table 45. The properties of all species are not changed in the same proportion by drying, and all the properties are not equally affected.

The figures in Table 47 are presented as an aid to the interpretation of data given in Tables 45 and 46. They will assist in rendering more nearly comparable data which are not compared directly because of differences of moisture.

Column 2 (Table 47).—Suppose, it is desired to compare the modulus of rupture of air-dry black locust with that of air-dry bitternut hickory. According to Table 47 a 1 per cent change of moisture causes a 4 per cent change of modulus of rupture. Changing the hickory from 9.2 to 10 per cent moisture will decrease the strength by $(10-9.2)\times 4$ per cent $=3.2$ per cent; 3.2 per cent of $18,850=600$. Then the moduli of rupture of black locust and bitternut hickory each at 10 per cent moisture are 20,700 and 18,250 lb./in.^{2}, respectively.

Column 3.—Strength properties of a given species can be estimated with fair accuracy from the average specific gravity, since each varies according to some power of the specific gravity.

Suppose it is desired to estimate the modulus of rupture and work to maximum load of a stick of timber whose specific gravity is known to be 25 per cent above the average. Since modulus of rupture varies as the first and work to maximum load as the second power of the specific gravity, it is probable that the modulus of rupture and work to maximum load are, respectively, about 125 and 156 per cent $(1.56=1.25^2)$ of the average values for the species.

TABLE 45.—Results of Tests on 126 Species of Wood Tested

U. S. Department of Agriculture

[Test specimens were 2 by 2 inches (50.8 by 50.8 mm) in section. Bending specimens

Common and botanical name and locality where grown.	Number of trees.	Number of rings— Per cm	Number of rings— Per in.	Percentage of summer wood.	Percentage of moisture content determined at 100° C. (212° F.).	Specific gravity oven dry (100° C. or 212° F.) based on— Volume when green	Specific gravity oven dry based on— Volume when oven dry.	Weight (green). kg/m³	Weight (green). lb./ft.³	Shrinkage from green to oven dry condition. In volume (per cent of dimensions when green).	Shrinkage: Radial (per cent of dimensions when green).	Shrinkage: Tangential (per cent of dimensions when green).	Static bending. Fiber stress at elastic limit. kg/cm²	Fiber stress at elastic limit. lb./in.²	Modulus of rupture. kg/cm²	Modulus of rupture. lb./in.²	Modulus of elasticity. th. kg/cm²	Modulus of elasticity. th. lb./in.²
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
HARDWOODS.																		
Alder, red (Alnus oregona), Washington.	6	4.3	11	...	98	0.37	0.43	736	46	12.6	4.4	7.3	267	3,800	457	6,500	82.3	1,170
Ash, biltmoren (Fraxinus biltmoreana), Tennessee.	5	6.7	17	49	42	.51	.58	720	45	12.6	4.2	6.9	387	5,500	654	9,300	94.2	1,340
Ash, black (Fraxinus nigra), Michigan, Wisconsin.	15	9.5	24	53	83	.46	.53	848	53	15.2	5.0	7.8	183	2,600	422	6,000	71.7	1,020
Ash, blue (Fraxinus quadrangulata), Kentucky.	5	4.7	12	49	39	.53	.60	736	46	11.7	3.9	6.5	401	5,700	675	9,600	87.2	1,240
Ash, green (Fraxinus lanceolata), Missouri, Louisiana.	10	7.1	18	58	48	.52	.61	768	48	12.5	4.6	7.1	372	5,300	668	9,500	98.4	1,400
Ash, Oregon (Fraxinus oregona), Oregon.	3	4.7	12	63	48	.50	.58	736	46	13.2	4.1	8.1	295	4,200	534	7,600	79.4	1,130
Ash, pumpkin (Fraxinus profunda), Missouri.	3	8.3	21	46	51	.48	.55	736	46	12.0	3.7	6.3	316	4,500	534	7,600	73.1	1,040
Ash, white (forest grown) (Fraxinus americana), Arkansas, West Virginia.	10	6.3	16	50	43	.52	.60	736	46	12.6	4.2	6.5	344	4,900	640	9,100	95.0	1,350
Ash, white (second growth) (Fraxinus americana), New York.	5	3.5	9	63	40	.58	.71	817	51	14.0	5.3	8.7	429	6,100	759	10,800	115.4	1,640
Aspen (Populus tremuloides), Wisconsin.	5	3.1	8	...	107	.36	.42	752	47	11.1	3.3	6.9	204	2,900	372	5,300	59.0	840
Aspen, large-tooth (Populus grandidentata), Wisconsin.	5	3.1	8	...	96	.35	.41	688	43	11.6	3.1	7.9	225	3,200	408	5,800	83.0	1,180
Basswood (Tilia americana), Pennsylvania, Wisconsin.	8	7.5	19	29	103	.33	.40	657	41	15.8	6.6	9.3	190	2,700	351	5,000	72.4	1,030
Beech (Fagus atropunicea), Indiana, Pennsylvania.	10	7.5	19	30	62	.54	.66	880	55	16.2	4.8	10.6	316	4,500	576	8,200	87.2	1,240
Birch, paper (Betula papyrifera), Wisconsin.	5	2.4	6	36	72	.47	.60	817	51	16.3	6.6	8.8	204	2,900	408	5,800	71.0	1,010
Birch, sweet (Betula lenta), Pennsylvania.	5	10.6	27	...	61	.59	.70	945	59	15.0	6.3	7.6	316	4,500	605	8,600	104.6	1,490
Birch, yellow (Betula lutea), Pennsylvania, Wisconsin.	10	7.5	19	26	68	.54	.66	928	58	16.8	7.4	9.0	323	4,600	605	8,600	108.2	1,540
Buckeye, yellow (Aesculus octandra), Tennessee.	5	5.9	15	...	141	.33	.38	785	49	12.0	3.5	7.8	183	2,600	337	4,800	68.9	980
Buckthorn, cascara (Rhamnus purshiana), Oregon.	5	6.7	17	...	61	.50	.55	801	50	7.6	3.2	4.6	239	3,400	443	6,300	44.3	630
Butternut (Juglans cinerea), Tennessee, Wisconsin.	10	3.5	9	...	104	.36	.40	737	46	10.2	3.3	6.1	204	2,900	380	5,400	68.2	970
Cherry, black (Prunus serotina), Pennsylvania.	5	4.3	11	...	55	.47	.53	737	46	11.5	3.7	7.1	295	4,200	562	8,000	92.1	1,310
Cherry, wild red (Prunus pennsylvanica), Tennessee.	5	2.4	6	...	46	.36	.42	528	33	12.8	2.8	10.3	204	2,900	351	5,000	73.1	1,040
Chestnut (Castanea dentata), Maryland, Tennessee.	10	3.9	10	48	122	.40	.46	881	55	11.6	3.4	6.7	218	3,100	394	5,600	65.4	930
Chinquapin, western (Castanopsis chrysophylla), Oregon.	5	5.9	15	...	134	.42	.48	976	61	13.2	4.6	7.4	295	4,200	492	7,000	71.7	1,020

in a Green Condition in the Form of Small, Clear Pieces.

Bulletin No. 556, Sept. 15, 1917.]

were 30 inches (762 mm) long; others were shorter, depending on the kind of test.]

Static bending—Continued.				Impact bending.						Compression parallel to grain.				Compression perpendicular to grain; fiber stress at elastic limit.		Shearing strength parallel to the grain.		Tensile strength perpendicular to grain.		Hardness, load required to embed a 1.13 cm (0.444 in.) ball to one-half its diameter.			
Work in bending—				Fiber stress at elastic limit.		Work in bending to elastic limit.		Height of drop causing complete failure; 11.03 kg (50 lb.) hammer.		Fiber stress at elastic limit.		Maximum crushing strength.								End.		Side.	
To elastic limit.		To maximum load.																					
kgcm/cm³	in. lb./in.³	kgcm/cm³	in. lb./in.³	kg/cm²	lb./in.²	kgcm/cm³	in. lb./in.³	cm	in.	kg/cm²	lb./in.²	kg/cm²	lb./in²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg	lb.	kg	lb.
20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
0.049	0.70	0.56	8.0	562	8,000	0.18	2.6	55.9	22	186	2,650	208	2,960	21.8	310	54.2	770	27.4	390	250	550	200	440
.092	1.31	.82	11.6	837	11,900	.34	4.9	76.2	30	250	3,560	280	3,980	61.9	880	86.5	1,230	38.0	540	431	950	386	850
.030	.42	.87	12.4	506	7,200	.18	2.5	81.3	32	114	1,620	161	2,290	30.2	430	61.2	870	34.4	490	263	580	250	550
.103	1.47	1.03	14.7	781	11,100	.35	5.0	109.2	43	249	3,540	294	4,180	69.6	990	108.3	1,540	40.8	580	518	1,140	468	1,030
.080	1.14	.83	11.8	802	11,400	.35	5.0	86.4	34	250	3,560	295	4,200	64.0	910	88.6	1,260	41.5	590	436	960	395	870
.065	.92	.86	12.2	626	8,900	.21	3.0	99.1	39	193	2,740	247	3,510	45.7	650	83.7	1,190	34.4	490	386	850	359	790
.076	1.08	.66	9.4	619	8,800	.26	3.7	78.8	31	199	2,830	236	3,360	69.6	990	85.1	1,210	40.1	570	400	880	341	750
.072	1.03	.94	13.4	823	11,700	.35	5.0	91.5	36	227	3,230	267	3,800	56.2	800	88.6	1,260	43.6	620	454	1,000	409	900
.091	1.30	1.15	16.3	970	13,800	.41	5.9	119.4	47	268	3,820	324	4,610	55.5	790	112.5	1,600	55.5	790	518	1,140	491	1,080
.046	.65	.48	6.9	485	6,900	.18	2.5	71.2	28	114	1,620	152	2,160	14.1	200	43.6	620	12.7	180	123	270	145	320
.035	.50	.43	6.1	534	7,600	.19	2.7	45.7	18	150	2,130	191	2,720	19.0	270	57.0	810	27.4	390	200	440	168	370
.030	.42	.37	5.2	436	6,200	.14	2.0	43.2	17	120	1,710	155	2,210	14.8	210	42.9	610	19.7	280	127	280	114	250
.070	.99	.88	12.5	732	10,400	.30	4.2	101.6	40	179	2,550	231	3,280	42.9	610	85.1	1,210	53.4	760	431	950	372	820
.034	.49	1.05	15.0	548	7,800	.19	2.7	114.3	45	116	1,650	155	2,210	21.1	300	55.5	790	26.7	380	182	400	222	490
.057	.81	1.10	15.6	668	9,500	.22	3.1	111.8	44	186	2,650	250	3,560	36.6	520	85.8	1,220	38.7	550	463	1,020	404	890
.056	.80	1.17	16.6	822	11,700	.32	4.5	101.6	40	194	2,760	243	3,460	31.6	450	78.0	1,110	33.7	480	372	820	336	740
.029	.41	.38	5.4	457	6,500	.15	2.1	45.7	18	115	1,640	144	2,050	14.8	210	46.4	660	22.5	320	164	360	132	290
.073	1.04	.94	13.4	612	8,700	.25	3.6	147.4	58	132	1,880	230	3,270	47.1	670	80.8	1,150	35.8	510	309	680	331	730
.037	.52	.58	8.2	513	7,300	.18	2.5	61.0	24	138	1,960	170	2,420	19.0	270	53.4	760	30.2	430	186	410	177	390
.056	.80	.90	12.8	717	10,200	.29	4.1	83.9	33	207	2,940	249	3,540	30.9	440	79.4	1,130	40.1	570	341	750	300	660
.033	.47	.44	6.2	464	6,600	.15	2.1	55.8	22	129	1,830	153	2,170	18.3	260	47.8	680	21.1	300	200	440	177	390
.041	.59	.49	7.0	555	7,900	.20	2.8	61.0	24	143	2,040	174	2,470	26.7	380	56.2	800	30.2	430	241	530	191	420
.077	1.09	.67	9.5	619	8,800	.24	3.4	78.8	31	135	1,920	212	3,020	34.4	490	71.0	1,010	33.7	480	331	730	272	600

TABLE 45.—Results of Tests on 126 Species of Wood Tested in

Common and botanical name and locality where grown.	Number of trees.	Number of rings— Per cm	Number of rings— Per in.	Percentage of summer wood.	Percentage of moisture content determined at 100° C. (212° F.).	Specific gravity oven dry (100° C. or 212° F.) based on— Volume when green.	Specific gravity oven dry (100° C. or 212° F.) based on— Volume when oven dry.	Weight (green). kg/m³	Weight (green). lb./ft.³	Shrinkage from green to oven dry condition. In volume (per cent of dimensions when green).	Shrinkage from green to oven dry condition. Radial (per cent of dimensions when green).	Shrinkage from green to oven dry condition. Tangential (per cent of dimensions when green).	Static bending. Fiber stress at elastic limit. kg/cm²	Static bending. Fiber stress at elastic limit. lb./in.²	Static bending. Modulus of rupture. kg/cm²	Static bending. Modulus of rupture. lb./in.	Static bending. Modulus of elasticity. th. kg/cm²	Static bending. Modulus of elasticity. th. lb./in.²
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
HARDWOODS—Continued.																		
Cottonwood (Populus deltoides), Missouri.	5	2.4	6	...	111	0.37	0.43	784	49	14.1	3.9	9.2	204	2,900	373	5,300	71.0	1,010
Cottonwood, black (Populus trichocarpa), Washington.	5	2.4	6	...	132	.32	.37	737	46	12.4	3.6	8.6	204	2,900	338	4,800	75.2	1,070
Cucumber tree (Magnolia acuminata), Tennessee.	5	5.5	14	...	80	.44	.52	800	50	13.6	5.2	8.8	295	4,200	520	7,400	110.0	1,560
Dogwood, flowering (Cornus florida), Tennessee.	5	9.5	24	...	62	.64	.80	1,040	65	19.9	7.1	11.3	338	4,800	619	8,800	82.9	1,180
Dogwood, western (Cornus nuttallii), Oregon.	5	8.3	21	...	52	.58	.70	880	55	17.2	6.4	9.6	295	4,200	577	8,200	76.6	1,090
Elder, pale (Sambucus glauca), Oregon.	5	2.4	6	...	124	.46	.57	1,040	65	15.6	4.4	9.0	239	3,400	464	6,600	63.2	900
Elm, cork (Ulmus racemosa), Wisconsin.	10	1.1	28	50	50	.58	.66	865	54	14.1	4.8	8.1	323	4,600	668	9,500	83.6	1,190
Elm, slippery (Ulmus, pubescens), Indiana, Wisconsin.	6	6.3	16	54	85	.48	.56	897	56	13.8	4.9	8.9	281	4,000	562	8,000	86.5	1,230
Elm, white (Ulmus americana), Wisconsin, Pennsylvania.	6	7.1	18	31	88	.44	.54	832	52	14.4	4.2	9.5	253	3,600	485	6,900	72.4	1,030
Gum, black (Nyssa sylvatica), Tennessee.	5	10.6	27	...	55	.46	.55	720	45	13.9	4.4	7.7	281	4,000	492	7,000	72.4	1,030
Gum, blue (Eucalyptus globulus), California.	5	....	...	...	79	.62	.80	1,120	70	22.5	7.6	15.3	534	7,600	717	11,200	141.0	2,010
Gum, cotton (Nyssa aquatica), Louisiana.	6	3.9	10	26	97	.46	.52	897	56	12.5	4.2	7.6	295	4,200	513	7,300	73.8	1,050
Gum, red (Liquidambar styraciflua), Missouri.	10	6.3	16	...	81	.44	.53	800	50	15.0	5.2	9.9	260	3,700	478	6,800	80.8	1,150
Hackberry (Celtis occidentalis), Indiana, Wisconsin.	6	4.7	12	56	65	.48	.56	800	50	13.8	4.8	8.9	204	2,900	457	6,500	66.8	950
Haw, pear (Crataegus tomentosa), Wisconsin.	2	4.3	11	...	63	.62	....	1,010	63	.....	....	....	274	3,900	534	7,600	67.5	960
Hickory, big shellbark (Hicoria laciniosa), Mississippi, Ohio.	19	7.5	19	65	61	.62	....	1,010	63	19.2	7.6	12.6	394	5,600	738	10,500	94.2	1,340
Hickory, bitternut (Hicoria minima), Ohio.	11	4.3	11	70	66	.60	....	1,010	63	.....	....	....	387	5,500	724	10,300	98.4	1,400
Hickory, mockernut (Hicoria alba), West Virginia, Mississippi, Pennsylvania.	20	7.1	18	63	59	.64	....	1,025	64	17.9	7.8	11.0	443	6,300	780	11,100	110.4	1,570
Hickory, nutmeg (Hicoria myristicaeformis), Mississippi.	5	8.7	22	59	74	.56	....	977	61	.....	....	....	344	4,900	640	9,100	90.7	1,290
Hickory, pecan (Hicoria pecan), Missouri.	5	4.7	12	63	63	.60	.69	977	61	13.6	4.9	8.9	366	5,200	689	9,800	96.3	1,370
Hickory, pignut (Hicoria glabra), Ohio, Mississippi, Pensylvania, West Virginia.	60	7.9	20	65	54	.66	....	1,025	64	17.9	7.2	11.5	436	6,200	822	11,700	116.0	1,650
Hickory, shagbark (Hicoria ovata), Ohio, Mississippi, Pennsylvania, West Virginia.	24	7.5	19	66	60	.64	....	1,025	64	16.7	7.0	10.5	415	5,900	774	11,000	110.0	1,570
Hickory, water (Hicoria aquatica), Mississippi.	2	5.9	15	67	80	.61	....	1,104	69	.....	....	....	422	6,000	752	10,700	119.6	1,560
Holly, American (Ilex opaca), Tennessee.	5	10.6	27	...	82	.50	.61	913	57	16.2	4.5	9.5	239	3,400	457	6,500	63.3	900
Hornbeam (Ostrya virginiana), Wisconsin.	5	11.4	29	...	52	.63	.76	962	60	18.6	8.2	9.6	316	4,500	597	8,500	80.8	1,150

a Green Condition in the Form of Small, Clear Pieces—Continued.

Static bending—Continued. Work in bending—To elastic limit.		Static bending—Continued. Work in bending—To maximum load.		Impact bending. Fiber stress at elastic limit.		Impact bending. Work in bending to elastic limit.		Impact bending. Height of drop causing complete failure; 11.03 kg (50-lb.) hammer.		Compression parallel to grain. Fiber stress at elastic limit.		Compression parallel to grain. Maximum crushing strength.		Compression perpendicular to grain; fiber stress at elastic limit.		Shearing strength parallel to the grain.		Tensile strength perpendicular to grain.		Hardness, load required to embed a 1.13 cm (0.444 in.) ball to one-half its diameter. End.		Hardness, load required to embed a 1.13 cm (0.444 in.) ball to one-half its diameter. Side.	
kgcm/cm³	in. lb./in.³	kgcm/cm³	in. lb./in.³	kg/cm²	lb./in.²	kgcm/cm³	in. lb./in.³	cm	in.	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg	lb.	kg	lb.
20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
0.034	0.49	0.51	7.3	506	7,200	0.16	2.3	53.4	21	124	1,770	160	2,280	16.9	240	47.8	680	28.8	410	173	380	154	340
.031	.44	.35	5.0	478	6,800	.15	2.2	50.8	20	124	1,770	152	2,160	14.1	200	42.2	600	19.0	270	127	280	114	250
.046	.66	.70	10.0	654	9,300	.20	2.9	76.2	30	194	2,760	221	3,140	28.8	410	69.6	990	30.9	440	272	600	236	520
.078	1.11	1.48	21.0	499	7,100	.25	3.5	147.4	58	.....	......	256	3,640	72.4	1,030	106.8	1,520	....	...	640	1,410	640	1,410
.065	.92	1.19	17.0	689	9,800	.25	3.6	142.3	56	160	2,280	256	3,640	61.2	870	91.4	1,300	52.0	740	518	1,140	445	980
.051	.72	.62	8.8	562	8,000	.20	2.9	96.6	38	172	2,450	214	3,040	36.5	520	76.6	1,090	39.4	560	345	760	327	720
.084	1.20	1.39	19.8	773	11,000	.29	4.1	127.0	50	202	2,870	266	3,780	52.7	750	89.3	1,270	46.4	660	445	980	449	990
.058	.82	1.08	15.4	647	9,200	.24	3.4	119.4	47	200	2,840	233	3,320	35.8	510	78.1	1,110	45.7	650	340	750	300	660
.058	.83	.77	11.0	570	8,100	.20	2.9	86.4	34	161	2,290	202	2,880	27.4	390	64.7	920	39.4	560	277	610	250	550
.064	.91	.56	8.0	689	9,800	.28	4.0	76.2	30	172	2,440	214	3,040	42.2	600	77.4	1,100	40.1	570	359	790	291	640
.116	1.65	.98	13.9	998	14,200	.33	4.7	101.6	40	342	4,870	369	5,250	71.7	1,020	109.0	1,550	45.0	640	595	1,310	608	1,340
.069	.98	.58	8.3	632	9,000	.23	3.3	76.2	30	194	2,760	237	3,370	41.5	590	83.7	1,190	42.2	600	363	800	322	710
.057	.81	.66	9.4	703	10,000	.27	3.9	83.9	33	166	2,360	200	2,840	32.3	460	75.2	1,070	35.8	510	286	630	236	520
.041	.58	1.20	14.5	556	7,900	.22	3.1	122.0	48	145	2,060	186	2,650	34.4	490	75.2	1,070	44.3	630	345	760	313	690
.063	.89	1.60	22.7	.....	......	....	...	.....	...	.....	......	219	3,110	68.9	980	95.6	1,360	....	...	554	1,220	545	1,200
.096	1.36	2.10	29.9	998	14,200	.49	7.0	264.1	104	193	2,740	276	3,920	70.3	1,000	83.7	1,190	....	...	...	......	...	.....
.086	1.22	1.41	20.0	1,116	15,900	.60	8.5	167.6	66	304	4,330	321	4,570	69.6	990	87.2	1,240	....	...	...	......	...	.....
.097	1.38	1.83	26.1	1,062	15,100	.47	6.7	223.5	88	274	3,900	315	4,480	70.3	1,000	90.0	1,280	....	...	...	......	...	.....
.075	1.06	1.60	22.8	900	12,800	.43	6.1	137.2	54	255	3,620	280	3,980	66.1	940	72.4	1,030	....	...	...	......	...	.....
.083	1.18	1.03	14.6	865	12,300	.35	5.0	134.6	53	214	3,040	280	3,990	67.5	960	104.0	1,480	47.8	680	577	1,270	595	1,310
.094	1.34	2.23	31.7	1,188	16,900	.62	8.8	226.0	89	278	3,950	338	4,810	80.2	1,140	96.3	1,370	....	...	...	......	...	.....
.090	1.28	1.67	23.7	1,012	14,400	.45	6.4	187.9	74	241	3,430	322	4,580	70.3	1,000	92.8	1,320	....	...	...	......	...	.....
.091	1.29	1.32	18.8	963	13,700	.43	6.1	142.4	56	228	3,240	328	4,660	76.7	1,090	101.2	1,440	....	...	...	......	...	.....
.051	.72	.76	10.8	627	8,900	.31	4.4	129.5	51	139	1,970	186	2,640	42.9	610	79.5	1,130	42.9	610	391	860	359	790
.072	1.02	.93	13.3	745	10,600	.25	3.5	185.4	73	184	2,620	251	3,570	51.3	730	96.3	1,370	31.6	450	527	1,160	532	1,170

TABLE 45.—Results of Tests on 126 Species of Wood Tested in

Common and botanical name and locality where grown.	Number of trees.	Number of rings—		Percentage of summer wood.	Percentage of moisture content determined at 100° C. (212° F.).	Specific gravity oven dry (100° C. or 212° F.) based on—		Weight (green).		Shrinkage from green to oven dry condition.			Static bending.					
		Per cm	Per in.			Volume when green.	Volume when oven dry.	kg/m³	lb./ft.³	In volume (per cent of dimensions when green).	Radial (per cent of dimensions when green).	Tangential (per cent of dimensions when green).	Fiber stress at elastic limit.		Modulus of rupture.		Modulus of elasticity.	
													kg/cm²	lb./in.²	kg/cm²	lb./in.²	th. kg/cm²	th. lb./in.²
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
HARDWOODS—Continued.																		
Laurel, California (Umbellularia californica), Oregon.	5	2.4	6	...	70	0.51	0.59	880	55	11.9	2.8	8.1	274	3,900	464	6,600	50.6	720
Laurel, mountain (Kalmia latifolia), Tennessee.	5	9.5	24	...	62	.62	.74	992	62	14.4	5.6	8.8	408	5,800	591	8,400	64.7	920
Locust, black (Robinia pseudacacia), Tennessee.	3	4.3	11	51	40	.66	.71	928	58	9.8	4.4	6.9	619	8,800	970	13,800	130.0	1,850
Locust, honey (Gleditsia triacanthos), Missouri, Indiana.	6	3.5	9	45	63	.60	.67	976	61	10.8	4.2	6.6	394	5,600	717	10,200	90.7	1,290
Madrona (Arbutus menziesii), California, Oregon.	6	3.9	10	...	68	.57	.69	962	60	17.4	5.4	11.9	330	4,700	534	7,600	61.9	880
Magnolia, evergreen (Magnolia foetida), Louisiana.	2	5.9	15	...	117	.46	.53	992	62	12.3	5.4	6.6	259	3,600	478	6,800	78.1	1,110
Maple, Oregon (Acer macrophyllum), Washington.	5	4.7	12	...	72	.44	.51	752	47	11.6	3.7	7.1	309	4,400	520	7,400	77.4	1,100
Maple, red (Acer rubrum), Pennsylvania, Wisconsin.	9	6.3	16	24	70	.48	.54	816	51	12.5	3.8	8.1	288	4,100	548	7,800	99.8	1,420
Maple, silver (Acer saccharinum), Wisconsin.	5	2.8	7	...	66	.44	.51	736	46	12.0	3.0	7.2	218	3,100	408	5,800	66.1	940
Maple, sugar (Acer saccharum), Indiana, Pennsylvania, Wisconsin.	17	8.3	21	49	60	.56	.66	897	56	14.5	4.8	9.2	351	5,000	640	9,100	104.2	1,480
Oak, bur (Quercus macrocarpa), Wisconsin.	5	4.7	12	59	70	.58	.67	977	61	12.7	4.4	8.8	253	3,600	506	7,200	61.9	880
Oak, California black (Quercus californica), California, Oregon.	10	6.3	16	52	106	.51	.58	1,058	66	12.1	3.6	6.6	239	3,400	436	6,200	52.0	740
Oak, canyon live (Quercus chrysolepsis), California.	3	5.1	13	...	62	.70	.84	1,138	71	16.2	8.0	14.3	443	6,300	745	10,600	94.2	1,340
Oak, chestnut (Quercus prinus), Tennessee.	5	9.1	23	50	72	.57	.67	992	62	16.7	5.5	9.7	323	4,600	563	8,000	96.3	1,370
Oak, cow (Quercus michauxii), Louisiana.	4	4.7	12	58	76	.60	.76	1,040	65	19.4	5.9	9.2	337	4,800	598	8,500	95.0	1,350
Oak, laurel (Quercus laurifolia), Louisiana.	5	4.3	11	61	84	.56	.70	1,025	64	19.0	3.9	9.5	316	4,500	550	7,900	97.8	1,390
Oak, Pacific post (Quercus garryana), Oregon.	10	6.3	16	49	72	.64	.75	1,105	69	13.4	4.2	9.0	323	4,600	541	7,700	55.5	790
Oak, post (Quercus minor), Arkansas, Louisiana.	10	10.2	26	54	69	.60	.74	1,010	63	16.2	5.4	9.8	351	5,000	570	8,100	76.6	1,090
Oak, red (Quercus rubra), Arkansas, Louisiana, Indiana, Tennessee.	21	4.3	11	62	84	.56	.65	1,025	64	14.2	3.9	8.3	260	3,700	541	7,700	90.7	1,290
Oak, Spanish (highland) (Quercus digitata), Louisiana.	4	7.9	20	46	90	.52	.62	992	62	16.3	4.5	8.7	395	4,200	485	6,900	80.2	1,140
Oak, Spanish (lowland) (Quercus pagodaefolia), Louisiana.	3	2.8	7	63	78	.61	.71	1,072	67	16.4	5.2	10.8	457	6,500	760	10,800	126.0	1,790
Oak, water (Quercus minor), Louisiana.	5	3.9	10	61	81	.56	.68	1,008	63	16.4	4.2	9.3	394	5,600	626	8,900	109.0	1,550
Oak, white (Quercus alba), Arkansas, Louisiana, Indiana.	20	6.7	17	60	68	.60	.71	992	62	15.8	5.3	9.0	330	4,700	584	8,300	87.9	1,250
Oak, willow (Quercus phellos), Louisiana.	2	5.5	14	56	94	.56	.69	1,072	67	18.9	5.0	9.6	309	4,400	520	7,400	90.7	1,290

a Green Condition in the Form of Small, Clear Pieces—Continued.

Static bending—Continued. Work in bending—To elastic limit.		Static bending—Continued. Work in bending—To maximum load.		Impact bending. Fiber stress at elastic limit.		Impact bending. Work in bending to elastic limit.		Impact bending. Height of drop causing complete failure; 11.03 kg (50-lb.) hammer.		Compression parallel to grain. Fiber stress at elastic limit.		Compression parallel to grain. Maximum crushing strength.		Compression perpendicular to grain; fiber stress at elastic limit.		Shearing strength parallel to the grain.		Tensile strength perpendicular to grain.		Hardness, load required to embed a 1.13 cm (0.444 in.) ball to one-half its diameter. End.		Hardness, load required to embed a 1.13 cm (0.444 in.) ball to one-half its diameter. Side.	
kgcm/cm³	in. lb./in.³	kgcm/cm³	in. lb./in.³	kg/cm²	lb./in.²	kgcm/cm³	in. lb./in.³	cm	in.	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg	lb.	kg	lb.
20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
0.086	1.23	1.18	16.8	584	8,300	0.29	4.1	144.8	57	138	1,960	212	3,020	56.2	800	89.3	1,270	54.8	780	463	1,020	454	1,000
.143	2.03	.88	12.5	717	10,200	.37	5.2	81.3	32	.....	......	303	4,310	78.1	1,110	117.4	1,670	....	...	636	1,400	590	1,300
.166	2.36	1.08	15.4	1,290	18,300	.56	7.9	111.8	44	442	6,280	478	6,800	100.5	1,430	123.6	1,760	54.2	770	745	1,640	713	1,570
.098	1.40	.89	12.6	830	11,800	.32	4.6	119.4	47	233	3,320	331	4,420	99.8	1,420	116.6	1,660	65.4	930	654	1,440	632	1,390
.100	1.43	.79	11.2	717	10,200	.33	4.7	101.6	40	165	2,340	233	3,320	54.8	780	99.8	1,420	54.2	770	509	1,120	427	940
.047	.67	1.08	15.4	618	8,800	.22	3.2	137.2	54	155	2,200	190	2,700	40.1	570	73.1	1,040	42.9	610	354	780	336	740
.072	1.02	.61	8.7	597	8,500	.20	2.8	58.5	23	167	2,380	228	3,240	38.6	550	78.1	1,110	42.2	600	345	760	281	620
.042	.60	.75	10.6	696	9,900	.26	3.7	76.2	30	176	2,500	235	3,350	36.5	520	75.9	1,080	40.8	580	336	740	272	600
.043	.61	.77	11.0	478	6,800	.18	2.6	73.7	29	137	1,950	175	2,490	32.3	460	73.8	1,050	39.4	560	304	670	268	590
.076	1.08	.84	11.9	851	12,100	.35	5.0	91.5	36	219	3,120	271	3,860	52.7	750	97.0	1,380	54.2	770	454	1,000	413	910
.063	.89	.75	10.7	703	10,000	.33	4.7	111.8	44	162	2,310	231	3,290	59.1	840	94.9	1,350	56.2	800	527	1,160	504	1,110
.072	1.03	.62	8.8	576	8,200	.24	3.4	76.2	30	132	1,880	197	2,800	62.6	890	80.2	1,140	49.2	700	413	910	386	850
.170	1.70	1.01	14.4	788	11,200	.27	3.9	119.4	47	285	4,050	330	4,690	104.0	1,480	119.6	1,700	68.2	970	722	1,590	713	1,570
.063	.90	.66	9.4	844	12,000	.32	4.6	88.9	35	203	2,890	247	3,520	46.4	660	85.1	1,210	48.5	690	440	970	404	890
.070	1.00	.90	12.8	731	10,400	.22	3.2	114.3	45	215	3,060	249	3,540	50.0	710	88.6	1,260	47.1	670	500	1,100	504	1,110
.060	.86	.79	11.2	731	10,400	.24	3.4	99.1	39	192	2,730	223	3,170	50.0	710	83.0	1,180	54.2	770	463	1,020	454	1,000
.106	1.51	.96	13.7	724	10,300	.34	4.8	124.5	49	176	2,510	251	3,570	97.1	1,380	114.5	1,630	66.1	940	649	1,430	631	1,390
.092	1.31	.77	11.0	766	10,900	.29	4.1	111.7	44	200	2,840	245	3,480	74.6	1,060	90.0	1,280	55.5	790	527	1,160	513	1,130
.046	.65	.81	11.5	731	10,400	.27	3.9	104.2	41	164	2,330	225	3,200	51.3	730	78.8	1,120	52.0	740	463	1,020	431	950
.065	.93	.56	8.0	640	9,100	.22	3.1	73.7	29	153	2,180	213	3,030	47.8	680	65.4	930	33.7	480	413	910	391	860
.093	1.32	1.03	14.7	865	12,300	.27	3.8	137.2	54	264	3,760	325	4,620	66.1	940	92.8	1,320	56.2	800	577	1,270	563	1,240
.080	1.14	.78	11.1	816	11,600	.27	3.8	99.1	39	225	3,200	263	3,740	54.2	770	87.2	1,240	57.6	820	477	1,050	459	1,010
.076	1.08	.81	11.5	752	10,700	.30	4.2	106.6	42	210	2,990	250	3,560	58.4	830	87.9	1,250	54.2	770	509	1,120	481	1,060
.062	.88	.62	8.8	647	9,200	.20	2.9	88.9	35	174	2,480	211	3,000	52.7	750	83.0	1,180	53.4	760	463	1,020	445	980

TABLE 45.—Results of Tests on 126 Species of Wood Tested in

Common and botanical name and locality where grown.	Number of trees.	Number of rings— Per cm	Number of rings— Per in.	Percentage of summer wood.	Percentage of moisture content determined at 100° C. (212° F.).	Specific gravity oven dry (100° C. or 212° F.) based on— Volume when green.	Specific gravity based on— Volume when oven dry.	Weight (green). kg/m³	Weight (green). lb./ft.³	Shrinkage from green to oven dry condition. In volume (per cent of dimensions when green).	Shrinkage: Radial (per cent of dimensions when green).	Shrinkage: Tangential (per cent of dimensions when green).	Static bending. Fiber stress at elastic limit. kg/cm²	Fiber stress at elastic limit. lb./in.	Modulus of rupture. kg/cm²	Modulus of rupture. lb./in.²	Modulus of elasticity. th. kg/cm²	Modulus of elasticity. th. lb./in.²
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
HARDWOODS—Continued.																		
Oak, yellow (Quercus velutina), Arkansas, Wisconsin.	8	5.9	15	71	78	0.56	.67	1,008	63	14.2	4.5	9.7	323	4,600	576	8,200	83.0	1,180
Persimmon (Diospyros virginiana), Missouri.	5	5.5	14	...	58	.64	.78	1,008	63	18.3	7.5	10.8	394	5,600	703	10,000	96.3	1,370
Poplar, yellow (Liriodendron tulipifera), Tennessee.	5	5.5	14	...	64	.37	.42	608	38	11.4	4.1	6.9	225	3,200	394	5,600	85.1	1,210
Rhododendron, great (Rhododendron maximum), Tennessee.	5	11.0	28	...	99	.50	.60	992	62	16.2	6.3	8.7	323	4,600	485	6,900	61.2	870
Sassafras (Sassafras sassafras), Tennessee.	5	7.5	19	48	67	.42	.47	704	44	10.3	4.0	6.2	253	3,600	422	6,000	64.0	910
Serviceberry (Amelanchier canadensis), Tennessee.	5	7.5	19	...	48	.66	.79	977	61	18.7	6.7	10.8	394	5,600	675	9,600	115.3	1,640
Silverbell-tree (Mohrodendrum carolinum), Tennessee.	5	7.9	20	...	70	.42	.48	704	44	12.6	3.8	7.6	246	3,500	457	6,500	81.6	1,160
Sourwood (Oxydendrum arboreum), Tennessee.	5	9.4	24	...	69	.50	.59	848	53	15.2	6.3	8.9	309	4,400	542	7,700	92.8	1,320
Sumac, staghorn (Rhus hirta), Wisconsin.	5	3.5	9	61	45	.45	....	656	41	......	......	....	211	3,000	408	5,800	57.0	810
Sugarberry (Celtis mississippiensis), Missouri.	5	6.7	17	38	62	.47	.54	768	48	12.7	5.0	7.3	225	3,200	464	6,600	57.0	810
Sycamore (Platanus occidentalis), Indiana, Tennessee.	10	6.3	16	77	83	.46	.54	832	52	14.2	5.1	7.6	232	3,300	457	6,500	74.6	1,060
Umbrella, Fraser (Magnolia fraseri), Tennessee.	5	5.9	15	...	89	.40	.48	753	47	13.0	4.4	7.5	239	3,400	429	6,100	83.7	1,190
Walnut, black (Juglans nigra), Kentucky.	5	4.7	12	...	81	.51	.56	928	58	11.3	5.2	7.1	380	5,400	668	9,500	99.8	1,420
Willow, black (Salix nigra), Wisconsin, Missouri.	10	2.0	5	...	138	.34	.41	800	50	13.8	2.6	7.8	127	1,800	267	3,800	39.4	560
Willow, western black (Salix lasiandra), Oregon.	5	2.0	5	...	105	.39	.47	800	50	13.8	2.9	9.0	218	3,100	394	5,600	71.7	1,020
Witch-hazel (Hamamelis virginiana), Tennessee.	5	5.5	14	...	70	.56	.71	944	59	18.8	.....	.....	351	5,000	584	8,300	78.1	1,110
CONIFERS.																		
Cedar, incense (Libocedrus decurrens), California, Oregon.	8	6.3	16	30	108	.35	.36	720	45	7.6	3.3	5.7	274	3,900	436	6,200	59.1	840
Cedar, Port Orford (Chamaecyparis lawsoniana), Oregon.	5	9.5	24	25	52	.41	.47	624	39	10.7	5.2	8.1	274	3,900	478	6,800	105.4	1,500
Cedar, western red (Thuja plicata), Washington, Montana.	10	7.9	20	36	39	.31	.34	432	27	8.1	2.5	5.1	232	3,300	366	5,200	66.8	950
Cedar, white (Thuja occidentalis), Wisconsin.	5	9.1	23	36	55	.29	.32	448	28	7.0	2.1	4.9	183	2,600	295	4,200	32.3	460
Cypress, bald (Taxodium distichum), Louisiana, Missouri.	10	6.3	16	31	87	.41	.47	768	48	10.7	3.8	6.0	281	4,000	478	6,800	83.7	1,190
Cypress, yellow (Chamaecyparis nootkatensis), Oregon.	5	12.2	31	...	40	.40	.44	560	35	7.9	1.9	5.0	253	3,600	436	6,200	67.5	960
Douglas fir (Pseudotsuga taxifolia), Washington, Oregon.	18	5.1	13	35	36	.45	.52	608	38	12.6	5.0	7.9	351	5,000	548	7,800	111.2	1,580

a Green Condition in the Form of Small, Clear Pieces—Continued.

Static bending—Continued.				Impact bending.						Compression parallel to grain.				Compression perpendicular to grain; fiber stress at elastic limit.		Shearing strength parallel to the grain.		Tensile strength perpendicular to grain.		Hardness, load required to embed a 1.13 cm (0.444 in.) ball to one-half its diameter.			
Work in bending—				Fiber stress at elastic limit.		Work in bending to elastic limit.		Height of drop causing complete failure; 11.03 kg (50-lb.) hammer.		Fiber stress at elastic limit.		Maximum crushing strength.								End.		Side.	
To elastic limit.		To maximum load.																					
kgcm/cm³	in. lb. in/.³	kgcm/cm³	in. lb./in.³	kg/cm²	lb./in²	kgcm/cm³	in. lb./in.³	cm	in.	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg	lb.	kg	lb.
20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
0.084	1.20	0.87	12.3	760	10,800	0.31	4.4	101.6	40	202	2,870	256	3,640	61.2	870	83.0	1,180	58.4	830	454	1,000	481	1,060
.095	1.35	.91	13.0	851	12,100	.32	4.5	104.1	41	213	3,030	293	4,170	78.0	1,110	103.4	1,470	54.2	770	563	1,240	581	1,280
.034	.48	.39	5.6	562	8,000	.18	2.6	43.2	17	141	2,000	179	2,550	21.8	310	55.5	790	32.3	460	191	420	154	340
.097	1.38	.85	12.1	.....	......	....	...	66.1	26	.....	......	263	3,470	62.6	890	87.2	1,240	....	...	454	1,000	391	860
.056	.80	.50	7.1	598	8,500	.25	3.5	94.0	37	170	2,410	192	2,730	32.3	460	66.8	950	36.5	520	277	610	236	520
.076	1.08	1.14	16.2	858	12,200	.29	4.1	160.0	63	225	3,200	287	4,080	54.8	780	88.6	1,260	51.3	730	568	1,250	563	1,240
.044	.62	.62	8.8	640	9,100	.23	3.3	68.6	27	148	2,110	199	2,830	30.2	430	65.4	930	32.3	460	250	550	213	470
.058	.82	.69	9.8	760	10,800	.29	4.1	96.6	38	191	2,720	229	3,250	47.8	680	81.6	1,160	49.9	710	391	860	331	730
.047	.67	.76	10.8	.....	......	....	...	.....	...	.....	......	188	2,680	33.7	480	.....	.....	....	...	304	670	268	590
.055	.78	.84	12.0	576	8,200	.22	3.2	83.9	33	137	1,950	197	2,800	40.8	580	73.8	1,050	46.4	660	381	840	336	740
.042	.60	.53	7.5	619	8,800	.23	3.3	66.1	26	168	2,390	205	2,920	31.6	450	70.3	1,000	44.3	630	318	700	277	610
.039	.55	.58	8.3	604	8,600	.20	2.9	58.4	23	158	2,250	184	2,610	23.2	330	58.4	830	31.6	450	259	570	227	500
.082	1.16	1.26	14.6	837	11,900	.32	4.5	94.0	37	253	3,600	302	4,300	42.2	600	85.8	1,220	40.1	570	436	960	409	900
.025	.36	.76	10.8	358	5,100	.14	2.0	91.5	36	68.2	970	106.1	1,510	14.8	210	43.6	620	30.2	430	159	350	164	360
.041	.58	.76	10.8	534	7,600	.18	2.5	83.9	33	127.1	1,810	164.4	2,340	23.2	330	61.2	870	25.3	360	223	490	227	500
.091	1.29	1.37	19.5	872	12,400	.44	6.3	101.6	40	.....	......	239	3,400	43.6	620	78.8	1,120	....	...	459	1,010	445	980
.066	.94	.45	6.4	513	7,300	.17	2.4	43.2	17	201.8	2,870	221.5	3,150	32.3	460	58.4	830	19.7	280	259	570	177	390
.041	.59	.55	7.8	654	9,300	.19	2.7	63.5	25	208.8	2,970	230.5	3,280	26.7	380	61.9	880	16.9	240	254	560	218	480
.045	.64	.35	5.0	499	7,100	.17	2.4	43.2	17	175.6	2,500	199.5	2,840	21.8	310	50.6	720	14.8	210	195	430	118	260
.042	.60	.40	5.7	372	5,300	.14	2.0	38.1	15	98.8	1,420	140	1,990	20.4	290	43.6	620	16.9	240	145	320	104	230
.060	.86	.45	6.4	562	8,000	.18	2.6	61.0	24	218	3,100	245	3,490	33.0	470	57.6	820	19.7	280	213	470	173	380
.054	.77	.67	9.5	604	8,600	.22	3.2	68.6	27	168	2,390	203	2,880	28.8	410	57.6	820	18.3	260	236	520	186	410
.060	.86	.47	6.7	661	9,400	.20	2.9	63.5	25	239	3,400	277	3,940	37.2	530	64.0	910	14.1	200	232	510	213	470

TABLE 45.—Results of Tests on 126 Species of Wood Tested in

Common and botanical name and locality where grown.	Number of trees.	Number of rings— Per cm	Number of rings— Per in.	Percentage of summer wood.	Percentage of moisture content determined at 100° C. (212° F.).	Specific gravity oven dry (100° C. or 212° F.) based on— Volume when green.	Specific gravity oven dry based on— Volume when oven dry.	Weight (green). kg/m³	Weight (green). lb./ft.³	Shrinkage from green to oven dry condition. In volume (per cent of dimensions when green).	Shrinkage: Radial (per cent of dimensions when green).	Shrinkage: Tangential (per cent of dimensions when green).	Static bending. Fiber stress at elastic limit. kg/cm²	Fiber stress at elastic limit. lb./in.²	Modulus of rupture. kg/cm²	Modulus of rupture. lb./in.²	Modulus of elasticity. th. kg/cm²	Modulus of elasticity. th. lb./in.²
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
CONIFERS—Continued.																		
Douglas fir (Pseudotsuga taxifolia), Montana, Wyoming.	10	8.7	22	27	38	0.40	0.44	544	34	10.6	3.6	6.2	253	3,600	450	6,400	83.0	1,180
Fir, Alpine (Abies lasiocarpa), Colorado.	5	5.9	15	14	47	.31	.32	448	28	9.0	2.5	7.1	169	2,400	309	4,400	60.4	860
Fir, amabilis (Abies amabilis), Oregon, Washington.	20	3.1	8	26	102	.37	.42	752	47	14.1	4.5	10.0	274	3,900	443	6,300	91.4	1,300
Fir, balsam (Abies balsamea), Wisconsin.	5	4.7	12	26	117	.34	.41	720	45	10.8	2.8	6.6	211	3,000	344	4,900	67.5	960
Fir, grand (Abies grandis), Montana, Oregon.	10	7.1	18	30	94	.37	.42	705	44	10.6	3.2	7.2	253	3,600	429	6,100	91.4	1,300
Fir, noble (Abies nobilis), Oregon.	5	9.1	23	17	41	.35	.41	496	31	13.6	4.9	9.1	239	3,400	401	5,700	90.0	1,280
Fir, white (Abies concolor), California.	5	3.9	10	30	156	.35	.44	897	56	10.2	3.4	7.0	274	3,900	422	6,000	79.4	1,130
Hemlock, black (Tsuga mertensiana), Montana.	5	9.1	23	45	70	.42	.48	720	45	10.8	4.4	7.1	246	3,500	422	6,000	66.1	940
Hemlock, eastern (Tsuga canadensis), Tennessee, Wisconsin.	10	7.9	20	34	105	.38	.44	768	48	10.4	3.0	6.4	295	4,200	471	6,700	78.7	1,120
Hemlock, western (Tsuga heterophylla), Washington.	5	3.9	10	27	71	.38	.43	656	41	11.6	4.5	7.9	239	3,400	429	6,100	83.7	1,190
Larch, western (Larix occidentalis), Montana, Washington.	13	12.6	32	37	58	.48	.59	768	48	13.2	4.2	8.1	323	4,600	527	7,500	94.9	1,350
Pine, Cuban (Pinus heterophylla), Florida.	5	6.7	17	44	47	.58	.68	849	53	12.7	5.9	7.5	393	5,600	618	8,800	114.6	1,630
Pine, jack (Pinus divaricata), Wisconsin.	5	2.8	7	30	105	.39	.46	801	50	10.4	3.4	6.5	211	3,000	380	5,400	64.7	920
Pine, Jeffrey (Pinus jeffreyi), California.	5	7.1	18	23	101	.37	.42	753	47	9.9	4.4	6.7	225	3,200	352	5,000	68.9	980
Pine, loblolly (Pinus taeda), Florida, North Carolina, South Carolina.	15	3.1	8	42	70	.50	.59	865	54	12.6	5.5	7.5	309	4,400	527	7,500	97.0	1,380
Pine, lodgepole (Pinus contorta), Colorado, Montana, Wyoming.	28	9.5	24	22	65	.38	.44	625	39	11.5	4.5	6.7	211	3,000	387	5,500	76.0	1,080
Pine, longleaf (Pinus palustris), Florida, Louisiana Mississippi.	34	7.1	18	39	47	.55	.64	801	50	12.3	5.3	7.5	380	5,400	612	8,700	114.5	1,630
Pine, Norway (Pinus resinosa), Wisconsin.	5	8.7	22	41	54	.44	.51	673	42	11.5	4.6	7.2	260	3,700	450	6,400	97.0	1,380
Pine, pitch (Pinus rigida), Tennessee.	5	4.7	12	30	85	.47	.54	865	54	11.7	4.8	7.4	260	3,700	471	6,700	78.8	1,120
Pine, pond (Pinus serotina), Florida.	5	5.1	13	35	56	.50	.58	785	49	11.2	5.1	7.1	316	4,500	520	7,400	90.0	1,280
Pine, shortleaf (Pinus echinata), Arkansas, Louisiana.	12	4.7	12	40	64	.50	.58	800	50	12.6	5.1	8.2	316	4,500	562	8,000	101.9	1,450
Pine, sugar (Pinus lambertiana), California.	5	4.7	12	34	123	.36	.39	800	50	8.4	2.9	5.6	232	3,300	372	5,300	68.2	970
Pine, table-mountain (Pinus pungens), Tennessee.	5	5.9	15	29	75	.49	.55	865	54	10.9	3.4	6.8	316	4,500	527	7,500	89.3	1,270
Pine, western white (Pinus monticola), Montana.	5	11.0	28	33	58	.39	.45	625	39	11.5	4.1	7.4	246	3,500	401	5,700	93.5	1,330

a Green Condition in the Form of Small, Clear Pieces—Continued.

Static bending—Continued.				Impact bending.						Compression parallel to grain.				Compression perpendicular to grain; fiber stress at elastic limit.		Shearing strength parallel to the grain.		Tensile strength perpendicular to grain.		Hardness, load required to embed a 1.13 cm (0.444 in.) ball to one-half its diameter.			
Work in bending—				Fiber stress at elastic limit.		Work in bending to elastic limit.		Height of drop causing complete failure; 11.03 kg (50-lb.) hammer.		Fiber stress at elastic limit.		Maximum crushing strength.								End.		Side.	
To elastic limit.		To maximum load.																					
kgcm/cm³	in. lb./in.³	kgcm/cm³	in. lb./in.³	kg/cm²	lb./in.²	kgcm/cm³	in. lb./in.³	cm	in.	kg/cm²	lb./in.²	kg/cm²	lb./in²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg	lb.	kg	lb.
20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
0.046	0.65	0.48	6.8	640	9,100	0.21	3.0	50.8	20	177	2,520	211	3,000	31.6	450	61.9	880	24.6	350	204	450	182	400
.027	.39	.31	4.4	373	5,300	.11	1.6	22.9	9	117	1,660	145	2,060	21.8	310	42.9	610	....	...	127	280	100	220
.042	.60	.42	6.0	548	7,800	.15	2.2	53.4	21	167	2,380	205	2,930	22.5	320	47.1	670	16.9	240	163	360	141	310
.037	.52	.33	4.7	485	6,900	.16	2.3	40.7	16	156	2,220	169	2,400	14.8	210	42.9	610	12.7	180	132	290	132	290
.041	.58	.39	5.6	569	8,100	.18	2.6	55.9	22	188	2,680	212	3,010	23.9	340	53.4	760	16.2	230	191	420	163	360
.037	.53	.44	6.2	555	7,900	.18	2.6	50.8	20	167	2,370	190	2,700	21.8	310	49.2	700	12.7	180	136	300	114	250
.054	.77	.37	5.2	507	7,200	.15	2.2	45.7	18	184	2,610	197	2,800	30.9	440	51.3	730	18.3	260	173	380	150	330
.055	.78	.66	9.4	619	8,800	.25	3.6	91.5	36	182	2,590	203	2,890	28.1	400	61.9	880	25.3	360	263	580	209	460
.062	.88	.48	6.8	555	7,900	.20	2.8	50.8	20	191	2,710	230	3,270	35.1	500	61.9	880	18.3	260	232	510	186	410
.041	.58	.42	6.0	548	7,800	.17	2.4	50.8	20	161	2,290	203	2,890	24.6	350	57.0	810	18.3	260	245	540	195	430
.071	1.01	.50	7.1	661	9,400	.26	3.7	61.0	24	228	3,250	267	3,800	39.4	560	64.7	920	16.2	230	213	470	204	450
.077	1.10	.56	7.9	795	11,300	.27	3.9	94.1	37	278	3,950	314	4,470	41.5	590	72.4	1,030	20.4	290	259	570	286	630
.039	.55	.41	5.9	548	7,800	.23	3.3	76.2	30	158	2,250	182	2,580	26.7	380	53.4	760	21.8	310	173	380	168	370
.042	.60	.33	4.7	506	7,200	.18	2.6	53.4	21	143	2,030	167	2,370	24.6	350	48.5	690	18.3	260	145	320	154	340
.057	.81	.56	8.0	668	9,500	.22	3.1	81.3	32	202	2,870	252	3,580	38.7	550	63.2	900	19.7	280	182	400	204	450
.034	.49	.39	5.6	506	7,200	.16	2.3	50.8	20	148	2,100	184	2,610	21.8	310	48.5	690	15.5	220	145	320	150	330
.070	1.00	.56	8.0	759	10,800	.25	3.5	86.4	34	270	3,840	309	4,390	42.2	600	75.2	1,070	20.4	290	250	550	268	590
.041	.59	.41	5.8	527	7,500	.15	2.2	71.2	28	174	2,470	217	3,080	25.3	360	54.8	780	13.4	190	163	360	154	340
.053	.75	.60	8.5	640	9,100	.24	3.4	73.7	29	148	2,100	214	3,040	35.9	510	66.8	950	24.6	350	209	460	218	480
.065	.93	.53	7.5	661	9,400	.22	3.2	83.9	33	210	2,990	257	3,660	38.0	540	66.1	940	19.7	280	209	460	232	510
.056	.79	.61	8.7	788	11,200	.28	4.0	99.1	39	256	3,650	268	3,810	33.7	480	62.6	890	23.2	330	223	490	254	560
.046	.66	.35	5.0	471	6,700	.16	2.3	43.2	17	164	2,340	183	2,600	24.6	350	49.9	710	19.0	270	150	330	145	320
.066	.94	.57	8.1	718	10,200	.27	3.8	73.7	29	210	2,980	249	3,540	39.4	560	67.5	960	22.5	320	218	480	223	490
.038	.54	.36	5.1	534	7,600	.16	2.3	58.4	23	195	2,770	216	3,070	21.1	300	49.9	710	17.6	250	150	330	150	330

TABLE 45.—Results of Tests on 126 Species of Wood Tested in

Common and botanical name and locality where grown.	Number of trees.	Number of rings— Per cm	Number of rings— Per in.	Percentage of summer wood.	Percentage of moisture content determined at 100° C. (212° F.).	Specific gravity oven dry (100° C. or 212° F.) based on— Volume when green.	Specific gravity oven dry (100° C. or 212° F.) based on— Volume when oven dry.	Weight (green). kg/m³	Weight (green). lb./ft.³	Shrinkage from green to oven dry condition. In volume (per cent of dimensions when green).	Shrinkage from green to oven dry condition. Radial (per cent of dimensions when green).	Shrinkage from green to oven dry condition. Tangential (per cent of dimensions when green).	Static bending. Fiber stress at elastic limit. kg/cm²	Static bending. Fiber stress at elastic limit. lb./in.²	Static bending. Modulus of rupture. kg/cm²	Static bending. Modulus of rupture. lb./in²	Static bending. Modulus of elasticity. th. kg/cm²	Static bending. Modulus of elasticity. th. lb./in.²
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
CONIFERS—Continued.																		
Pine, western yellow (Pinus ponderosa), Colorado, Montana, Arizona, Washington, California.	25	7.9	20	22	95	0.38	0.42	737	46	10.0	3.9	6.4	218	3,100	365	5,200	71.0	1,010
Pine, white (Pinus strobus), Wisconsin.	5	6.3	16	31	74	.36	.39	625	39	7.8	2.2	5.9	239	3,400	372	5,300	75.2	1,070
Spruce, Engelmann (Picea engelmanni), Colorado.	10	5.5	14	14	100	.31	.35	609	38	10.4	3.4	6.6	176	2,500	295	4,200	58.3	830
Spruce, red (Picea rubens), New Hampshire, Tennessee.	9	6.7	17	27	43	.38	.41	545	34	11.8	3.8	7.8	239	3,400	401	5,700	83.0	1,180
Spruce, Sitka (Picea sitchensis), Washington.	5	3.5	9	24	53	.34	.37	529	33	11.2	4.5	7.4	211	3,000	387	5,500	83.0	1,180
Spruce, white (Picea canadensis), New Hampshire, Wisconsin.	7	5.5	14	27	46	.36	.43	529	33	14.8	3.7	7.3	232	3,300	380	5,400	68.9	980
Tamarack (Larix laricina), Wisconsin.	5	7.9	20	38	52	.49	.56	753	47	13.6	3.7	7.4	295	4,200	506	7,200	87.2	1,240
Yew, western (Taxus brevifolia), Washington.	5	10.6	27	...	44	.60	.67	865	54	9.7	4.0	5.4	457	6,500	710	10,100	69.6	990

a Green Condition in the Form of Small, Clear Pieces—Continued.

Static bending—Continued.				Impact bending.						Compression parallel to grain.				Compression perpendicular to grain; fiber stress at elastic limit.		Shearing strength parallel to the grain.		Tensile strength perpendicular to grain.		Hardness, load required to embed a 1.13 cm (0.444 in.) ball to one-half its diameter.			
Work in bending—To elastic limit.		Work in bending—To maximum load.		Fiber stress at elastic limit.		Work in bending to elastic limit.		Height of drop causing complete failure; 11.03 kg (50-lb.) hammer.		Fiber stress at elastic limit.		Maximum crushing strength.								End.		Side.	
kgcm/cm³	in. lb./in.³	kgcm/cm³	in. lb./in.³	kg/cm²	lb./in.²	kgcm/cm³	in. lb./in.³	cm	in.	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg	lb.	kg	lb.
20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
0.038	0.54	0.36	5.1	471	6,700	0.16	2.3	48.3	19	146	2,080	173	2,460	23.9	340	47.8	680	19.7	280	141	310	145	320
.044	.62	.41	5.9	457	6,500	.15	2.1	45.7	18	167	2,370	191	2,720	21.8	310	45.0	640	18.3	260	136	300	136	300
.030	.43	.34	4.9	408	5,800	.13	1.9	35.6	14	122	1,740	139	1,980	20.4	290	41.5	590	....	...	113	250	109	240
.039	.56	.43	6.1	506	7,200	.16	2.3	45.7	18	166	2,360	193	2,740	24.6	350	54.2	770	15.5	220	191	420	159	350
.031	.44	.45	6.4	555	7,900	.18	2.5	73.7	29	160	2,280	183	2,600	23.2	330	54.8	780	16.2	230	195	430	168	370
.046	.66	.40	5.7	478	6,800	.14	2.0	50.8	20	160	2,280	167	2,380	19.0	270	47.1	670	14.1	200	136	300	127	280
.059	.84	.51	7.2	548	7,800	.19	2.7	71.2	28	211	3,010	245	3,480	33.7	480	60.4	860	18.3	260	182	400	173	380
.173	2.46	1.42	20.2	921	13,100	.44	6.2	96.6	38	239	3,400	323	4,600	73.2	1,040	114.0	1,620	31.6	450	608	1,340	522	1,150

TABLE 46.—Results of Tests on 126 Species of Wood Tested

U. S. Department of Agriculture

[Test specimens were 2 by 2 in. (50.8 by 50.8 mm) in section. Bending specimens

Common and botanical name and locality where grown.	Number of rings.		Percentage of summer wood.	Percentage of moisture content determined at 100° C. (212° F.).	Specific gravity oven dry (100° C. or 212° F.) based on volume when air dry.	Weight (air dry).		Static bending.									
								Fiber stress at elastic limit.		Modulus of rupture.		Modulus of elasticity.		Work in bending.			
														To elastic limit.		To maximum load.	
	Per cm	Per in.				kg/m³	lb./ft.³	kg/cm²	lb./in.²	kg/cm²	lb./in.²	th. kg/cm²	th. lb./in.²	kgcm/cm³	in. lb./in.³	kgcm/cm³	in. lb./in.³
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
HARDWOODS.																	
Alder, red (Alnus oregona), Washington.	4.3	11	...	8.6	0.42	464	29	570	8,100	759	10,800	101.1	1,440	0.17	2.37	0.60	8.5
Ash, biltmore (Fraxinus biltmoreana), Tennessee.	6.7	17	49	5.3	.57	608	38	851	12,100	1,096	15,600	123.6	1,760	.32	4.60	.82	11.7
Ash, black (Fraxinus nigra), Michigan, Wisconsin.	9.5	24	52	10.4	.50	544	34	584	8,300	978	13,900	118.0	1,680	.13	1.84	1.09	15.5
Ash, blue (Fraxinus quadrangulata), Kentucky.	4.7	12	49	9.6	.58	640	40	612	8,700	1,040	14,800	100.5	1,430	.21	3.00	1.00	14.3
Ash, green (Fraxinus lanceolata), Missouri, Louisiana.	7.1	18	58	10.4	.57	624	39	665	9,460	1,046	14,900	118.8	1,690	.21	3.00	.96	13.6
Ash, Oregon (Fraxinus oregona), Oregon.	4.7	12	63	8.4	.57	624	39	562	8,000	1,019	14,500	100.5	1,430	.18	2.58	1.06	15.1
Ash, pumpkin (Fraxinus profunda), Missouri.	8.3	21	46	9.6	.53	576	36	492	7,000	830	11,800	92.1	1,310	.15	2.11	.55	7.8
Ash, white (forest grown) (Fraxinus americana), Arkansas, West Virginia.	6.3	16	50	8.7	.58	641	40	717	10,200	1,180	16,800	127.2	1,810	.23	3.29	1.06	15.1
Ash, white (second growth) (Fraxinus americana), New York.	3.5	9	63	9.5	.64	705	44	1054	15,000	1,306	18,600	139.2	1,980	.34	4.80	1.19	17.0
Aspen (Populus tremuloides), Wisconsin.	3.1	8	...	5.2	.42	448	28	534	7,600	760	10,800	90.7	1,290	.17	2.43	.51	7.3
Aspen, large-tooth (Populus grandidentata), Wisconsin.	3.1	8	...	8.0	.40	432	27	499	7,100	767	10,900	115.2	1,640	.13	1.83	.47	6.7
Basswood (Tilia americana), Pennsylvania, Wisconsin.	7.5	19	29	8.4	.38	416	26	513	7,300	717	10,200	111.1	1,580	.14	1.99	.57	8.1
Beach (Fagus atropunicea), Indiana, Pennsylvania.	7.5	19	30	11.2	.63	705	44	632	9,000	1,054	15,000	118.0	1,680	.20	2.91	.96	13.7
Birch, paper (Betula papyrifera), Wisconsin.	2.4	6	36	4.2	.58	608	38	802	11,400	1,124	16,000	127.1	1,810	.30	4.32	.93	13.2
Birch, sweet (Betula lenta), Pennsylvania.	10.6	27	...	9.0	.66	721	45	935	13,300	1,376	19,600	150.4	2,140	.32	4.56	1.19	17.0
Birch, yellow (Betula lutea), Pennsylvania, Wisconsin.	7.5	19	26	9.6	.63	705	44	865	12,300	1,329	18,900	154.6	2,200	.28	3.93	1.42	20.2
Buckeye, yellow (Aesculus octandra), Tennessee.	5.9	15	...	6.2	.38	400	25	492	7,000	654	9,300	90.0	1,280	.16	2.20	.44	6.2
Buckthorn, cascara (Rhamnus purshiana), Oregon.	6.7	17	...	4.0	.53	545	34	597	8,500	738	10,500	87.2	1,240	.23	3.28	.40	5.7
Butternut (Juglans cinerea), Tennessee, Wisconsin.	3.5	9	...	7.6	.39	416	26	513	7,300	654	9,300	88.6	1,260	.16	2.32	.58	8.2
Cherry, black (Prunus serotina), Pennsylvania.	4.3	11	...	9.2	.51	560	35	774	11,000	971	13,800	108.2	1,540	.32	4.48	.77	11.0
Cherry, wild red (Prunus pennsylvanica), Tennessee.	2.4	6	...	6.6	.41	432	27	548	7,800	752	10,700	98.5	1,400	.18	2.54	.65	9.3
Chestnut (Castanea dentata), Maryland, Tennessee.	3.9	10	48	8.6	.44	480	30	520	7,400	682	9,700	93.5	1,330	.17	2.41	.45	6.4
Chinquapin, western (Castanopsis chrysophylla), Oregon.	5.9	15	...	4.8	.48	496	31	837	11,900	992	14,100	99.2	1,410	.43	6.14	.67	9.5
Cottonwood (Populus deltoides), Missouri.	2.4	6	...	4.7	.43	448	28	604	8,600	801	11,400	115.4	1,640	.18	2.61	.52	7.4
Cottonwood, black (Populus trichocarpa), Washington.	2.4	6	...	8.5	.36	384	24	436	6,200	675	9,600	92.1	1,310	.11	1.62	.51	7.2
Cucumber tree (Magnolia acuminata), Tennessee.	5.5	14	...	6.8	.50	529	33	752	10,700	1,083	15,400	136.4	1,940	.23	3.22	.94	13.4
Dogwood, flowering (Cornus florida), Tennessee.	9.5	24	...	7.5	.77	833	52	830	11,800	1,288	18,300	119.5	1,700	.33	4.63	1.33	18.9

in an Air-Dry Condition in the Form of Small, Clear Pieces.

Bulletin No. 556, Sept, 15, 1917.

were 30 in. (762 mm) long; others were shorter, depending on kind of test.]

Impact bending.				Height of drop causing complete failure; 11.03 kg (50-lb.) hammer.		Compression parallel to grain.				Compression perpendicular to grain; fiber stress at elastic limit.		Shearing strength parallel to the grain.		Tensile strength perpendicular to grain.		Hardness, load required to embed a 1.13 cm (0.444 in.) ball to one-half its diameter.			
Fiber stress at elastic limit.		Work in bending to elastic limit.				Fiber stress at elastic limit.		Maximum crushing strength.								End.		Side.	
kg/cm²	lb./in.²	kgcm/cm³	in.lb./in.³	cm	in.	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg	lb.	kg	lb.
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
914	13,000	0.41	5.9	50.8	20	376	5,350	496	7,050	45.7	650	58.1	1,210	30.2	430	531	1,170	295	650
1.391	19,800	.73	10.4	116.9	46	502	7,140	729	10,370	142.0	2,020	138.5	1,970	56.9	810	936	2,060	604	1,330
858	12,200	.37	5.3	91.5	36	356	5,070	484	6,890	75.9	1,080	121.5	1,730	51.3	730	568	1,250	404	890
1,447	20,600	.74	10.5	106.6	42	430	6,120	544	7,740	134.3	1,910	151.0	2,150	30.9	440	858	1,890	618	1,360
1,223	17,400	.58	8.2	78.8	31	375	5,330	533	7,580	123.6	1,760	146.1	2,080	49.9	710	804	1,770	572	1,260
1,054	15,000	.44	6.2	78.8	31	331	4,710	499	7,100	140.6	2,000	146.9	2,090	54.8	780	758	1,670	590	1,300
1,069	15,200	.56	7.9	55.9	22	284	4,040	443	6,300	140.6	2,000	132.8	1,890	58.4	830	700	1,540	468	1,030
1,195	17,000	.62	8.8	91.5	36	394	5,600	576	8,190	108.3	1,540	148.2	2,110	61.9	880	886	1,950	599	1,320
1,673	23,800	.90	12.8	116.9	46	598	8,500	662	9,420	147.0	2,090	177.1	2,520	79.4	1,130	1,017	2,240	763	1,680
738	10,500	.28	4.0	61.0	24	316	4,490	450	6,400	38.7	550	62.5	890	26.7	380	386	850	191	420
1,061	15,100	.49	7.0	68.6	27	356	5,060	498	7,080	45.7	650	91.4	1,300	26.7	380	322	710	209	460
788	11,200	.32	4.6	40.7	16	311	4,430	420	5,980	40.8	580	97.2	1,240	26.0	370	268	590	204	450
1,385	19,700	.65	9.2	88.9	35	342	4,870	520	7,400	94.2	1,340	138.4	1,970	62.6	890	636	1,400	540	1,190
970	13,800	.46	6.6	61.0	24	477	6,780	666	9,470	64.0	910	114.5	1,630	......	.....	677	1,490	581	1,280
1,876	26,700	.93	13.2	122.0	48	511	7,270	751	10,680	123.0	1,750	188.3	2,680	42.9	610	949	2,090	677	1,490
1,490	21,200	.70	9.9	147.3	58	543	7,720	686	9,760	99.2	1,410	132.0	1,880	62.6	890	722	1,590	599	1,320
893	12,700	.45	6.4	35.6	14	297	4,220	413	5,870	45.0	640	80.2	1,140	46.4	660	250	550	181	400
788	11,200	.38	5.4	40.7	16	387	5,510	646	9,190	140.5	2,000	140.0	1,990	......	.....	813	1,790	581	1,280
907	12,900	.40	5.7	61.0	24	316	4,490	470	6,680	53.4	760	95.6	1,360	30.9	440	295	650	241	530
1,040	14,800	.41	5.9	71.2	28	515	7,330	588	8,370	71.7	1,020	135.6	1,930	39.4	560	768	1,690	468	1,030
851	12,100	.37	5.2	91.5	36	384	5,460	456	6,490	49.2	700	87.2	1,240	23.9	340	422	930	263	580
808	11,500	.38	5.4	45.7	18	311	4,420	465	6,620	65.4	930	81.6	1,160	33.0	470	354	780	263	580
879	12,500	.42	6.0	73.7	29	406	5,780	560	7,970	60.4	860	101.9	1,450	......	.....	418	920	377	830
527	7,500	.17	2.4	48.3	19	356	5,060	550	7,830	51.3	730	78.8	1,120	49.2	700	336	740	218	480
766	10,900	.31	4.4	55.9	22	310	4,410	382	5,440	32.3	460	81.6	1,160	23.9	340	304	670	177	390
1,251	17,800	.53	7.6	94.0	37	423	6,020	600	8,540	60.5	860	107.5	1,530	57.3	815	527	1,160	359	790
1,356	19,300	.71	10.1	101.6	40	424	6,030	498	7,090	173.5	2,470	192.8	2,740	121.5	1,730	1,353	2,980	1,149	2,530

TABLE 46.—Results of Tests on 126 Species of Wood Tested in

Common and botanical name and locality where grown.	Number of rings.		Percentage of summer wood.	Percentage of moisture content determined at 100° C. (212° F.).	Specific gravity oven dry (100° C. or 212° F.) based on volume when air dry.	Weight (air dry).		Static bending.									
								Fiber stress at elastic limit.		Modulus of rupture.		Modulus of elasticity.		Work in bending.			
														To elastic limit.		To maximum load.	
	Per cm	Per in.				kg/m³	lb./ft.³	kg/cm²	lb./in.²	kg/cm²	lb./in.²	th. kg/cm²	th. lb./in.²	kgcm/cm³	in. lb./in.³	kgcm/cm³	in. lb./in.³
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
HARDWOODS—Continued.																	
Dogwood, western (Cornus nuttaliii), Oregon.	8.3	21	...	5.3	0.68	721	45	710	10,100	858	12,200	123.8	1,760	0.23	3.26	0.60	8.5
Elder, pale (Sambucus glauca), Oregon.	2.4	6	...	4.6	.55	577	36	534	7,600	795	11,300	78.7	1,120	.18	2.51	.75	10.7
Elm, cork (Ulmus racemosa), Wisconsin.	11.0	28	50	8.5	.66	705	44	661	9,400	1,160	16,500	113.3	1,610	.23	3.32	1.32	18.7
Elm, slippery (Ulmus pubescens), Indiana, Wisconsin.	6.3	16	54	8.3	.54	592	37	661	9,400	1,048	14,900	110.5	1,570	.23	3.28	1.22	17.3
Elm, white (Ulmus americana), Wisconsin, Pennsylvania.	7.1	18	34	8.8	.51	560	35	647	9,200	1,027	14,600	104.9	1,490	.24	3.46	.96	13.7
Gum, black (Nyssa sylvatica), Tennessee.	10.6	27	...	7.2	.52	560	35	647	9,200	767	10,900	89.3	1,270	.27	3.84	.39	5.6
Gum, blue (Eucalyptus globulus), California.	....	...	...	5.7	.82	865	54	1012	1,440	1,448	20,600	182.6	2,600	.34	4.82	.82	11.6
Gum, cotton (Nyssa aquatica), Louisiana.	3.9	10	26	6.1	.52	545	34	689	9,800	795	11,300	96.3	1,370	.29	4.19	.45	6.4
Gum, red (Liquidambar styraciflua), Missouri.	6.3	16	...	11.3	.49	545	34	591	8,400	865	12,300	105.4	1,500	.24	3.39	.83	11.8
Hackberry (Celtis occidentalis), Indiana, Wisconsin.	4.7	12	56	9.2	.54	592	37	485	6,900	865	12,300	87.9	1,250	.15	2.18	.87	12.4
Haw, pear (Crataegus tomentosa), Wisconsin.	4.3	11	...	8.6	.70	768	48	632	9,000	1,209	1,720	96.2	1,370	.23	3.30	1.67	23.8
Hickory, big shellbark (Hicoria laciniosa), Mississippi, Ohio.	7.1	18	77	8.7	.71	768	48	689	9,800	1,440	20,500	143.4	2,040	.18	2.59	1.57	22.4
Hickory, bitternut (Hicoria minima), Ohio.	5.1	13	77	9.2	.68	737	46	724	10,300	1,320	18,800	132.0	1,880	.22	3.19	1.26	17.9
Hickory, mockernut (Hicoria alba), Mississippi, Pennsylvania.	7.1	18	73	8.9	.75	801	50	949	13,500	1,518	21,600	167.2	2,380	.29	4.19	1.55	22.0
Hickory, nutmeg (Hicoria myristicaeformis), Mississippi.	....	...	...	8.9	.62	673	42	647	9,200	1,356	19,300	127.9	1,820	.17	2.40	1.81	25.7
Hickory, pecan (Hicoria pecan), Missouri.	4.7	12	63	6.2	.70	737	46	844	12,000	1,139	16,200	136.4	1,940	.30	4.33	.94	13.4
Hickory, pignut (Hicoria glabra), Ohio, Mississippi, Pennsylvania, West Virginia.	6.3	16	74	9.6	.78	849	53	893	12,700	1,581	22,500	169.4	2,410	.27	3.87	2.12	30.2
Hickory, shagbark (Hicoria ovata), Ohio, Mississippi, Pennsylvania, West Virginia.	8.7	22	70	9.4	.74	801	50	837	11,900	1,588	22,600	160.9	2,290	.25	3.55	1.85	26.3
Hickory, water (Hicoria aquatica), Mississippi.	5.9	15	70	8.8	.62	673	42	830	11,800	1,409	20,200	151.8	2,160	.25	3.55	1.36	19.4
Holly, American (Ilex opaca), Tennessee.	10.6	27	...	6.4	.60	641	40	562	8,000	893	12,700	86.5	1,230	.21	2.95	.75	10.6
Hornbeam (Ostrya virginiana), Wisconsin.	11.4	29	...	5.6	.75	785	49	977	13,900	1,306	18,600	148.3	2,110	.38	5.34	1.01	14.4
Laurel, California (Umbellularia californica), Oregon.	2.4	6	...	4.9	.58	608	38	471	6,700	632	9,000	78.0	1,110	.17	2.40	.37	5.2
Laurel, mountain (Kalmia latifolia), Tennessee.	9.5	24	...	5.0	.72	753	47	766	10,900	928	13,200	99.2	1,410	.34	4.77	.64	9.1
Locust, black (Robinia pseudacacia), Tennessee.	4.3	11	51	10.0	.70	768	48	971	13,800	1,454	20,700	146.9	2,090	.37	5.29	1.34	19.1
Locust, honey (Gleditsia triacanthos), Missouri.	3.9	10	37	6.0	.63	673	42	752	10,700	1,174	16,700	118.7	1,690	.26	3.76	.89	12.6
Madrona (Arbutus menziessii), California, Oregon.	3.9	10	...	4.5	.70	721	45	668	9,500	893	12,700	105.4	1,500	.24	3.45	.54	7.6
Magnolia, evergreen (Magnolia foetida), Louisiana.	5.9	15	...	8.8	.51	560	35	548	7,800	879	12,500	104.1	1,480	.17	2.39	.86	12.3
Maple, Oregon (Acer macrophyllum), Washington.	4.7	12	...	8.3	.50	545	34	534	7,600	844	12,000	111.1	1,580	.14	1.93	.54	7.6
Maple, red (Acer rubrum), Pennsylvania, Wisconsin.	5.5	14	24	10.1	.54	592	37	647	9,200	998	14,200	122.2	1,740	.20	2.80	.90	12.8

an Air-Dry Condition in the Form of Small, Clear Pieces—Continued.

Impact bending.				Height of drop causing complete failure; 11.03 kg (50-lb.) hammer.		Compression parallel to grain.				Compression perpendicular to grain; fiber stress at elastic limit.		Shearing strength parallel to the grain.		Tensile strength perpendicular to grain.		Hardness, load required to embed a 1.13 cm (0.444 in.) ball to one-half its diameter.			
Fiber stress at elastic limit.		Work in bending to elastic limit.				Fiber stress at elastic limit.		Maximum crushing strength.								End.		Side.	
kg/cm²	lb./in.²	kgcm/cm³	in. lb./in.³	cm	in.	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg	lb.	kg	lb.
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
766	10,900	0.27	3.8	66.1	26	418	5,950	795	11,310	173.5	2,470	144.9	2,060	98.5	1,400	1,139	2,510	745	1,640
851	12,100	.48	6.9	76.2	30	291	4,140	492	6,990	68.9	980	......	......	......	.....	418	920	409	900
1,301	18,500	.66	9.4	134.6	53	387	5,510	592	8,420	130.6	1,860	150.5	2,140	52.0	740	786	1,730	668	1,470
1,251	17,800	.66	9.4	114.3	45	377	5,370	548	7,800	87.2	1,240	127.2	1,810	34.4	490	554	1,220	409	900
1,166	16,600	.70	9.9	111.8	44	370	5,270	482	6,850	59.7	850	122.3	1,740	42.8	610	563	1,240	395	870
1,209	17,200	.64	9.1	48.3	19	285	4,060	493	7,000	105.4	1,500	102.6	1,460	33.0	470	626	1,380	386	850
1,770	25,200	.89	12.6	106.6	42	802	11,400	977	13,900	158.1	2,250	144.0	2,050	......	.....	836	1,840	749	1,650
1,034	14,700	.55	7.8	50.8	20	383	5,450	556	7,910	107.5	1,530	129.3	1,840	66.1	940	668	1,470	449	990
1,355	19,300	.73	10.4	81.3	32	348	4,960	423	6,020	55.5	790	123.0	1,750	61.2	870	458	1,010	327	720
1,110	15,800	.61	8.7	106.6	42	295	4,200	453	6,450	93.5	1,330	125.9	1,790	40.1	570	549	1,210	422	930
950	13,500	.39	5.5	50.8	20	334	4,750	592	8,420	132.1	1,880	134.9	1,920	......	.....	1,030	2,270	766	1,680
1,764	25,100	1.02	14.5	213.3	84	....	......	682	9,710	186.9	2,660	170.8	2,430	......	.....	.....	......	.....	......
1,862	26,500	.98	14.0	167.6	66	....	......	744	10,600	168.0	2,390	144.0	2,050	......	.....	.....	......	.....	......
1,540	21,900	.75	10.6	188.0	74	....	......	746	10,610	178.5	2,540	133.5	1,900	......	.....	.....	......	.....	......
......	....	....	.....	......	....	....	......	559	7,960	163.0	2,320	147.5	2,100	......	.....	.....	......	.....	......
1,434	20,400	.73	10.4	104.2	41	434	6,170	766	10,890	235.4	3,350	178.5	2,540	92.1	1,310	1,075	2,370	971	2,140
1,841	26,200	.94	13.4	177.8	70	....	......	748	10,640	201.0	2,860	172.2	2,450	......	.....	.....	......	.....	......
1,580	22,500	.75	10.7	165.1	65	....	......	752	10,700	173.5	2,470	164.5	2,340	......	.....	.....	......	.....	......
......	....	....	.....	132.1	52	435	6,190	713	10,140	155.4	2,210	130.5	1,860	......	.....	.....	......	.....	......
1,040	14,800	.60	8.5	68.6	27	313	4,450	550	7,820	107.1	1,520	144.9	2,060	52.0	740	804	1,770	522	1,150
1,166	16,600	.53	7.6	101.6	40	584	8,310	826	11,750	161.7	2,300	148.4	2,110	......	.....	1,430	3,150	1,085	2,390
879	12,500	.44	6.2	55.9	22	367	5,220	572	8,140	135.6	1,930	164.4	2,340	66.8	950	899	1,980	663	1,460
1,223	17,400	.65	9.3	116.9	46	370	5,270	501	7,120	170.1	2,420	......	......	......	.....	1,212	2,670	990	2,180
1,519	21,600	.71	10.1	150.0	59	547	7,790	765	10,880	177.2	2,520	190.5	2,710	43.6	620	713	1,570	786	1,730
1,195	17,000	.65	9.3	114.3	45	458	6,520	669	9,520	196.9	2,800	181.4	2,580	57.6	820	922	2,030	726	1,600
752	10,700	.31	4.4	40.7	16	407	5,790	765	10,800	185.5	2,640	154.0	2,190	......	.....	1,190	2,620	876	1,930
1,054	15,000	.53	7.5	63.5	25	277	3,940	464	6,600	87.9	1,250	119.5	1,700	54.8	780	672	1,480	508	1,120
......	....	....	.....	76.2	30	448	6,370	505	7,180	78.8	1,120	141.3	2,010	36.6	520	740	1,630	431	950
1,195	17,000	.58	8.2	78.8	31	382	5,430	515	7,330	90.0	1,280	138.5	1,970	46.4	660	695	1,530	449	990

TABLE 46.—Results of Tests on 126 Species of Wood Tested in

Common and botanical name and locality where grown.	Number of rings.		Percentage of summer wood.	Percentage of moisture content determined at 100° C. (212° F.).	Specific gravity oven dry (100° C. or 212° F.) based on volume when air dry.	Weight (air dry).		Static bending.									
								Fiber stress at elastic limit.		Modulus of rupture.		Modulus of elasticity.		Work in bending. To elastic limit.		Work in bending. To maximum load.	
	Per cm	Per in.				kg/m³	lb./ft.³	kg/cm²	lb./in.²	kg/cm²	lb./in²	th. kg/cm²	th. lb./in.²	kgcm/cm³	in. lb./in.³	kgcm/cm³	in. lb./in.³
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
HARDWOODS—Continued.																	
Maple, silver (Acer saccharinum), Wisconsin.	2.8	7	...	8.2	0.48	513	32	542	7,700	710	10,100	85.1	1,210	0.19	2.67	0.53	7.6
Maple, sugar (Acer saccharum), Indiana, Pennsylvania, Wisconsin.	8.3	21	49	10.5	.62	689	43	731	10,400	1,110	15,800	127.9	1,820	.25	3.52	.96	13.6
Oak, bur (Quercus macrocarpa), Wisconsin.	4.7	12	59	10.2	.65	721	45	492	7,000	766	10,900	74.5	1,060	.20	2.79	.68	9.6
Oak, California black (Quercus californica), California, Oregon.	6.3	16	52	5.2	.60	641	40	590	8,400	738	10,500	81.6	1,160	.26	3.72	.40	5.7
Oak, canyon live (Quercus chrysolepsis), California.	5.1	13	...	5.0	.82	865	54	837	11,900	1,033	14,700	127.2	1,810	.61	8.67	.55	7.8
Oak, chestnut (Quercus prinus), Tennessee.	9.1	23	50	9.5	.68	737	46	745	10,600	1,054	15,000	115.2	1,640	.27	3.85	.81	11.5
Oak, cow (Quercus michauxii), Louisiana.	4.7	12	58	11.3	.68	753	47	527	7,500	1,019	14,500	127.1	1,810	.12	1.75	.84	11.9
Oak, laurel (Quercus laurifolia), Louisiana.	4.3	11	61	9.5	.64	705	44	612	8,700	984	14,000	124.4	1,770	.17	2.47	.84	12.0
Oak, Pacific post (Quercus garryana), Oregon.	6.3	16	49	6.6	.76	817	51	548	7,800	823	11,700	89.3	1,270	.19	2.73	.60	8.5
Oak, post (Quercus minor), Arkansas, Louisiana.	10.2	26	54	11.2	.68	753	47	548	7,800	956	13,600	108.2	1.540	.16	2.34	.94	13.3
Oak, red (Quercus rubra), Louisiana, Arkansas, Indiana, Tennessee.	4.3	11	62	10.9	.63	705	44	604	8,600	999	14,200	131.4	1,870	.16	2.32	.94	13.3
Oak, Spanish (highland) (Quercus digitata), Louisiana.	7.9	20	46	10.1	.60	656	41	450	6,400	830	11,800	109.6	1,560	.11	1.55	.68	9.7
Oak, Spanish (lowland) (Quercus pagodaefolia), Louisiana.	2.8	7	63	10.0	.69	753	47	844	12,000	1,363	19,400	166.0	2,360	.24	3.45	1.32	18.8
Oak, water (Quercus nigra), Louisiana.	3.9	10	61	10.8	.64	705	44	647	9,200	1,124	16,000	144.6	2,060	.17	2.36	1.59	22.6
Oak, white (Quercus alba), Arkansas, Louisiana, Indiana.	6.7	17	60	11.5	.69	768	48	584	8,300	1,069	15,200	125.0	1,780	.16	2.31	1.04	14.8
Oak, willow (Quercus phellos), Louisiana.	5.5	14	56	9.8	.72	785	49	752	10,700	1,153	16,400	143.4	2,040	.22	3.18	1.12	16.0
Oak, yellow (Quercus velutina), Arkansas, Wisconsin.	5.5	14	62	11.6	.61	673	42	562	8,000	992	14,100	116.0	1,650	.15	2.18	.96	13.7
Persimmon (Diospyros virginiana), Missouri.	5.5	14	...	5.5	.81	849	53	1082	15,400	1,666	23,700	173.0	2,460	.40	5.70	1.19	16.9
Poplar, yellow (Liriodendron tulipifera), Tennessee.	5.5	14	...	6.1	.41	433	27	591	8,400	830	11,800	113.1	1,610	.18	2.52	.53	7.5
Rhododendron, great (Rhododendron maximum), Tennessee.	11.0	28	...	4.6	.63	656	41	591	8,400	1,012	14,400	89.3	1,270	.22	3.09	.88	12.5
Sassafras (Sassafras sassafras), Tennessee.	7.5	19	48	6.8	.46	497	31	542	7,700	745	10,600	85.8	1,220	.19	2.71	.67	9.5
Serviceberry (Amelanchier canadensis), Tennessee.	7.5	19	...	8.4	.77	833	52	942	13,400	1,406	20,000	137.7	1,960	.34	4.88	1.39	19.8
Silverbell-tree (Mohrodendrum carolinum), Tennessee.	7.9	20	...	6.1	.47	497	31	513	7,300	689	9,800	98.4	1,400	.16	2.22	.44	6.2
Sourwood (Oxydendrum arboreum), Tennessee.	9.5	24	...	6.8	.57	608	38	766	10,900	970	13,800	115.2	1,640	.27	3.87	.80	11.4
Sumac, staghorn (Rhus hirta), Wisconsin.	3.5	9	61	8.0	.48	513	32	732	10,400	851	12,100	95.0	1,350	.32	4.50	.55	7.8
Sugarberry (Celtis mississippiensis), Missouri.	6.7	17	38	5.0	.54	560	35	668	9,500	914	13,000	99.2	1,410	.30	4.23	.75	10.7
Sycamore (Platanus occidentalis), Indiana, Tennessee.	6.3	16	77	9.2	.50	545	34	534	7,600	795	11,300	106.1	1,510	.15	2.20	.65	9.2
Umbrella, Fraser (magnolia fraseri), Tennessee.	5.9	15	...	6.4	.47	497	31	654	9,300	893	12,700	106.9	1,520	.23	3.27	.77	10.9
Walnut, black (Juglans nigra), Kentucky.	4.7	12	...	4.8	.57	592	37	1020	14,500	1,259	17,900	128.0	1,820	.45	6.43	.65	9.2

an Air-Dry Condition in the Form of Small, Clear Pieces—Continued.

Impact bending.				Height of drop causing complete failure; 11.03 kg (50-lb.) hammer.		Compression parallel to grain.				Compression perpendicular to grain; fiber stress at elastic limit.		Shearing strength parallel to the grain.		Tensile strength perpendicular to grain.		Hardness, load required to embed a 1.13 cm (0.444 in.) ball to one-half its diameter.			
Fiber stress at elastic limit.		Work in bending to elastic limit.				Fiber stress at elastic limit.		Maximum crushing strength.								End.		Side.	
kg/cm²	lb./in.²	kgcm/cm³	in. lb./in.³	cm	in.	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg	lb.	kg	lb.
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
1,054	15,000	0.66	9.4	61.0	24	394	5,600	464	6,600	83.0	1,180	120.2	1,710	34.4	490	626	1,380	341	750
1,343	19,100	.65	9.3	83.9	33	426	6,060	602	8,570	113.9	1,620	172.2	2,450	54.2	770	908	2,000	649	1,430
1,075	15,300	.60	8.6	68.6	27	260	3,700	467	6,640	117.3	1,670	135.0	1,920	45.7	650	663	1,460	645	1,420
647	9,200	.29	4.2	30.5	12	312	4,440	592	8,420	130.8	1,860	120.2	1,710	58.4	830	617	1,360	581	1,280
1,005	14,300	.47	6.7	81.3	32	570	8,100	939	13,360	203.0	2,890	192.5	2,740	105.5	1,500	1,525	3,360	1,430	3,150
1,490	21,200	.63	9.0	106.7	42	371	5,280	551	7,840	83.0	1,180	112.5	1,600	106.1	1,510	608	1,340	545	1,200
1,350	19,200	.57	8.1	104.2	41	311	4,420	533	7,580	99.9	1,420	154.0	2,190	49.2	700	595	1,310	572	1,260
1,069	15,200	.41	5.9	99.1	39	371	5,280	578	8,230	104.6	1,490	142.6	2,030	55.5	790	581	1,280	572	1,260
893	12,700	.40	5.7	58.4	23	353	5,020	602	8,570	180.0	2,560	155.2	2,210	56.9	810	949	2,090	808	1,780
1,251	17,800	.60	8.6	116.9	46	278	3,960	484	6,890	133.5	1,900	133.5	1,900	54.8	780	618	1,360	632	1,390
1,300	18,500	.64	9.1	99.1	39	324	4,610	518	7,370	85.1	1,210	123.6	1,760	54.8	780	681	1,500	595	1,310
1,160	16,500	.58	8.3	66.1	26	213	3,030	478	6,800	82.9	1,180	107.5	1,530	36.5	520	477	1,050	499	1,100
1,771	25,200	.93	13.2	124.4	49	493	7,010	683	9,720	121.5	1,730	152.5	2,170	60.4	860	645	1,640	699	1,540
1,364	19,400	.60	8.6	111.8	44	276	3,930	506	7,200	92.9	1,320	141.3	2,010	66.1	940	658	1,450	554	1,220
1,210	17,200	.53	7.6	96.6	38	306	4,350	535	7,610	94.2	1,340	147.0	2,090	56.2	800	699	1,540	622	1,370
1,230	17,500	.65	9.3	111.8	44	345	4,910	578	8,230	115.2	1,640	126.5	1,800	100.5	1,430	695	1,530	736	1,620
1,012	14,400	.45	6.4	104.2	41	336	4,780	468	6,660	81.6	1,160	138.5	1,970	57.6	820	636	1,400	549	1,210
1,574	22,400	.82	11.7	88.9	35	647	9,210	987	14,050	275.0	3,910	187.5	2,670	106.9	1,520	1,694	3,730	1,444	3,180
1,300	18,600	.63	8.9	55.9	22	314	4,470	526	7,480	52.0	740	82.3	1,170	40.1	570	268	590	204	450
647	9,200	.23	3.3	40.7	16	387	5,510	658	9,360	135.0	1,920	......	......	62.6	890	.....	......	.....	......
823	11,700	.43	6.1	78.8	31	244	3,470	426	6,060	103.4	1,470	97.0	1,380	43.6	620	304	670	313	690
1,722	24,500	.86	12.3	147.4	58	608	8,640	775	11,020	161.6	2,300	120.9	1,720	......	.....	1,130	2,490	921	2,030
1,124	16,000	.56	8.0	58.4	23	304	4,330	484	6,890	60.4	860	92.1	1,310	33.7	480	482	1,060	295	650
1,455	20,700	.81	11.5	96.6	38	394	5,600	576	8,190	96.3	1,370	118.0	1,680	31.6	450	763	1,680	482	1,060
.....	....	....	.....	......	....	398	5,660	545	7,750	96.4	1,370	......	......	......	.....	436	960	327	720
992	14,100	.52	7.4	94.0	37	419	5,960	594	8,450	141.3	2,010	101.9	1,450	49.2	700	745	1,640	504	1,110
760	10,800	.28	4.0	71.2	28	301	4,260	441	6,280	71.0	1,010	102.5	1,460	52.7	750	441	970	368	810
1,152	16,400	.52	7.4	71.2	28	367	5,220	527	7,500	59.1	840	94.2	1,340	55.5	790	445	980	313	690
1,363	19,400	.79	11.3	83.9	33	554	7,880	750	10,660	137.8	1,960	104.0	1,480	54.8	780	504	1,110	490	1,080

TABLE 46.—Results of Tests on 126 Species of Wood Tested in

Common and botanical name and locality where grown.	Number of rings.		Percentage of summer wood.	Percentage of moisture content determined at 100° C. (212° F.).	Specific gravity oven dry (100° C. or 212° F.) based on volume when air dry.	Weight (air dry).		Static bending. Fiber stress at elastic limit.		Static bending. Modulus of rupture.		Static bending. Modulus of elasticity.		Static bending. Work in bending. To elastic limit.		Static bending. Work in bending. To maximum load.	
	Per cm	Per in.				kg/m³	lb./ft.³	kg/cm²	lb./in.²	kg/cm²	lb./in.²	th. kg/cm²	th. lb./in.²	kgcm/cm³	in. lb./in.³	kgcm/cm³	in. lb./in.³
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
HARDWOODS—Continued.																	
Willow, black (Salix nigra), Wisconsin, Missouri.	2.0	5	...	6.4	0.38	417	26	394	5,600	534	7,600	58.4	830	0.17	2.45	0.48	6.8
Willow, western black (Salix lasiandra), Oregon.	2.0	5	...	4.0	.47	497	31	562	8,000	781	11,100	108.2	1,540	.17	2.39	.59	8.4
Witch-hazel (Hamamelis virginiana), Tennessee.	5.5	14	...	5.1	.65	689	43	844	12,000	1,428	20,300	116.6	1,660	.34	4.85	1.53	21.8
CONIFERS.																	
Cedar incense (Libocedrus decurrens), California, Oregon.	6.7	17	30	5.1	.36	386	24	520	7,400	661	9,400	91.4	1,300	.16	2.31	.34	4.9
Cedar, Port Orford (Chamaecyparis lawsoniana), Oregon.	9.5	24	25	9.0	.45	497	31	626	8,900	1,020	14,500	143.4	2,040	.16	2.25	.....	.....
Cedar, western red (Thuja plicata), Washington, Montana.	7.9	20	36	7.4	.34	352	22	429	6,100	619	8,800	87.9	1,250	.12	1.68	.45	6.4
Cedar, white (Thuja occidentalis), Wisconsin.	9.1	23	36	11.2	.31	352	22	358	5,100	471	6,700	56.9	810	.13	1.84	.33	4.7
Cypress, bald (Taxodium distichum), Louisiana, Missouri.	6.3	16	31	9.0	.44	481	30	612	8,700	794	11,300	108.3	1,540	.21	3.03	.51	7.3
Cypress, yellow (Chamaecyparis nootkatensis), Oregon.	12.2	31	...	5.5	.43	448	28	632	9,000	900	12,800	100.5	1,430	.24	3.37	.60	8.5
Douglas fir (Pseudotsuga taxifolia), Montana, Wyoming.	8.7	22	27	9.4	.44	481	30	485	6,900	724	10,300	102.5	1,460	.13	1.83	.46	6.5
Douglas fir (Pseudotsuga taxifolia), Washington, Oregon.	5.1	13	35	6.2	.51	545	34	745	10,600	984	14,000	155.2	2,210	.21	2.94	.59	8.4
Fir, Alpine (Abies lasiocarpa), Colorado.	5.9	15	14	15.9	.32	368	23	337	4,800	422	6,000	62.6	890	.12	1.73	.24	3.4
Fir, amabilis (Abies amabilis), Washington.	4.7	12	36	9.3	.39	433	27	492	7,000	745	10,600	112.4	1,600	.12	1.73	.72	10.3
Fir, balsam (Abies balsamea), Wisconsin.	4.7	12	26	4.8	.38	400	25	513	7,300	696	9,900	101.3	1,440	.15	2.11	.38	5.4
Fir, grand (Abies grandis), Montana, Oregon.	7.1	18	30	6.8	.41	433	27	499	7,100	773	11,000	125.8	1,790	.12	1.66	.58	8.3
Fir, noble (Abies nobilis), Oregon.	9.1	23	17	8.4	.39	417	26	542	7,700	844	12,000	123.0	1,750	.13	1.92	.66	9.4
Fir, white (Abies concolor), California.	3.9	10	30	9.6	.38	417	26	492	7,000	689	9,800	104.7	1,490	.13	1.86	.39	5.5
Hemlock, black (Tsuga mertensiana), Montana.	9.1	23	45	8.0	.46	497	31	520	7,400	802	11,400	83.0	1,180	.19	2.74	.64	9.1
Hemlock, eastern (Tsuga canadensis), Tennessee, Wisconsin.	7.9	20	34	8.6	.42	448	28	506	7,200	682	9,700	91.4	1,300	.16	2.32	.41	5.8
Hemlock, western (Tsuga heterophylla), Washington.	3.9	10	27	5.4	.42	448	28	562	8,000	759	10,800	106.8	1,520	.17	2.48	.43	6.1
Larch, western (Larix occidentalis), Montana, Washington.	14.2	36	37	8.3	.54	577	36	710	10,100	949	13,500	128.5	1,830	.22	3.06	.58	8.2
Pine, Cuban (Pinus heterophylla), Florida.	6.7	17	44	8.8	.66	721	45	872	12,400	1,285	18,300	156.0	2,220	.27	3.83	.92	13.1
Pine, jack (Pinus divaricata), Wisconsin.	2.8	7	30	6.1	.44	465	29	457	6,500	682	9,700	98.5	1,400	.13	1.81	.36	5.1
Pine, Jeffrey (Pinus jeffreyi), California.	7.1	18	23	8.7	.41	448	28	619	8,800	766	10,900	92.1	1,310	.24	3.42	.50	7.1
Pine, loblolly (Pinus taeda), Florida.	3.5	9	42	6.5	.57	608	38	823	11,700	1,096	15,600	149.6	2,130	.26	3.70	.63	9.0
Pine, lodgepole (Pinus contorta), Montana, Wyoming, Colorado.	9.5	24	22	7.1	.43	448	28	632	9,000	809	11,500	102.6	1,460	.23	3.24	.53	7.6
Pine, longleaf (Pinus palustris), Florida, Louisiana, Mississippi.	7.1	18	38	9.2	.66	673	42	830	11,800	1,175	16,700	154.6	2,200	.25	3.58	.79	11.3
Pine, Norway (Pinus resinosa), Wisconsin.	8.7	22	41	12.5	.48	545	34	647	9,200	865	12,300	125.8	1,790	.19	2.68	.70	9.9

an Air-Dry Condition in the Form of Small, Clear Pieces—Continued.

Impact bending.				Height of drop causing complete failure; 11.03 kg (50-lb.) hammer.		Compression parallel to grain.				Compression perpendicular to grain; fiber stress at elastic limit.		Shearing strength parallel to the grain.		Tensile strength perpendicular to grain.		Hardness, load required to embed a 1.13 cm (0.444 in.) ball to one-half its diameter.			
Fiber stress at elastic limit.		Work in bending to elastic limit.				Fiber stress at elastic limit.		Maximum crushing strength.								End.		Side.	
kg/cm²	lb./in.²	kgcm/cm³	in. lb./in.³	cm	in.	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg/cm²	lb./in.²	kg	lb.	kg	lb.
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
647	9,200	0.34	4.8	41.7	16	202	2,880	353	5,030	49.9	710	94.2	1,340	33.0	470	309	680	227	500
977	13,900	.50	7.1	76.2	30	351	5,000	500	7,120	64.7	920	99.1	1,410	46.4	660	558	1,230	332	730
......	......	....	.....	......	....	453	6,440	592	8,430	152.5	2,170	......	......	......	.....	1,163	2,560	881	1,940
780	11,100	.37	5.2	43.2	17	450	6,400	506	7,200	59.0	840	63.3	900	19.0	270	472	1,040	236	520
1,236	17,600	.51	7.2	99.1	39	541	7,700	545	7,750	71.7	1,020	105.4	1,500	44.3	630	431	950	318	700
675	9,600	.24	3.4	40.7	16	379	5,390	444	6,320	49.2	700	64.7	920	12.7	180	341	750	173	380
506	7,200	.20	2.8	30.5	12	200	2,840	291	4,140	27.4	390	63.3	900	16.9	240	213	470	154	340
788	11,200	.33	4.7	66.1	26	419	5,970	540	7,690	64.0	910	76.0	1,080	19.7	1,280	363	800	250	550
1,026	14,600	.56	7.9	73.7	29	547	7,780	568	8,080	67.5	960	78.8	1,120	30.2	430	368	810	266	580
935	13,300	.39	5.6	71.2	28	374	5,320	498	7,090	66.7	950	76.0	1,080	22.5	320	341	750	300	660
1,005	14,300	.38	5.4	83.9	33	651	9,260	751	10,680	85.8	1,220	89.3	1,270	23.2	330	418	920	368	810
471	6,700	.15	2.1	35.5	14	230	3,270	239	3,400	35.1	500	71.0	1,010	......	.....	191	420	154	340
837	11,900	.37	5.3	61.0	24	356	5,070	460	6,540	40.8	580	83.0	1,180	20.4	290	327	720	213	470
597	8,500	.20	2.9	58.4	23	....	......	467	6,640	37.3	530	55.5	790	12.7	180	336	740	227	500
984	14,000	.41	5.8	81.3	32	420	5,970	496	7,060	59.7	850	70.3	1,000	13.4	190	372	820	254	560
879	12,500	.32	4.6	68.6	27	432	6,140	509	7,240	59.7	850	76.6	1,090	9.1	130	391	860	213	470
591	8,400	.23	3.2	35.5	14	294	4,180	432	6,150	50.4	720	74.5	1,060	18.3	260	354	780	209	460
1,096	15,600	.56	7.9	91.5	36	306	4,360	528	7,510	99.8	1,420	88.6	1,260	23.9	340	586	1,290	313	690
879	12,500	.42	6.0	61.0	24	368	5,240	496	7,060	74.5	1,060	81.6	1,160	13.4	190	391	860	222	490
914	13,000	.42	6.0	66.1	26	547	7,780	556	7,910	58.3	830	82.3	1,170	11.9	170	463	1,020	282	620
1,195	17,000	.60	8.6	86.4	34	592	8,420	677	9,640	90.0	1,280	107.5	1,530	23.9	340	627	1,380	395	870
1,265	18,000	.51	7.2	106.6	42	644	9,160	836	11,890	113.9	1,620	135.0	1,920	45.7	650	545	1,200	527	1,160
921	13,100	.39	5.6	94.0	37	....	......	546	7,770	80.9	1,150	93.5	1,330	30.9	440	395	870	336	740
999	14,200	.44	6.2	73.7	29	365	5,200	490	6,980	70.3	1,000	101.9	1,450	28.8	410	336	740	250	550
1,040	14,800	.41	5.9	66.1	26	561	7,980	794	11,300	112.4	1,600	120.9	1,720	26.0	370	468	1,030	381	840
759	10,800	.33	4.7	50.8	20	441	6,270	513	7,300	78.7	1,120	68.9	980	26.7	380	291	640	227	500
1,052	16,400	.46	6.6	81.3	32	650	9,250	765	10,880	117.4	1,670	115.3	1,640	29.5	420	518	1,140	463	1,020
1,062	15,100	.44	6.3	63.5	25	398	5,660	498	7,080	58.3	830	88.6	1,260	33.0	470	318	700	272	600

TABLE 46.—Results of Tests on 126 Species of Wood Tested in

Common and botanical name and locality where grown.	Number of rings.		Percentage of summer wood.	Percentage of moisture content determined at 100° C. (212° F.).	Specific gravity oven dry (100° C. or 212° F.) based on volume when air dry.	Weight (air dry).		Static bending. Fiber stress at elastic limit.		Static bending. Modulus of rupture.		Static bending. Modulus of elasticity.		Static bending. Work in bending. To elastic limit.		Static bending. Work in bending. To maximum load.	
	Per cm	Per in.				kg/m³	lb./ft.³	kg/cm²	lb./in.²	kg/cm²	lb./in.²	th. kg/cm²	th. lb./in.²	kgcm/cm³	in. lb./in.³	kgcm/cm³	in. lb./in.³
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
CONIFERS—Continued.																	
Pine, pitch (Pinus rigida), Tennessee.	4.7	12	30	7.6	0.52	560	35	548	7,800	872	12,400	105.4	1,500	0.18	2.56	0.61	8.7
Pine, pond (Pinus serotina), Florida.	5.1	13	35	6.2	.56	592	37	794	11,300	1,027	14,600	144.0	2,050	.24	3.43	.65	9.2
Pine, shortleaf (Pinus echinata), Arkansas, Louisiana.	3.9	10	40	11.0	.54	608	38	647	9,200	977	13,900	138.4	1,970	.17	2.46	.71	10.1
Pine, sugar (Pinus lambertiana), California.	4.7	12	34	11.4	.37	417	26	450	6,400	604	8,600	85.1	1,210	.13	1.79	.35	5.0
Pine, table mountain (Pinus pungens), Tennessee.	5.9	15	29	8.0	.53	577	36	661	9,400	942	13,400	116.0	1,650	.22	3.06	.63	8.9
Pine, western white (Pinus monticola), Montana.	11.0	28	33	7.9	.43	464	29	555	7,900	808	11,500	118.8	1,690	.15	2.17	.70	10.0
Pine, western yellow (Pinus ponderosa), Colorado, Montana, Arizona, Washington, California.	7.9	20	22	10.8	.41	448	28	485	6,900	689	9,800	94.2	1,340	.15	2.13	.45	6.4
Pine, white (Pinus strobus), Wisconsin.	6.3	16	31	9.9	.39	433	27	492	7,000	675	9,600	99.8	1,420	.14	2.04	.45	6.4
Spruce, Engelmann (Picea, engelmanni), Colorado.	5.5	14	14	14.8	.32	384	24	316	4,500	478	6,800	72.4	1,030	.077	1.09	.38	5.4
Spruce, red (Picea rubens), New Hampshire, Tennessee.	6.7	17	32	10.8	.41	448	28	520	7,400	760	10,800	109.0	1,550	.14	1.97	.61	8.7
Spruce, Sitka (Picea sitchensis), Washington.	3.5	9	24	8.9	.38	417	26	506	7,200	788	11,200	113.3	1,610	.13	1.78	.73	10.4
Spruce, white (Picea canadensis), New Hampshire, Wisconsin.	5.5	14	27	9.6	.40	448	28	415	5,900	647	9,200	97.8	1,390	.10	1.40	.58	8.2
Tamarack (Larix laricina), Wisconsin.	7.9	20	38	11.0	.53	592	37	590	8,400	844	12,000	118.0	1,680	.17	2.35	.50	7.1
Yew, western (Taxus brevifolia), Washington.	10.6	27	...	9.2	.63	689	43	710	10,100	1,180	16,800	102.8	1,460	.28	3.94	1.29	18.4

an Air-Dry Condition in the Form of Small, Clear Pieces—Continued.

Impact bending.				Height of drop causing complete failure; 11.03 kg (50-lb.) hammer.		Compression parallel to grain.				Compression perpendicular to grain; fiber stress at elastic limit.		Shearing strength parallel to the grain.		Tensile strength perpendicular to grain.		Hardness, load required to embed a 1.13 cm (0.444 in.) ball to one-half its diameter.			
Fiber stress at elastic limit.		Work in bending to elastic limit.				Fiber stress at elastic limit.		Maximum crushing strength.								End.		Side.	
kg/cm^2	$lb./in.^2$	$kgcm/cm^3$	$in. lb./in.^3$	cm	in.	kg/cm^2	$lb./in.^2$	kg/cm^2	$lb./in.^2$	kg/cm^2	$lb./in.^2$	kg/cm^2	$lb./in.^2$	kg/cm^2	$lb./in.^2$	kg	lb.	kg	lb.
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
1,210	17,200	0.75	10.7	71.2	28	316	4,490	534	7,600	82.3	1,170	117.4	1,670	40.8	580	372	820	313	690
1,104	15,700	.44	6.3	66.1	26	578	8,220	752	10,690	111.0	1,580	121.0	1,720	28.8	410	463	1,020	404	890
1,166	16,600	.46	6.5	91.5	36	498	7,080	608	8,660	92.1	1,310	97.8	1,390	28.8	410	427	940	399	880
710	10,100	.30	4.3	43.2	17	333	4,740	365	5,190	45.0	640	75.9	1,080	24.6	350	295	650	209	460
1,116	15,900	.53	7.6	73.7	29	320	4,560	597	8,500	107.6	1,530	90.7	1,290	......	.....	377	830	331	730
1,046	14,900	.41	5.8	73.7	29	408	5,810	551	7,840	56.9	810	41.4	590	......	.....	213	470	191	420
703	10,000	.29	4.1	40.7	16	316	4,490	421	5,990	53.4	760	81.6	1,160	28.8	410	259	570	209	460
654	9,300	.23	3.3	45.7	18	356	5,070	447	6,360	53.4	760	75.2	1,070	23.9	340	277	610	213	470
584	8,300	.22	3.2	38.1	15	209	2,980	268	3,810	36.5	520	64.0	910	......	.....	177	390	132	290
851	12,100	.34	4.9	71.2	28	385	5,470	448	6,380	43.6	620	81.6	1,160	26.7	380	304	670	232	510
977	13,900	.37	5.2	63.5	25	....	......	406	5,770	71.0	1,010	85.1	1,210	......	.....	354	780	241	530
682	9,700	.25	3.5	50.8	20	325	4,620	423	6,020	41.5	590	68.2	970	24.6	350	345	760	254	560
914	13,000	.40	5.7	58.4	23	362	5,150	534	7,590	76.0	1,080	96.3	1,370	28.8	410	327	720	291	640
837	11,900	.37	5.3	76.2	30	332	4,720	648	9,220	188.3	2,680	174.2	2,480	28.8	410	1,058	2,330	818	1,800

TABLE 47.—Approximate Figures for Change of Properties of Woods With Change of Moisture Content; Variation of Property With Specific Gravity.

[For use with Tables 45 and 46.]

Property.	Average increase (or decrease) in value effected by lowering (or raising) the moisture content 1 per cent when at about 12 per cent.	Approximate power of specific gravity according to which property varies.
	Per cent.	
Shrinkage	....	1
Static bending:		
Fiber stress at elastic limit	6	1
Modulus of rupture	4	1
Modulus of elasticity	2	1
Work to elastic limit	8	2
Work to maximum load	—[1] 1	2
Impact bending:		
Fiber stress at elastic limit	4	1
Work to elastic limit	5	2
Height of drop	—[1] 3	2
Compression parallel to grain:		
Fiber stress at elastic limit	5	1
Crushing strength	4	1
Compression perpendicular to grain:		
Fiber stress at elastic limit	6	2
Hardness, end	3	2
Hardness, side	1	2
Shearing strength parallel to grain	4	1
Tension perpendicular to grain	1	2

[1] Minus indicates decrease effected by lowering moisture contents.

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INDEX

In view of the volume of this circular and a considerable number of graphical charts scattered through it, the cross references have been made fairly complete.

However, the general arrangement of materials made it unnecessary to indicate where a particular property of a given material is mentioned.

This index will locate an individual property only when it is found in a table or chart separate from the main table of properties of the material.

The reader should consult first the material in question and then the key words for individual properties, which may be given separately somewhere else.