Copper and Copper Base Alloys

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The Physical and Mechanical Properties of Copper and Its Commercial Alloys in Wrought Form

BY

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COPPER AND COPPER BASE ALLOYS

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ACKNOWLEDGMENT

The data presented here have been compiled for the purpose of rendering readily available reasonably complete engineering data on each of those many alloys of copper that are of commercial significance and, except when otherwise noted, are based on tests conducted by the Research and Development Department of Revere Copper and Brass Incorporated.

PREFACE

Copper has certain basic properties that have rendered it of unusual significance in the development of our industrial economy. Copper in itself possesses the valuable properties of high electrical conductivity, high thermal conductivity, reasonable strength, great malleability, and an excellent resistance to the corrosive action of the atmosphere, sea water, and many chemical media.

Copper can be alloyed readily with many other metals and in commercial practice such alloying is resorted to extensively where it is desired to improve certain of the basic properties of copper itself and where such an improvement can be effected with the sacrifice only of such other properties as are of limited significance in the application intended.

Although many variations in properties are obtained through a control of alloy constituents, there are further controllable variations that are introduced in each case by the method of fabrication.

It is necessary that the engineer or technician in contemplating the use of copper-base alloys or in specifying the properties of a specific alloy for a given use be fully aware of the limitations to which the specific alloy is subject as well as of the interrelationship that exists between properties.

It is equally essential that the fabricator have data at hand by which to establish alloying, working, and annealing schedules directed toward the production of material to meet a particular specification.

R. A. Wilkins,
E. S. Bunn.

Rome, N. Y.,
March, 1943.

CONTENTS

COPPER AND COPPER-BASE ALLOYS

CHAPTER I

THE COPPERS

Electrolytic tough-pitch copper is the type of copper most widely used in industrial applications in the United States. Such copper contains controlled amounts of cuprous oxide introduced during refining. The cuprous oxide, which ordinarily is present in amounts ranging from 0.02 to 0.05 per cent, causes the copper to take a "level set" on solidifying and does not impair its electrical conductivity or materially affect its physical properties.

Oxygen-free copper (high-conductivity and low-conductivity). The following oxygen-free coppers have been developed during the past several years:

1. An oxygen-free copper that is prepared by melting and casting copper under special atmospheres and out of contact with oxygen.

2. An oxygen-free copper that is prepared by melting cathodes and removing oxygen by the judicious use of phosphorus. A residual phosphorus content of under 0.01 per cent is maintained.

3. Coalesced copper—manufactured by compressing specially prepared granular cathodes in a reducing atmosphere while hot and then extruding through a die into commercial shapes without any previous melting.

4. Copper which is deoxidized with calcium boride or other such deoxidants and which contains no residual deoxidant.

5. Copper that is deoxidized with phosphorus and contains between 0.01 and 0.03 per cent residual phosphorus. This is the common type of "phosphorized copper."

Types 1, 2, 3, and 4 are known as "high-conductivity oxygen-free copper" because they possess electrical conductivities sufficiently high to meet A.S.T.M. and other specification requirements for use as electrical conductors.

Type 5 is known as "low-conductivity oxygen-free copper" because of the lower electrical conductivity incidental to the phosphorus content.

Lake or silver-bearing copper derives its name from the fact that large deposits of this type of copper were located in the vicinity of Lakes Superior and Michigan. Lake copper usually contains silver in amounts ranging from 7 to 30 ounces per ton and may or may not contain arsenic from 0.001 to 0.50 per cent, depending upon the exact source of the ore. Natural Lake copper is fire-refined to a high degree of purity, and some types have sufficiently high electrical properties to be suitable for electrical conductors. Because the Lake deposits have been extensively worked and are approaching exhaustion, it has become the practice recently to add silver to electrolytic copper. Such copper is known as "synthetic Lake" or "silver-bearing" copper.

In addition to the coppers of major importance, already mentioned, the following special coppers are of commercial significance:

1. *Arsenical copper*—in which arsenic in controlled amounts up to 0.60 per cent is added to electrolytic cathode copper for the purpose of improving certain mechanical properties and properties of corrosion resistance. Oxygen may or may not be present.

2. *Tellurium copper*—in which tellurium in amounts up to 0.75 per cent is added to previously deoxidized copper to produce free-cutting properties without impairing too seriously electrical conductivity or hot-working properties.

3. *Leaded copper*—in which 1 per cent or more lead is added to previously deoxidized copper for the purpose of imparting free-cutting properties without seriously impairing electrical or thermal conductivities, but with a sacrifice of hot-working properties.

The coppers, with the exception of leaded copper, are exceptionally plastic through a wide range of temperature and possess no critical range in which plasticity is seriously reduced. It is commercial practice to hot-roll copper through a temperature range of 1200 to 1650°F. as this is the range of maximum plasticity. Copper, with the above exception, may be hot-worked by any of the commercial fabricating methods.

The coppers possess almost unlimited capacity for being cold-worked. However, although it is common practice in the manufacture of certain types of products to effect reductions of 90 per cent without intermediate annealing, copper that is to be used for deep drawing or stamping operations is usually brought to its final gage by reductions not exceeding 50 per cent of its cross-sectional area.

Copper to be used for drawing, stamping, or forming is, of course, supplied in the annealed condition. Copper is annealed at temperatures between 450 and 1500°F., depending on the properties desired. Those grades of copper which contain oxygen must not be annealed in reducing atmospheres as under such conditions copper becomes gassed, *i.e.*, the copper oxide eutectic is reduced to pure copper leaving voids or fissures (see Figs. 1 and 2). Copper that has been gassed is completely lacking in ductility and unsuited for further use. Those grades of copper which are oxygen-free or have been deoxidized by phosphorus or other deoxidants are not materially affected by exposure to reducing atmospheres at elevated temperatures.

The presence of small amounts of phosphorus, silver, arsenic, or antimony has the affect of raising the minimum temperature at which copper will soften. In many applications this higher annealing point is desirable and silver in amounts up to 25 ounces per ton is frequently specified.

FIG. 1.—Structure of cold-worked and annealed copper (tough pitch). Etchant $NH_4OH + H_2O_2$. Magnification 75 ×.

Corrosion Resistance.—Although the commonly available commercial coppers differ in their content of certain minor constituents, none of these significantly alter the characteristics of the metal in respect to its ability to resist corrosion.

Copper withstands atmospheric corrosion and sea-water corrosion as satisfactorily as any other commercially available metal, and it has been used for centuries in construction where resistance to attack of this nature is desired. In addition, copper is substantially immune to the chemical attack of a large number and variety of industrial chemicals, although copper ordinarily should not be used in contact with oxidizing acids and most oxidizing agents, or in services where alternate exposure to oxidizing conditions and acid reagents is anticipated.

Metallic salts readily susceptible of chemical reduction are particularly dangerous in respect to the corrosion of copper; and ferric, stannic, mercuric, and cupric compounds, particularly, constitute a source of danger when present in an otherwise non-oxidizing acid solution, which of and by itself might be inactive with respect to copper.

Ammonia and carbon dioxide in the presence of moisture and in relatively low concentration can constitute active corrosive agents with respect to copper.

USES

Electrolytic (Tough-pitch) Copper.—Electrolytic (tough-pitch) copper is the most important type of copper commercially available. It is consumed in large quantities by the electrical industry as wire for electrical conductors, bars for bus-bar and commutator use, and in forms such as sheet, strip, plate, etc., for widespread architectural and industrial applications.

Phosphor Deoxidized Copper.—The phosphor deoxidized coppers are used for refrigerator tubing and other applications where flaring, flanging, and spinning operations might be deleteriously affected by the presence of the copper–copper oxide eutectic dispersion that is characteristic of electrolytic copper. The

FIG. 2.—Embrittled copper (tough-pitch copper that has been annealed in a reducing atmosphere). Etchant $NH_4OH + H_2O_2$. Magnification 75 ×.

phosphor deoxidized coppers also are preferable to electrolytic copper when welding operations are to be performed. The small residual quantities of phosphorus reduce the electrical conductivity of copper materially, as indicated in Chart 1, and phosphor deoxidized copper, therefore, is seldom found in electrical applications.

Oxygen-free Copper Containing No Residual Deoxidant.—The modification in physical properties introduced by the elimination of oxygen is indicated in the data following. Although this type of copper is more expensive to produce than the tough pitch, its satisfactory performance in many manufacturing operations and the reduction of manufacturing scrap consequential to its use in such operations compensate in many applications for its higher initial cost.

Silver-bearing Coppers.—Silver present in amounts ordinarily ranging from 5 to 6 ounces per ton up to 12 or 13, but in special cases running as high as 30 ounces per ton, does not impair the electrical conductivity of copper where this property is of significance and does have the effect of increasing the equicohesive or recrystallization temperature of the metal materially, as is indicated by the data in Chart. 2.

Copper with a silver content of from 8 ounces per ton up has a recrystallization or softening temperature materially in excess of the melting point of commercial soft solders so that copper of this type can be soldered into assemblies, such as automobile radiators, without impairment of the physical properties imparted to such copper by means of cold work.

Arsenical Copper.—Copper containing arsenic in moderate amount appears to form a tenacious, adherent, initial film on exposure to the atmosphere and many other corrosive media. With such coppers subsequent mild corrosion appears to progress uniformly and without causing pitting.

In mechanical applications where vibration and alternation of stresses by reason of expansion and contraction introduce the possibility of cracking or failure in fatigue, the presence of small pits introduces the notch effect with a drastic lowering of the resistance of the copper to fatigue failure. Arsenical coppers find useful application where stresses of this type are to be combated.

It has also been observed that copper containing arsenic in moderate amount hardens less rapidly on cold working than arsenic-free copper. This in itself indicates a higher resistance to failure in corrosion fatigue, particularly as influenced by the notch effect.

The arsenical coppers are widely used in England and have found wide application in the construction of such parts as locomotive fireboxes where the arsenic appears to prevent excessive scaling of the metal at elevated temperatures. In this country the use of deoxidized arsenical copper as a condenser tube material for combating the corrosive attack of inland waters is growing. More recently tough-pitch arsenical copper with an arsenic content of 0.3 to 0.5 per cent arsenic has found wide application in the building field as roofing, flashing, and gutter material.

Tellurium Copper.—This alloy is rapidly supplanting leaded copper in the fabrication of electrical hardware requiring machining operations in its manufacture.

Fire-refined Copper.—This type of copper, resulting either from the processing of scrap metal or from the treatment of ores, is usually cast as ingot bar for use in the production of copper-base alloys.

However, shapes cast for use in the direct fabrication of wrought-copper forms are produced in certain types of fire-refined coppers. In general, such copper is used in applications which do not require the higher electrical conductivities attainable with electrolytically refined copper.

Tables 1 to 8 on pages 4 to 23 give the physical properties and a summarization of the mechanical properties of the more important coppers. Charts 1 to 74 on pages 3 to 26 show in greater detail the effect of cold working and annealing on the mechanical properties.

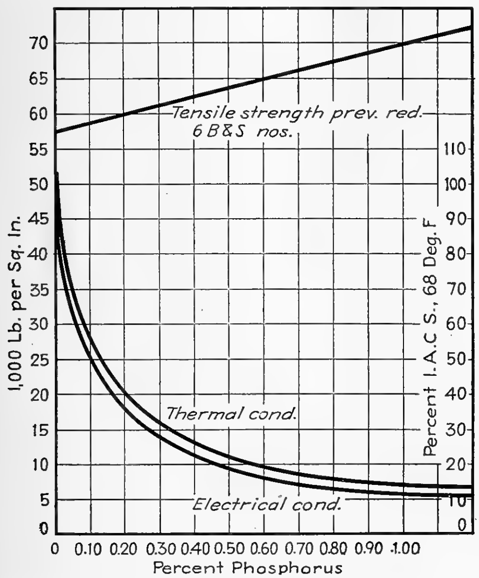


Chart 1.—The effect of phosphorus on the electrical conductivity, thermal conductivity, and tensile strength of copper, cold-rolled 6 B. & S. Nos. (50 per cent reduction of area). Based on data by Smith.[88]

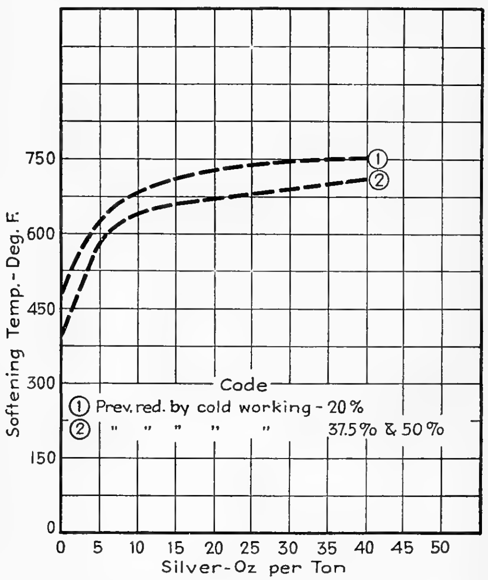


Chart 2.—The effect of silver on the softening temperature of cold-worked tough-pitch copper according to J. L. Gregg.[2]

TABLE 1
ELECTROLYTIC COPPER (TOUGH PITCH)

General Data—Rod

Copper, 99.03 %; oxygen, 0.04 %; phosphorus, nil; silver, nil

Property	Hard[a]	Soft[b]	Forgings		
			Hot	Cold[c]	Cold[d]
Tensile strength, p.s.i. (000 omitted)	55	33	33–36	35–50	55
Apparent elastic limit, p.s.i. (000 omitted)	40	4	4–8	8–35	44
Yield strength, 0.5% extension, p.s.i. (000 omitted)	48	8	8	22–46	50
Yield strength, 0.2% offset, p.s.i. (000 omitted)	49	7	7	21–45	45
Yield strength, 0.1% offset, p.s.i. (000 omitted)	43	6	6	10–40	44
Elongation, % in 2 in.	10	50	50–45	40–10	5
Reduction of area, %	45	65	60–40	60–50	40
Endurance limit, p.s.i. (000 omitted)	15	10	10	12–15	15
Rockwell hardness F, 1/16-in. ball, 60-kg. load	90	25	25–65	65–85	90
Rockwell hardness B, 1/16-in. ball, 100-kg. load	55	...	.....	15–50	55
Brinell hardness, 10-mm. ball, 500-kg. load	194	40	40–60	60–83	89
Modulus of elasticity, p.s.i.	16,000,000				
Forging range, °F	1250–1450				
Forging quality	Good				
Type structure	Single phase, alpha				

General Data—Strip

Copper, 99.92%; oxygen, 0.05%

Property	Hard[e]	Soft[f]
Tensile strength, p.s.i. (000 omitted)	52–55	33
Elongation, % in 2 in.	4	45
Apparent elastic limit, p.s.i. (000 omitted)	40–45	
Yield strength, 0.5% extension, p.s.i. (000 omitted)	48–51	7
Yield strength, 0.2% offset, p.s.i. (000 omitted)	48–51	7
Yield strength, 0.1% offset, p.s.i. (000 omitted)	45–48	7
Rockwell hardness F, 1/16-in. ball, 60-kg. load	91–93	45
Rockwell hardness B, 1/16-in. ball, 100-kg. load	53–57	
Rockwell hardness G, 1/16-in. ball, 150-kg. load	18–22	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	80–81	
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	57–59	
Endurance limit (at 10^8 reversals):(1,6)		
Soft, p.s.i. (000 omitted)	11	
2 B. & S. Nos., p.s.i. (000 omitted)	13	
8 B. & S. Nos., hard, p.s.i. (000 omitted)	14	
Young's modulus of elasticity, p.s.i.	16,000,000	

Physical Data

Melting point, °F	1981
Coefficient of expansion, per °C. from 25–300°C	0.0000177
Electrical conductivity,(87) % I.A.C.S, 68°F	101.6
Thermal conductivity,(87) B.t.u. per sq. ft. per ft. per hr. per °F., 68 °F	227
Density, lb. per cu. in	0.322

Available Creep Data(3)

(Electrolytic tough-pitch copper; fully annealed)

At 400°F. a stress of 3,100 p.s.i. is required to produce a rate of creep per 1,000 hr. of 0.01%

At 400°F. a stress of 6,700 p.s.i. is required to produce a rate of creep per 1,000 hr. of 0.10%

Superior numbers in parentheses in tables refer to the numbered items in the Bibliography, page 331.

[a] Refers to rod previously hard-drawn 50%; rod under 1 in. in diameter, ready to finish grain size 0.030 mm.

[b] Refers to 1100°F. anneal for 1 hr.

[c] Material cold-forged from soft rod (5 to 40% reduction).

[d] Material cold-forged from ld-worked condition (40%).

[e] 6 B. & S. Nos., hard, 0.045–0.015 mm. grain size at ready-to-finish, respectively.

[f] Refers to 800°F anneal (1 hr. at temperature).

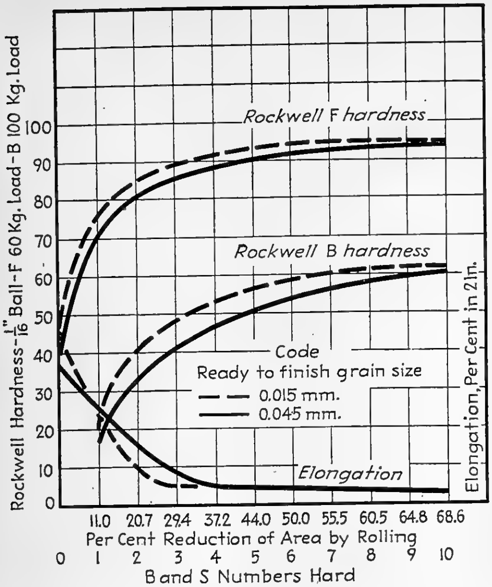


Chart 3.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of electrolytic (tough-pitch) copper (99.92 % copper, 0.05 % oxygen) strip previously annealed to two different grain sizes (0.015 and 0.045 mm.) (0.040-in. stock).

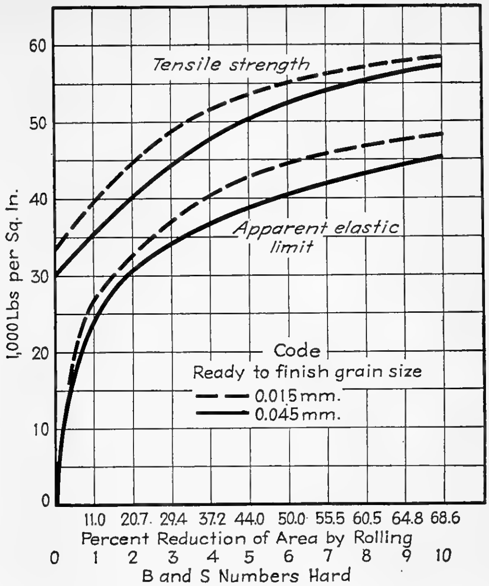


Chart 4.—The effect of cold rolling on the tensile strength and apparent elastic limit of electrolytic (tough-pitch) copper (99.92 % copper, 0.05 % oxygen) strip previously annealed to two different grain sizes (0.015 and 0.045 mm.) (0.040-in. stock).

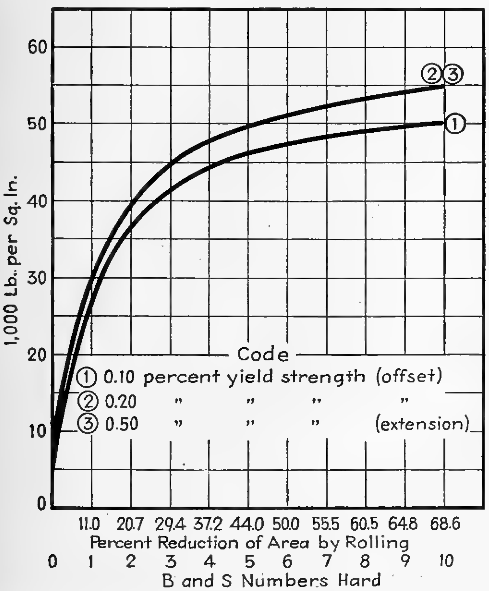


Chart 5.—The effect of cold rolling on the yield strengths of electrolytic (tough-pitch) copper (99.92 % copper, 0.05 % oxygen) strip previously annealed to a grain size of 0.015 mm. (0.040-in. stock).

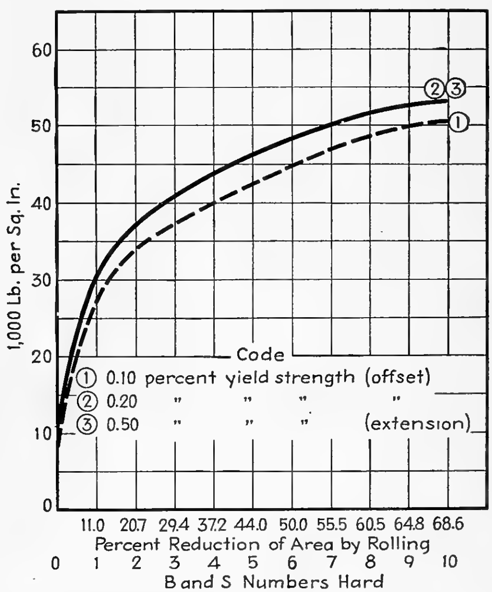


Chart 6.—The effect of cold rolling on the yield strengths of electrolytic (tough-pitch) copper (99.92 % copper, 0.05 % oxygen) strip previously annealed to a grain size of 0.045 mm. (0.040-in. stock).

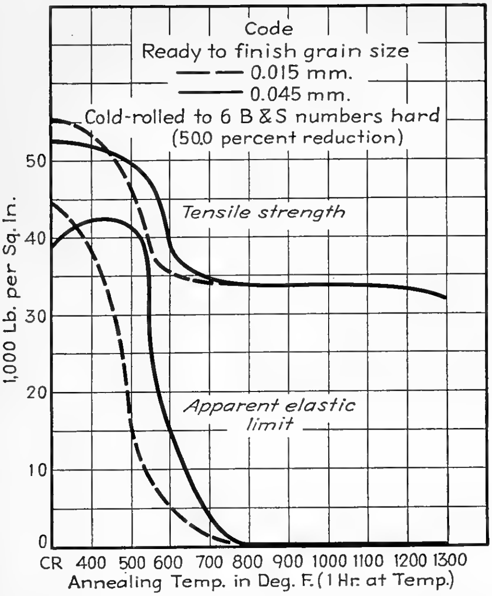


CHART 7.—The effect of annealing on the tensile strength and apparent elastic limit of electrolytic (tough-pitch) copper previously cold-rolled 6 B. & S. Nos. hard (50 per cent reduction of area) from two different ready-to-finish grain sizes (0.015 and 0.045 mm.) (0.040-in. stock).

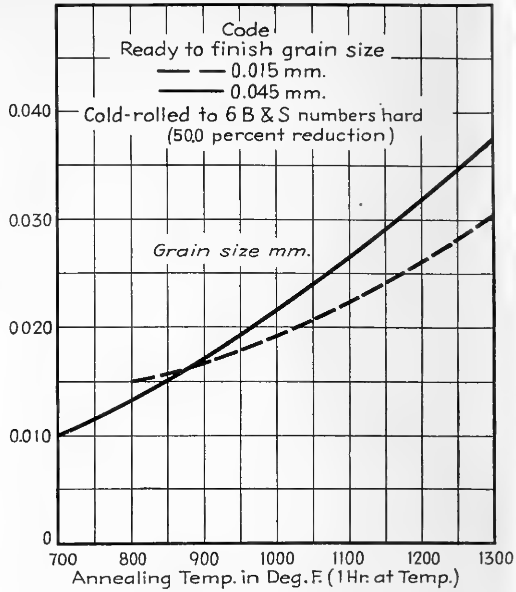


CHART 8.—The effect of annealing on the grain-growing characteristics of electrolytic (tough-pitch) copper previously cold-rolled 6 B. & S. Nos. hard (50 per cent reduction of area) from two different ready-to-finish grain sizes (0.015 and 0.045 mm.) (0.040-in. stock).

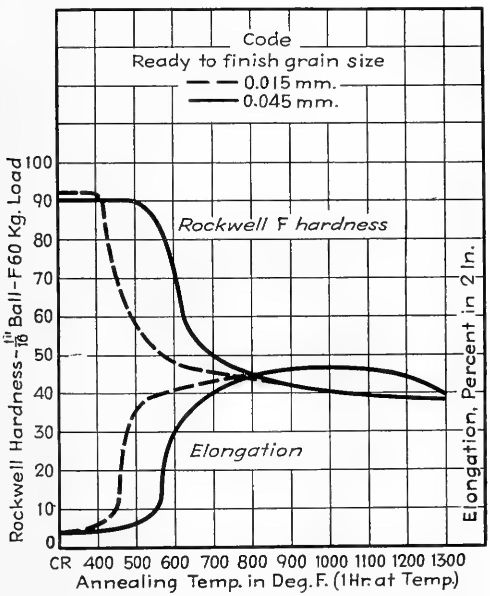


CHART 9.—The effect of annealing on the Rockwell F hardness and percentage elongation in 2 in. of electrolytic (tough-pitch) copper previously cold-rolled 6 B. & S. Nos. hard (50 per cent reduction of area) from two different ready-to-finish grain sizes (0.015 and 0.045 mm.) (0.040-in. stock).

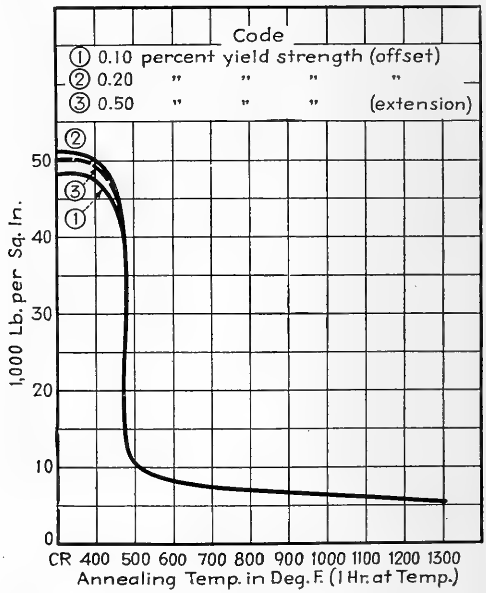


CHART 10.—The effect of annealing on the yield strengths of electrolytic (tough-pitch) copper previously cold-rolled 6 B. & S. Nos. hard (50 per cent reduction of area) from a ready-to-finish grain size of 0.015 mm.) (0.040-in. stock).

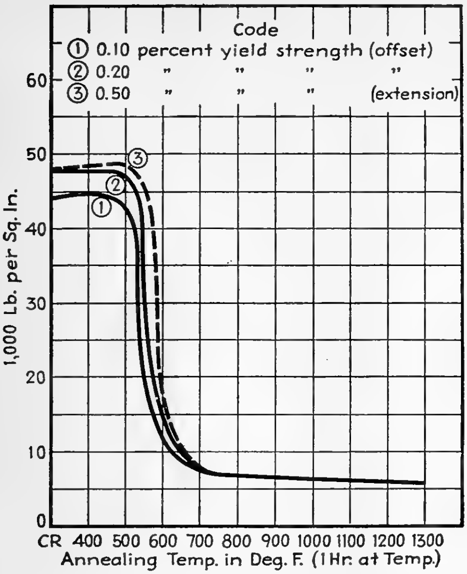


CHART 11.—The effect of annealing on the yield strengths of electrolytic (tough-pitch) copper previously cold-rolled 6 B. & S. Nos. hard (50 per cent reduction of area) from a ready-to-finish grain size of 0.045 mm.) (0.040-in. stock).

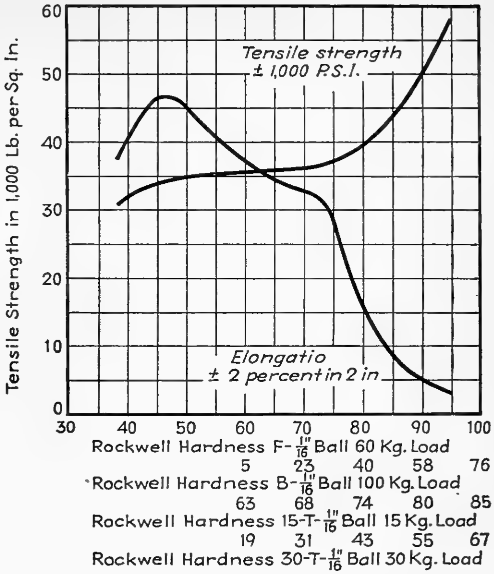


CHART 12.—This chart can be employed to determine the approximate tensile strength and percentage elongation in 2 in. of electrolytic (tough-pitch) copper when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

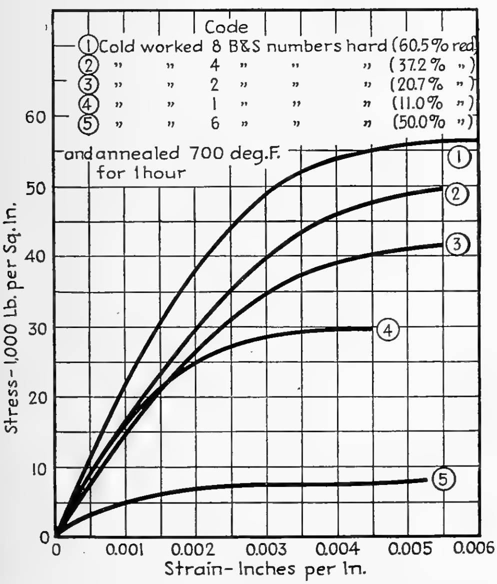


CHART 13.—The effect of cold rolling on the stress-strain characteristics of electrolytic (tough-pitch) copper strip having a ready-to-finish grain size of 0.015 mm. (0.040-in.-thick stock); 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used.

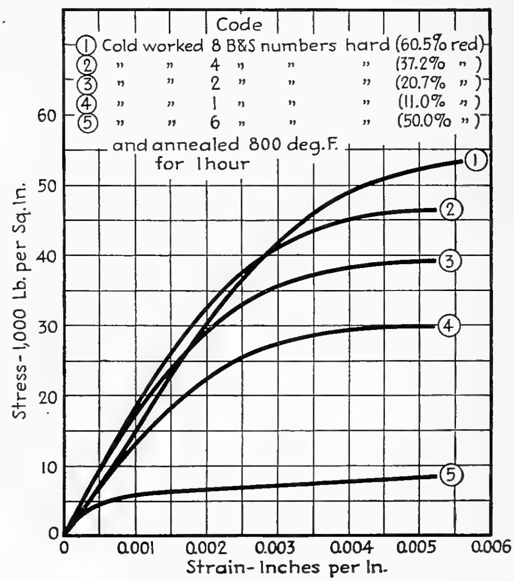


CHART 14.—The effect of cold rolling on the stress-strain characteristics of electrolytic (tough-pitch) copper strip having a ready-to-finish grain size of 0.045 mm. (0.040-in.-thick stock); 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used.

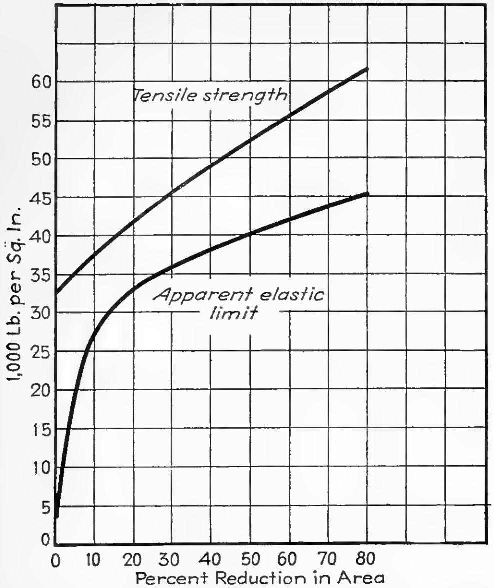


CHART 15.—The effect of cold drawing on the tensile strength and apparent elastic limit of electrolytic (tough-pitch) copper rod (99.93 % copper, 0.04 % oxygen) previously annealed to a grain size of 0.030 mm. (rod under 1 in. in diameter).

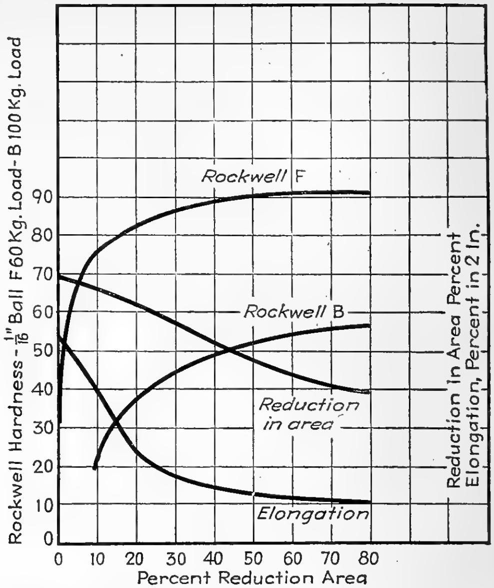


CHART 16.—The effect of cold drawing on the Rockwell F and B hardness, percentage elongation in 2 in., and percentage reduction of area of electrolytic (tough-pitch) copper rod (99.93 % copper, 0.04 % oxygen) previously annealed to a grain size of 0.030 mm. (rod under 1 in. in diameter).

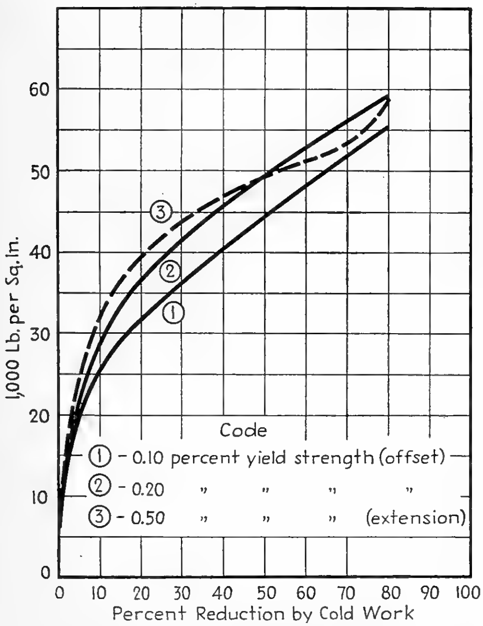


CHART 17.—The effect of cold drawing on the yield strengths of electrolytic (tough-pitch) copper rod (99.93 % copper, 0.04 % oxygen) previously annealed to a grain size of 0.030 mm. (rod under 1 in. in diameter).

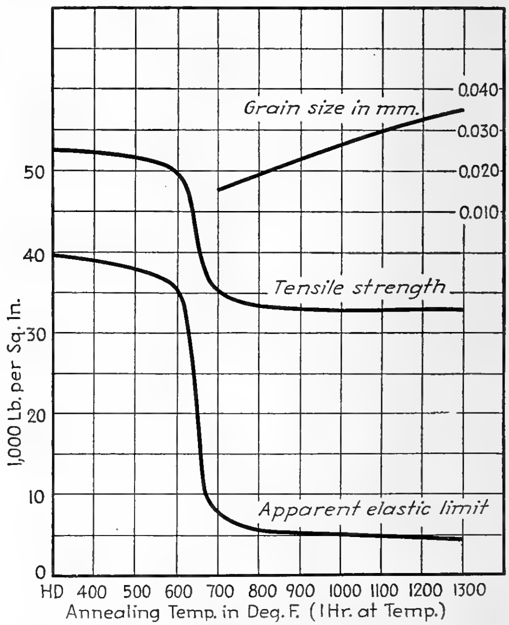


CHART 18.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of electrolytic (tough-pitch) copper rod (99.93 % copper, 0.04 % oxygen) previously cold-drawn 50 per cent (reduction of area) from a grain size of 0.030 mm. (rod under 1 in. in diameter).

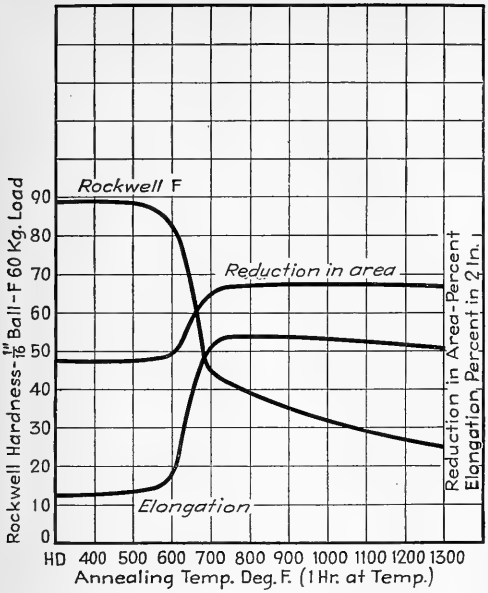


Chart 19.—The effect of annealing on the Rockwell F hardness, percentage reduction of area, and percentage elongation in 2 in. of electrolytic (tough-pitch) copper rod (99.93 % copper, 0.04 % oxygen) previously cold-drawn 50 per cent (reduction of area) from a grain size of 0.030 mm. (rod under 1 in. in diameter).

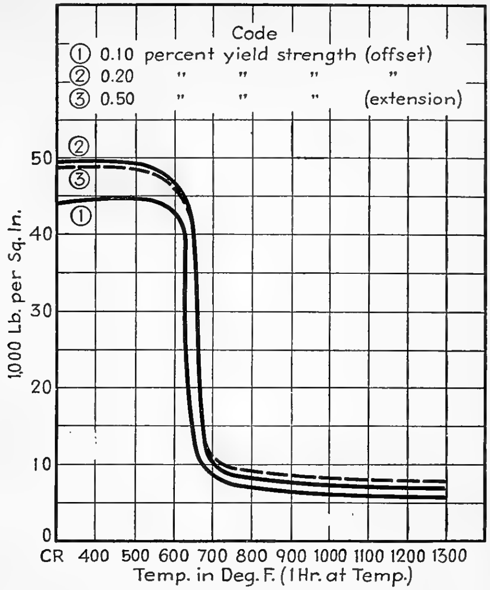


Chart 20.—The effect of annealing on the yield strengths of electrolytic (tough-pitch) copper rod (99.93 % copper, 0.04 % oxygen) previously cold-drawn 50 per cent (reduction of area) from a grain size of 0.030 mm. (rod under 1 in. in diameter).

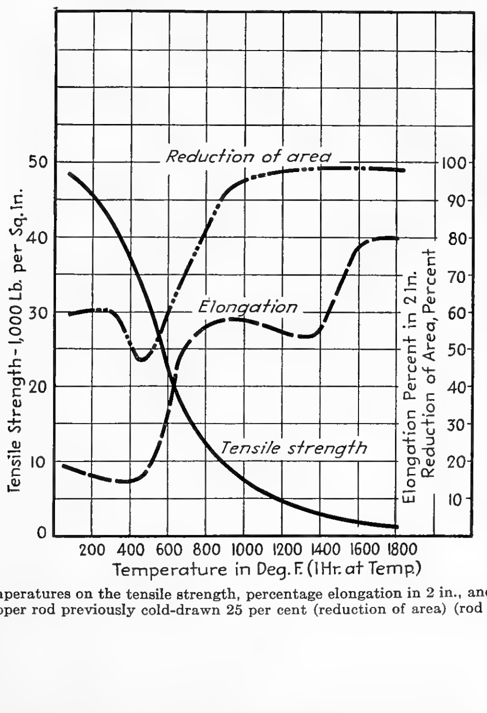


Chart 21.—The effect of elevated temperatures on the tensile strength, percentage elongation in 2 in., and percentage reduction of area of electrolytic (tough-pitch) copper rod previously cold-drawn 25 per cent (reduction of area) (rod under 1 in. in diameter).

TABLE 2
PHOSPHORIZED COPPER
TYPE OF PRODUCT—TUBE
Copper, 99.96%; phosphorus, 0.02%

Property	Hard[a]	Soft[d]
Tensile strength, p.s.i. (000 omitted)[b]	59	35
Elongation, % in 2 in.[b]	5	45
Apparent elastic limit, p.s.i. (000 omitted)[b]	55	12
Rockwell hardness F, 1/16-in. ball, 60-kg. load	98	42
Endurance limit[c] (at 20 × 10^6 reversals), p.s.i. (000 omitted)	..	12
Young's modulus of elasticity, p.s.i	16,000,000	
Melting point, °F.	1977	
Density, lb. per cu. in.	0.323	
Coefficient of expansion, per °C. from 25–300°C.	0.0000177	
Electrical conductivity,[87] % I.A.C.S., 68°F.	75–90	
Thermal conductivity,[87] B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	176–205	
Specific gravity	8.89	

AVAILABLE CREEP DATA[3]
(Deoxidized Copper)

Previous history: cold-drawn 0.750-in. rod; tensile strength 43,300 p.s.i.; % elongation in 2 in., 31; % reduction of area, 81.
At 400°F. a stress of 9,400 p.s.i. is required to produce a rate of creep per 1,000 hr. of 0.01%
At 400°F. a stress of 20,500 p.s.i. is required to produce a rate of creep per 1,000 hr. of 0.10%

[a] Extruded and cold-drawn to 0.750 in. O.D. by 0.049 in. wall.
[b] Apply to tube only.
[c] Annealed ½ hr. at 1290°F.
[d] 700°F. anneal for 1 hr.

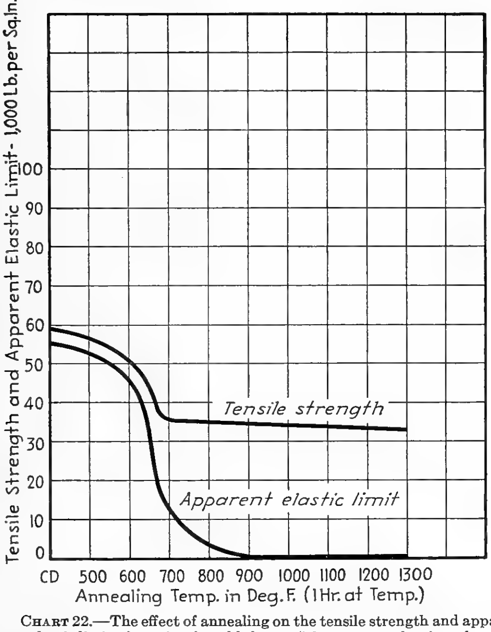


CHART 22.—The effect of annealing on the tensile strength and apparent elastic limit of previously cold-drawn (70 per cent reduction of area) phosphorized copper tubing (99.96% copper, 0.02% phosphorus).

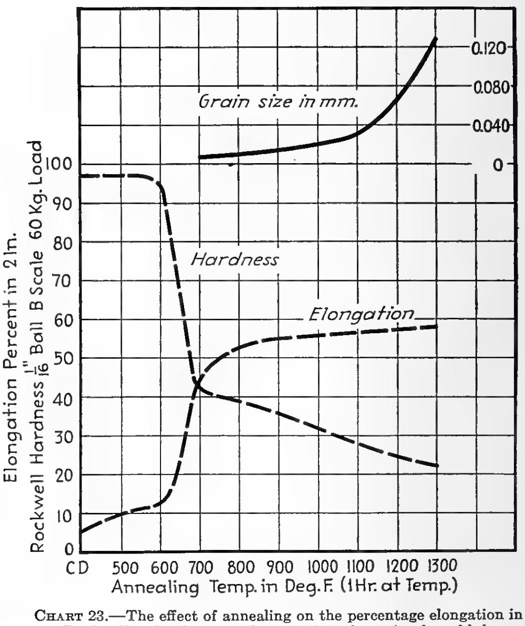


CHART 23.—The effect of annealing on the percentage elongation in 2 in., Rockwell F hardness, and grain size of previously cold-drawn (70 per cent reduction of area) phosphorized copper tubing (99.96% copper, 0.02% phosphorus).

TABLE 3

HIGH-CONDUCTIVITY, OXYGEN-FREE COPPER[a]

Copper, 99.94%; phosphorus, nil

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	50–56	32
Apparent elastic limit, p.s.i. (000 omitted)	38–43	3
Yield strength 0.5% extension, p.s.i. (000 omitted)	47–55	8
Yield strength 0.2% offset, p.s.i. (000 omitted)	47–54	6
Yield strength 0.1% offset, p.s.i. (000 omitted)	45–52	6
Elongation, % in 2 in.	3	43
Rockwell hardness F, 1/16-in. ball, 60-kg. load	90–92	33
Rockwell hardness B, 1/16-in. ball, 100-kg. load	53–59	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	84	43
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	62–64	
Endurance limit, p.s.i. (000 omitted)	17	
Young's modulus of elasticity, p.s.i.	16,000,000	
Melting point, °F	1980	
Density, lb. per cu. in.	0.323	
Coefficient of expansion, per °C. from 25–300°C.	0.0000177	
Electrical conductivity, % I.A.C.S.,[87] 68°F.	102	
Thermal conductivity,[87] B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	228	

[a] Apply to strip only (all tests conducted on 0.040-in stock).

[b] 6 B. & S. Nos., hard, 0.040–0.015 mm. grain size at ready-to-finish.

[c] Refers to 1300°F. anneal (1 hr. at temperature).

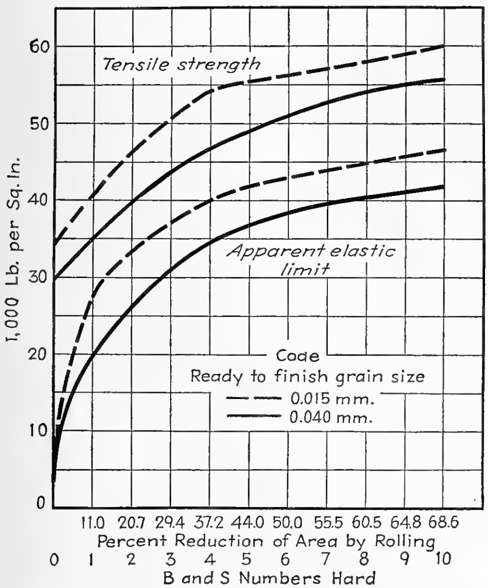


CHART 24.—The effect of cold rolling on the tensile strength and apparent elastic limit of oxygen-free copper strip (no residual deoxidant) previously annealed to two different grain sizes, 0.015 and 0.040 mm. (99.94% copper) (0.040-in. stock).

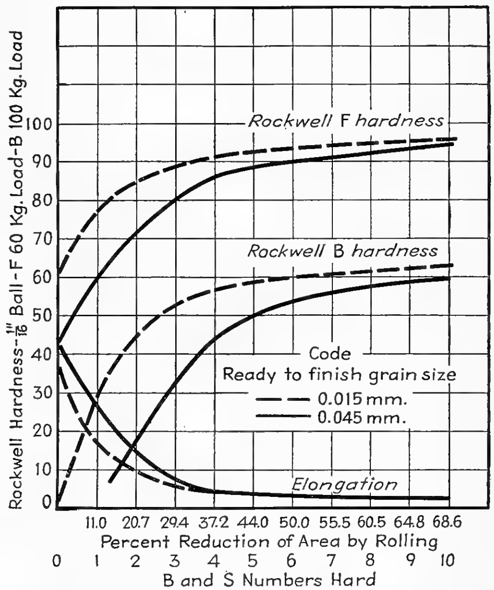


CHART 25.—The effect of cold rolling on the Rockwell F and B hardness and percentage elongation of oxygen-free copper strip (no residual deoxidant) previously annealed to two different grain sizes, 0.015 and 0.040 mm. (99.94% copper) (0.040-in. stock).

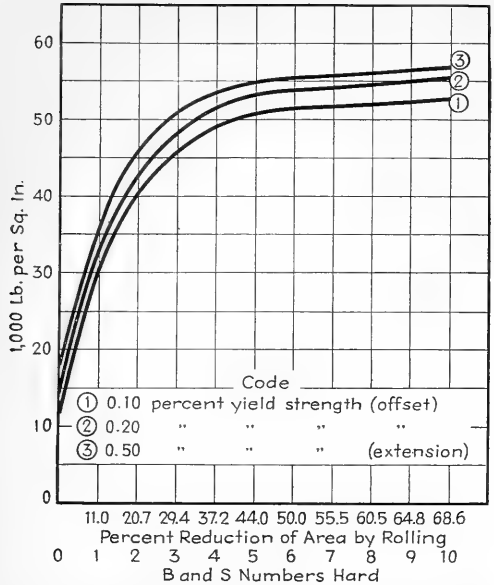


Chart 26.—The effect of cold rolling on the yield strength of oxygen-free copper strip (no residual deoxidant) previously annealed to a grain size of 0.015 mm. (99.94 % copper) (0.040-in. stock).

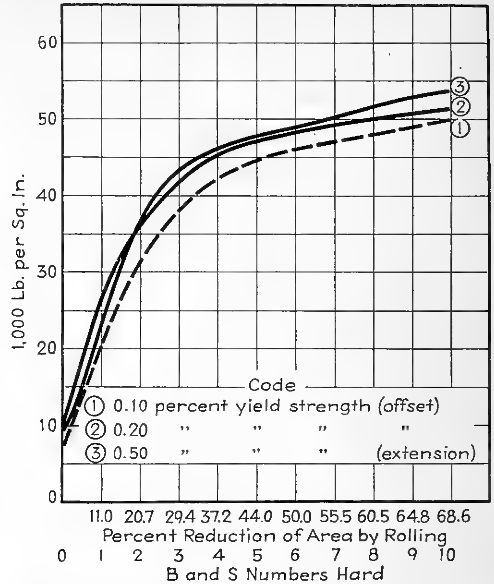


Chart 27.—The effect of cold rolling on the yield strength of oxygen-free copper strip (no residual deoxidant) previously annealed to a grain size of 0.040 mm. (99.94 % copper) (0.040-in. stock).

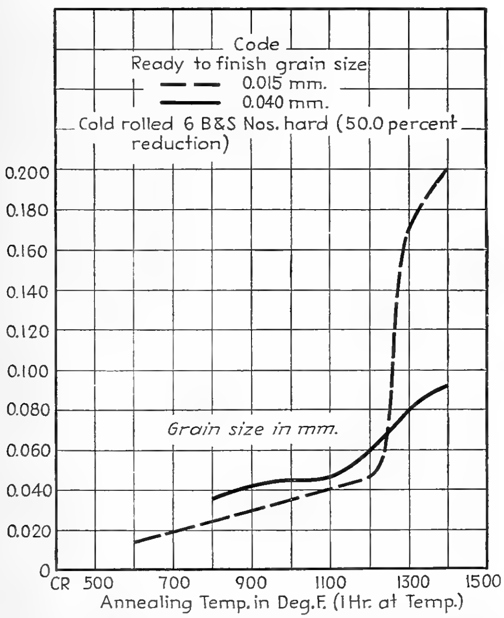


Chart 28.—The effect of annealing on the grain-growing characteristics of oxygen-free copper strip (no residual deoxidant) previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from material annealed to different grain sizes, 0.015 and 0.040 mm. (99.94 % copper) (0.040-in. stock).

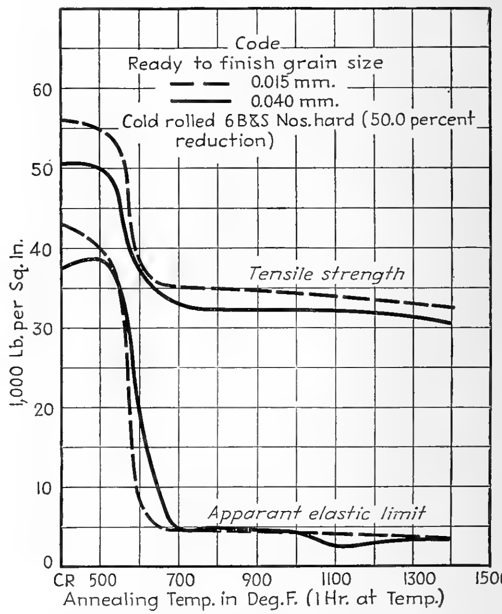


Chart 29.—The effect of annealing on the tensile strength, and apparent elastic limit of oxygen-free copper strip (no residual deoxidant) previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from material annealed to different grain sizes, 0.015 and 0.040 mm. (99.94 % copper) (0.040-in. stock).

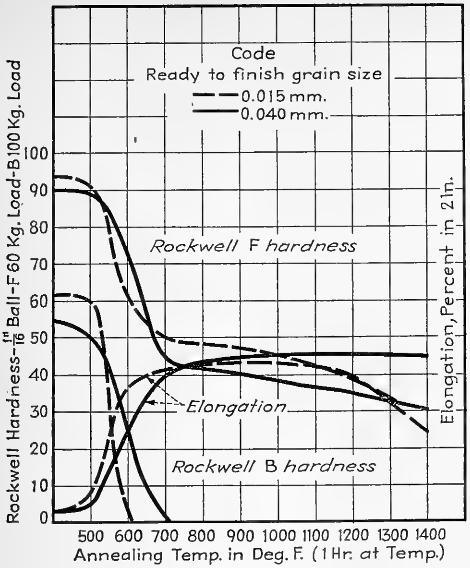


CHART 30.—The effect of annealing on the Rockwell F and B hardness and percentage elongation in 2 in. of oxygen-free copper strip (no residual deoxidant) previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from material annealed to different grain sizes, 0.015 and 0.040 mm. (99.94 % copper) (0.040-in. stock).

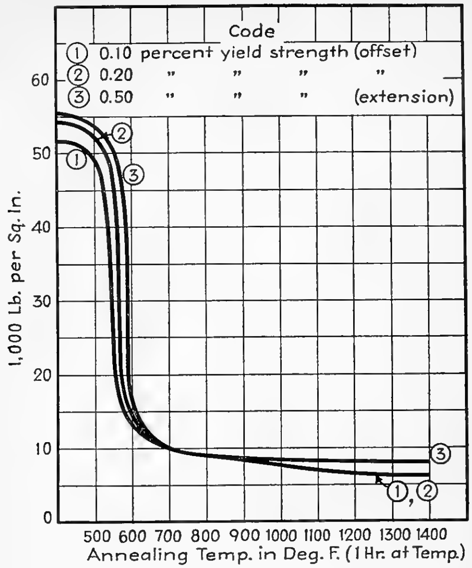


CHART 31.—The effect of annealing on the yield strengths of oxygen-free copper strip (no residual deoxidants) previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a material having a grain size of 0.015 mm. (99.94 % copper) (0.040-in. stock).

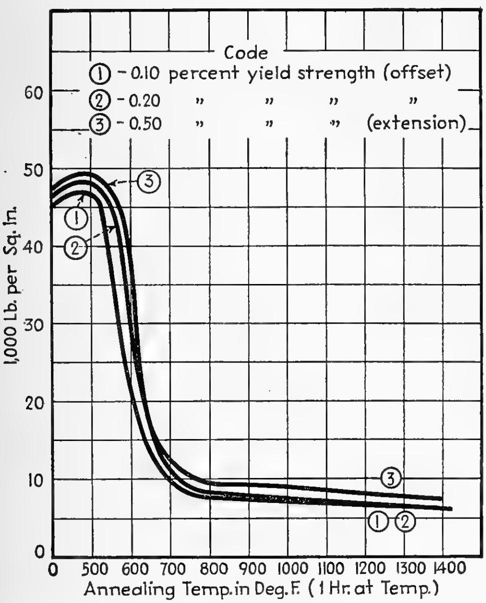


CHART 32.—The effect of annealing on the yield strengths of oxygen-free copper strip (no residual deoxidants) previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a material having a grain size of 0.040 mm. (99.94 % copper) (0.040-in. stock).

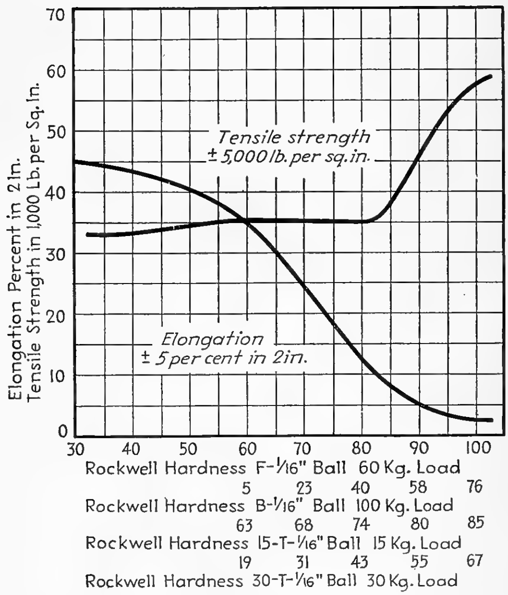


CHART 33.—This chart can be employed to determine the approximate tensile strength and percentage elongation in 2 in. of oxygen-free copper strip when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits (99.94 % copper).

TABLE 4
SILVER-BEARING COPPER

TYPE OF PRODUCT—STRIP[a]
Silver, 10 oz. per ton; copper, 99.95%; phosphorus, nil

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	52–58	33
Apparent elastic limit, p.s.i. (000 omitted)	39–46	5
Yield strength, 0.5% extension, p.s.i. (000 omitted)	49–57	6–8
Yield strength, 0.2% offset, p.s.i. (000 omitted)	48–55	6
Yield strength, 0.1% offset, p.s.i. (000 omitted)	46–52	6
Elongation, % in 2 in.	4	40
Rockwell hardness F, 1/16-in. ball, 60-kg. load	92–95	34
Rockwell hardness B, 1/16-in. ball, 100-kg. load	56–64	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	85–86	53
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	62–67	
Endurance limit, p.s.i. (000 omitted)	15	
Young's modulus of elasticity, p.s.i.	16,000,000	
Melting point, °F.	1975	
Density, lb. per cu. in.	0.322	
Coefficient of expansion, per °C. from 25–300°C.	0.0000174	
Electrical conductivity, % I.A.C.S.,(87) 68°F.	101.6	
Thermal conductivity,(87) B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	228	

[a] Apply to strip only (all tests conducted on 0.040-in. stock).
[b] 6 B. & S. Nos., hard, 0.035–0.015 mm. grain size at ready-to-finish.
[c] Refer to 1200°F. anneal (1 hr. at temperature).

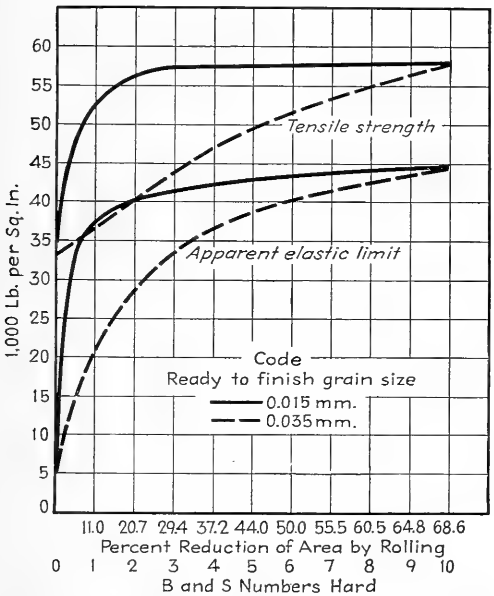


CHART 34.—The effect of cold rolling on the tensile strength and apparent elastic limit of silver-bearing copper strip previously annealed to two different grain sizes (99.95% copper, 10 oz. of silver per ton) (0.040-in. stock).

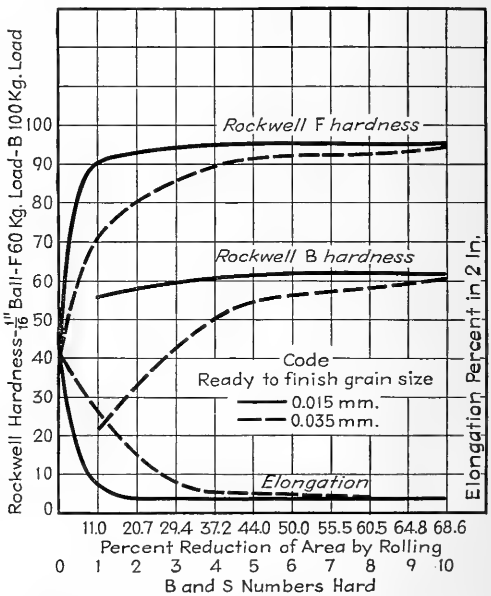


CHART 35.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of silver-bearing copper strip previously annealed to two different grain sizes (99.95% copper, 10 oz. of silver per ton) (0.040-in. stock).

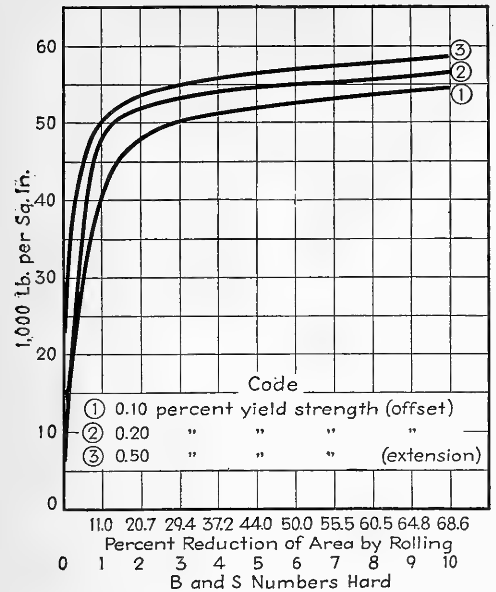


CHART 36.—The effect of cold rolling on the yield strengths of silver-bearing copper strip previously annealed to a grain size of 0.015 mm. (99.95 % copper, 10 oz. of silver per ton) (0.040-in. stock).

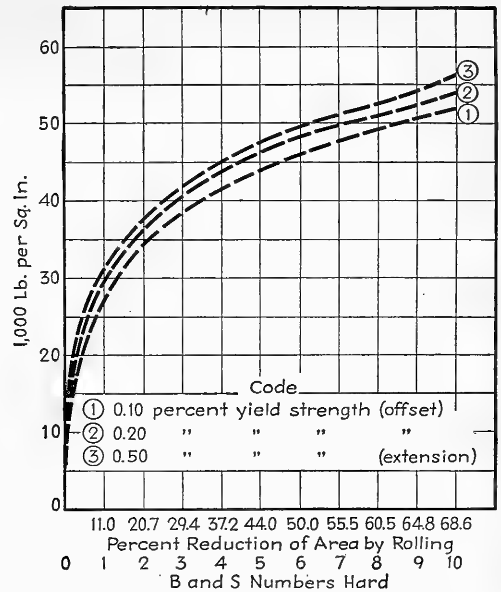


CHART 37.—The effect of cold rolling on the yield strengths of silver-bearing copper strip previously annealed to a grain size of 0.035 mm. (99.95 % copper, 10 oz. of silver per ton) (0.040-in. stock).

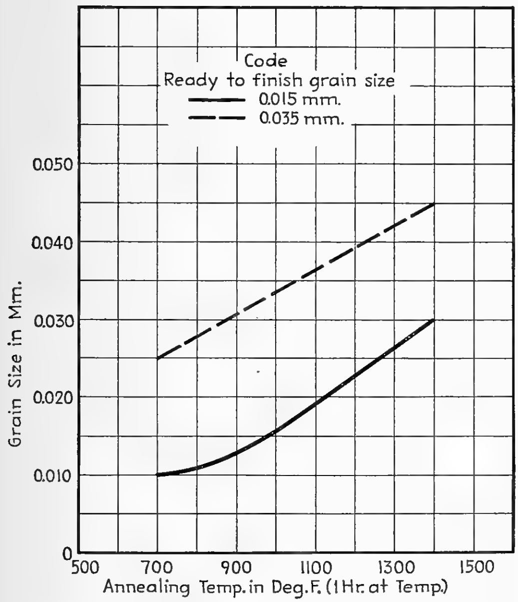


CHART 38.—The effect of annealing on the grain-growing characteristics of silver-bearing copper strip previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.035 mm. (99.95 % copper, 10 oz. of silver per ton) (0.040-in. stock).

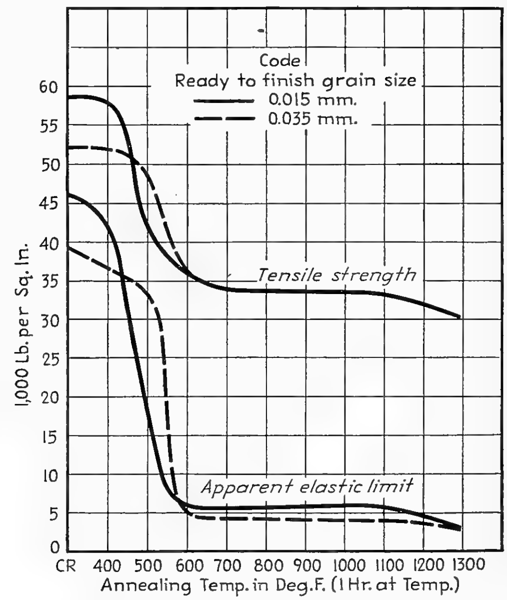


CHART 39.—The effect of annealing on the tensile strength and apparent elastic limit of silver-bearing copper strip previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.035 mm. (99.95 % copper, 10 oz. of silver per ton) (0.040-in. stock).

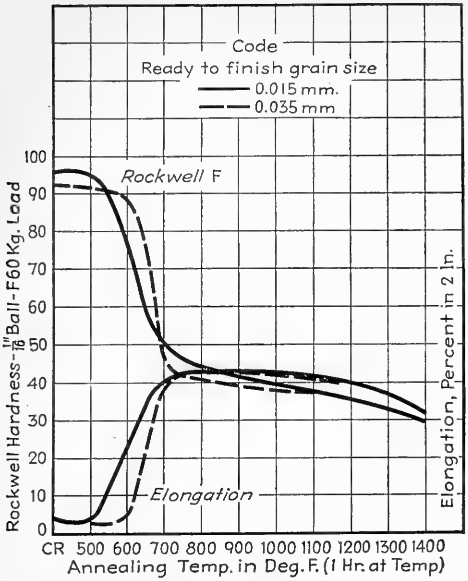


CHART 40.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of silver-bearing copper strip previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.035 mm. (99.95 % copper, 10 oz. of silver per ton) (0.040-in. stock).

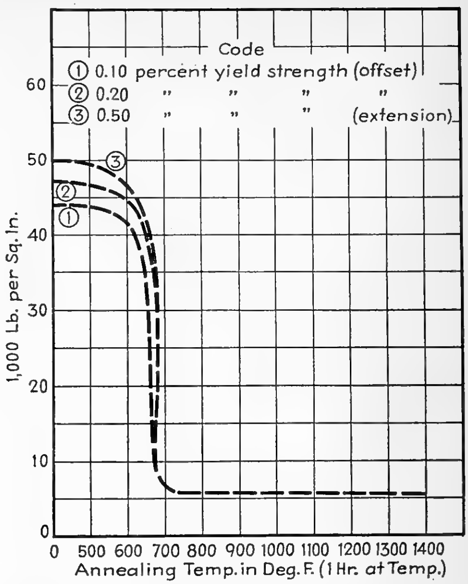


CHART 41.—The effect of annealing on the yield strength of silver-bearing copper strip previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.035 mm. (99.95 % copper, 10 oz. of silver per ton) (0.040-in. stock).

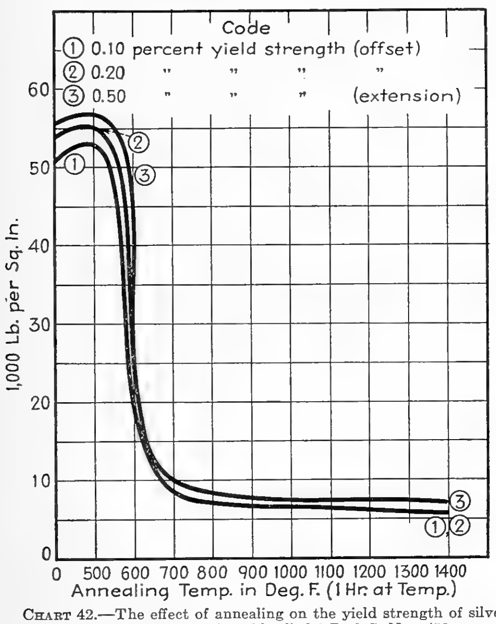


CHART 42.—The effect of annealing on the yield strength of silver-bearing copper strip previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (99.95 % copper, 10 oz. of silver per ton) (0.040-in. stock).

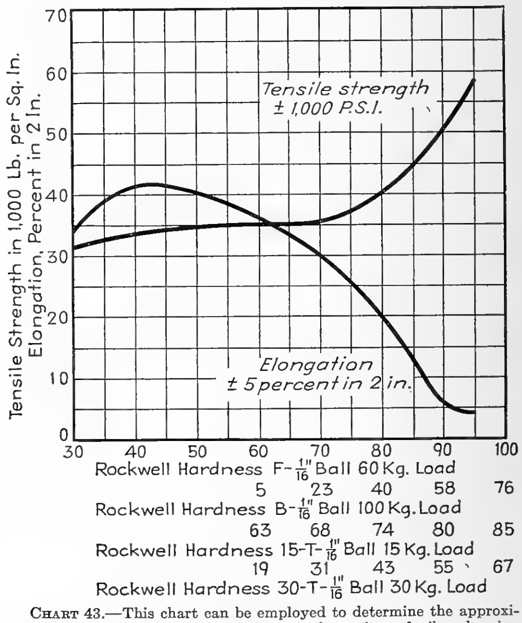


CHART 43.—This chart can be employed to determine the approximate tensile strength and percentage elongation of silver-bearing copper strip (99.95 % copper, 10 oz. of silver per ton) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

TABLE 5
PHOSPHORIZED ARSENICAL COPPER
GENERAL DATA—TUBE
Copper, 99.61%; phosphorus, 0.024%; arsenic, 0.35%

Property	Hard[a]	Soft[b]
Tensile strength, p.s.i. (000 omitted)	60	37
Apparent elastic limit, p.s.i. (000 omitted)	55	9
Elongation, % in 2 in.	4	43
Rockwell hardness F, 1/16-in. ball, 60-kg. load	98	42
Endurance limit[c] (at 20 × 10[6] reversals), p.s.i. (000 omitted)		15
Melting point, °F.	1978	
Young's modulus of elasticity, p.s.i.	16,000,000	
Density, lb. per cu. in.	0.323	
Coefficient of expansion, per °C. from 25–300°C.	0.0000174	
Electrical conductivity, % I.A.C.S., 68°F.	45.0	
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	102	
Specific gravity	8.89	

[a] Extruded and cold-drawn to 3/4 × 0.049 in.
[b] 900°F. anneal for 1 hr.
[c] Annealed 1/2 hr. at 1290°F.

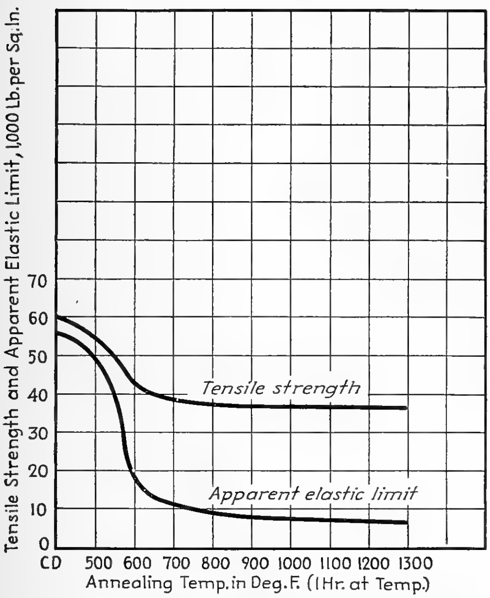


CHART 44.—The effect of annealing on the tensile strength and apparent elastic limit of phosphorized arsenical copper condenser tube previously cold-drawn 70 per cent (reduction of area) (99.61 % copper, 0.35 % arsenic, 0.024 % phosphorus).

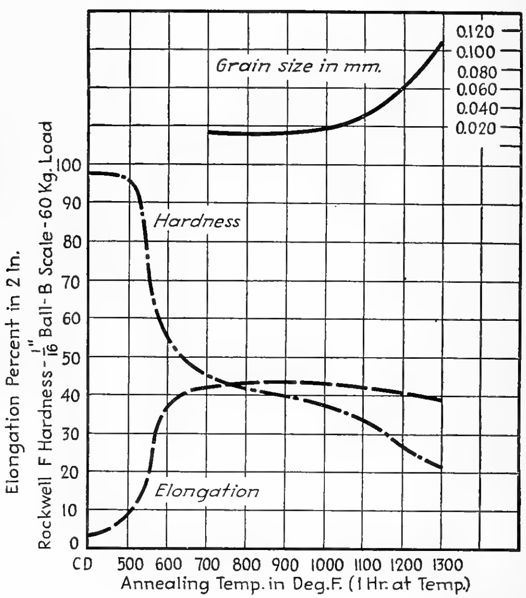


CHART 45.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and grain size of phosphorized arsenical copper condenser tube previously cold-drawn 70 per cent (reduction of area) (99.61 % copper, 0.35 % arsenic, 0.024 % phosphorus).

TABLE 6

ARSENICAL (TOUGH-PITCH) COPPER

General Data—Sheet and Strip[a]

Copper, 99.50%; arsenic, 0.45%

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	55–60	34
Apparent elastic limit, p.s.i. (000 omitted)	38–47	2
Yield strength, 0.5% extension, p.s.i. (000 omitted)	38–40	5
Yield strength, 0.2% offset, p.s.i. (000 omitted)	50–54	5
Yield strength, 0.1% offset, p.s.i. (000 omitted)	45–49	5
Elongation, % in 2 in.	4	47–42
Endurance limit, p.s.i. (000 omitted)	17	13
Rockwell hardness F, 1/16-in. ball, 60-kg. load	93–97	41
Rockwell hardness B, 1/16-in. ball, 100-kg. load	60–65	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	86–87	48–49
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	64–65	
Modulus of elasticity, p.s.i.	17,000,000	
Melting point, °F.	1981	
Density, lb. per cu. in.	0.322	
Coefficient of expansion, per °C. from 25–300°C.	0.0000174	
Electrical conductivity, % I.A.C.S., 68°F.	45	
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	102	

[a] Apply to strip only (tests conducted on 0.040-in. stock).

[b] 6 B. & S. Nos., hard, 0.050–0.020 mm. grain size at ready-to-finish.

[c] Refers to 1100°F. anneal (1 hr. at temperature).

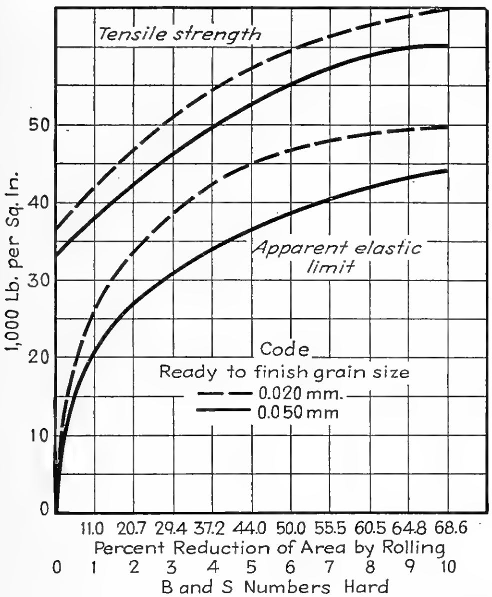


Chart 46.—The effect of cold rolling on the tensile strength and apparent elastic limit of arsenical tough-pitch copper strip previously annealed to two different grain sizes, 0.020 and 0.050 mm. (99.50 % copper, 0.45 % arsenic) (0.040-in. stock).

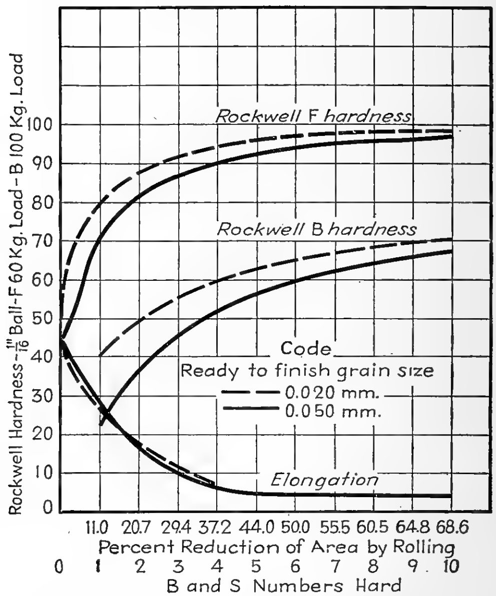


Chart 47.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of arsenical tough-pitch copper strip previously annealed to two different grain sizes, 0.020 and 0.050 mm. (99.50 % copper, 0.45 % arsenic) (0.040-in. stock).

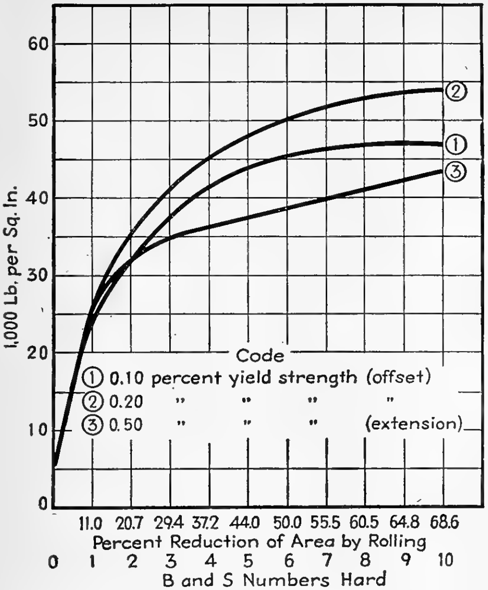


CHART 48.—The effect of cold rolling on the yield strengths of arsenical tough-pitch copper strip previously annealed to a grain size of 0.050 mm. (99.50 % copper, 0.45 % arsenic) (0.040-in. stock).

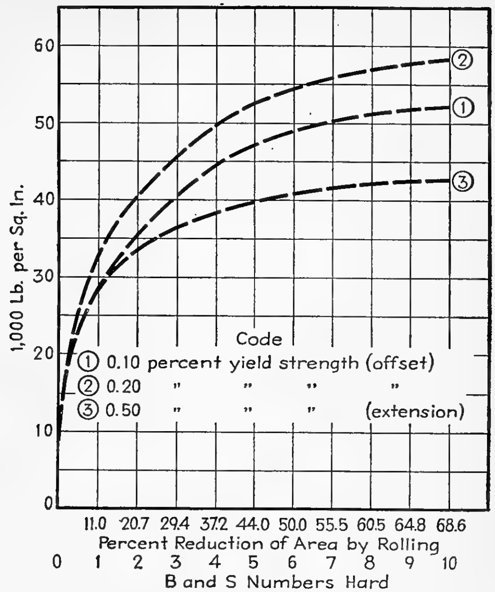


CHART 49.—The effect of cold rolling on the yield strengths of arsenical tough-pitch copper strip previously annealed to a grain size of 0.020 mm. (99.50 % copper, 0.45 % arsenic) (0.040-in. stock).

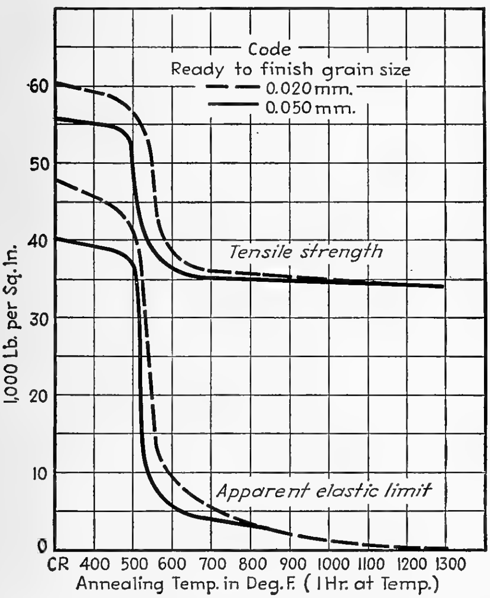


CHART 50.—The effect of annealing on the tensile strength and apparent elastic limit of arsenical tough-pitch copper strip previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.020 and 0.050 mm. (99.50 % copper, 0.45 % arsenic) (0.040-in. stock).

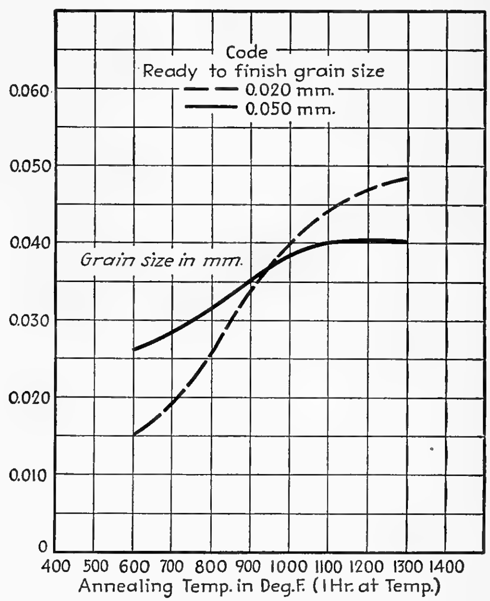


CHART 51.—The effect of annealing on the grain-growing characteristics of arsenical tough-pitch copper strip previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.020 and 0.050 mm. (99.50 % copper, 0.45 % arsenic) (0.040-in. stock).

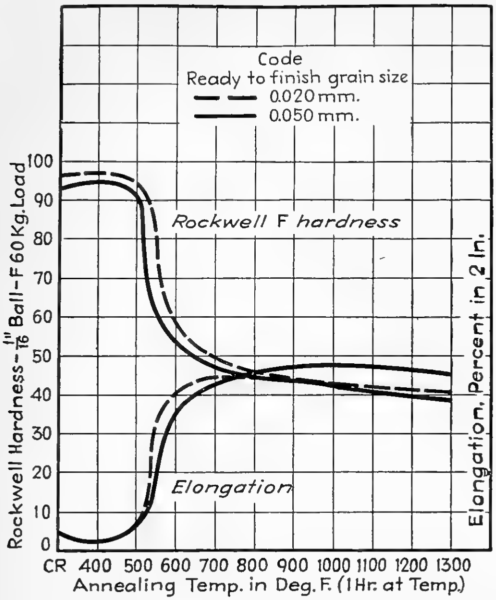


CHART 52.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of arsenical tough-pitch copper strip previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.020 and 0.050 mm. (99.50 % copper, 0.45 % arsenic) (0.040-in. stock).

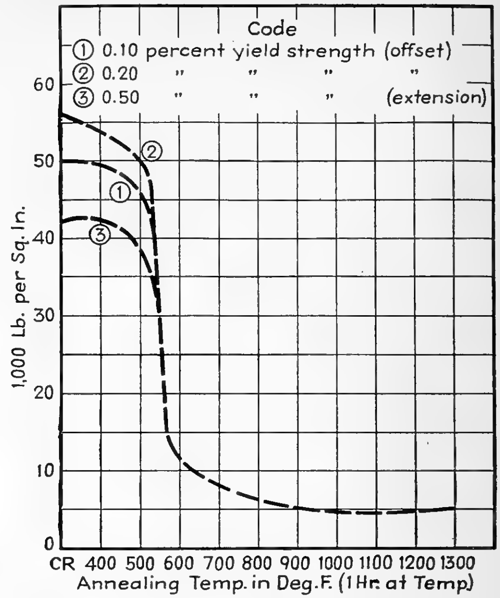


CHART 53.—The effect of annealing on the yield strength of arsenical tough-pitch copper strip previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.020 mm. (99.50 % copper, 0.45 % arsenic) (0.040-in. stock).

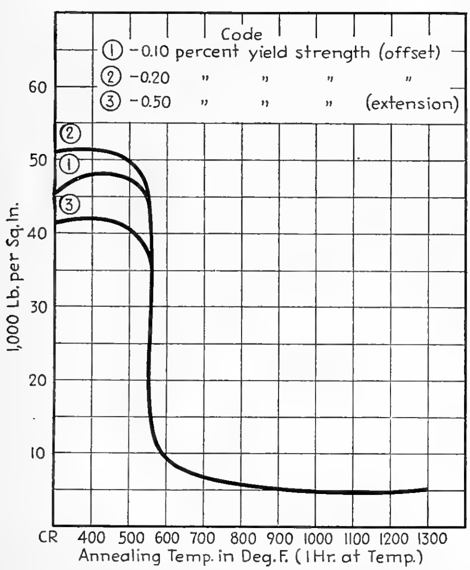


CHART 54.—The effect of annealing on the yield strength of arsenical tough-pitch copper strip previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.050 mm. (99.50 % copper, 0.45 % arsenic) (0.040-in. stock).

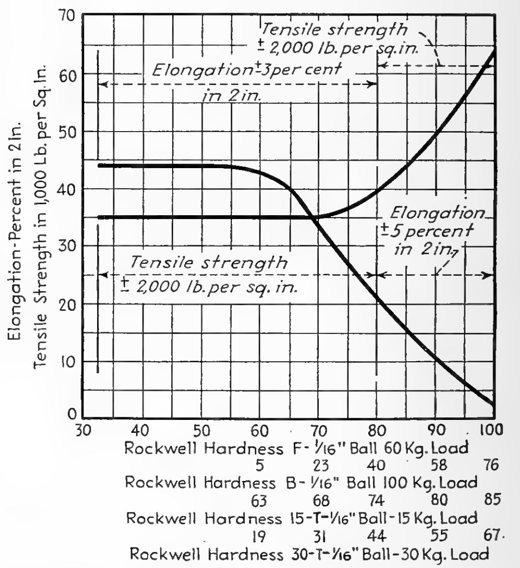


CHART 55.—This chart can be employed to determine the approximate tensile strength and percentage elongation of arsenical tough-pitch copper strip (99.50 % copper, 0.45 % arsenic) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

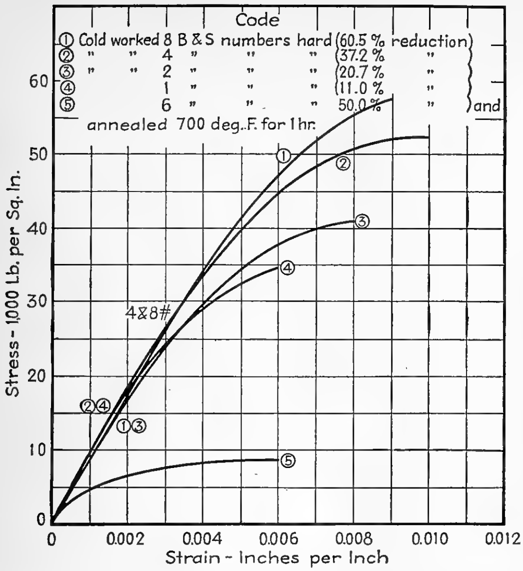


Chart 56.—The effect of cold rolling on the stress-strain characteristics of arsenical tough-pitch copper strip (0.040-in. thick) having a ready-to-finish grain size of 0.020 mm. (99.50 % copper, 0.45 % arsenic); 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used.

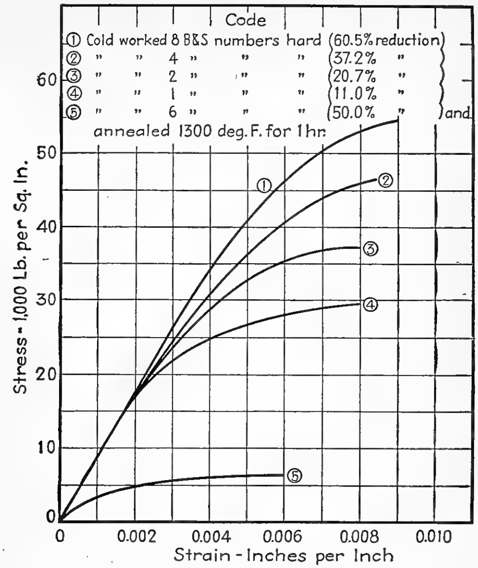


Chart 57.—The effect of cold rolling on the stress-strain characteristics of arsenical tough-pitch copper strip (0.040 in. thick) having a ready-to-finish grain size of 0.050 mm. (99.50 % copper, 0.45 % arsenic); 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used.

TABLE 7

LEADED COPPER

General Data—Rod

Copper, 99.00%; lead, 1.00%

Property	Hard[a]	Soft[b]
Tensile strength, p.s.i. (000 omitted)	55	35
Apparent elastic limit, p.s.i. (000 omitted)	38	5
Yield strength, 0.5% extension, p.s.i. (000 omitted)	48	8
Yield strength, 0.2% offset, p.s.i. (000 omitted)	49	7
Yield strength, 0.1% offset, p.s.i. (000 omitted)	43	6
Elongation, % in 2 in.	50	10
Reduction of area, %	68	40
Rockwell hardness F, 1/16-in. ball, 60-kg. load	90	30
Rockwell hardness B, 1/16-in. ball, 100-kg. load	52	
Modulus of elasticity, p.s.i.	15,000,000	
Melting point, °F.	1980	
Coefficient of expansion, per °C. from 25–300°C.	0.0000177	
Electrical conductivity, % I.A.C.S., 68°F.	98	
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	221	
Density, lb. per cu. in.	0.323	
Type structure	Two phase, alpha + lead	

[a] Refers to rod cold-drawn 50%; from a ready-to-finish grain size of 0.030 mm.

[b] Refers to 1100°F. anneal for 1 hr.

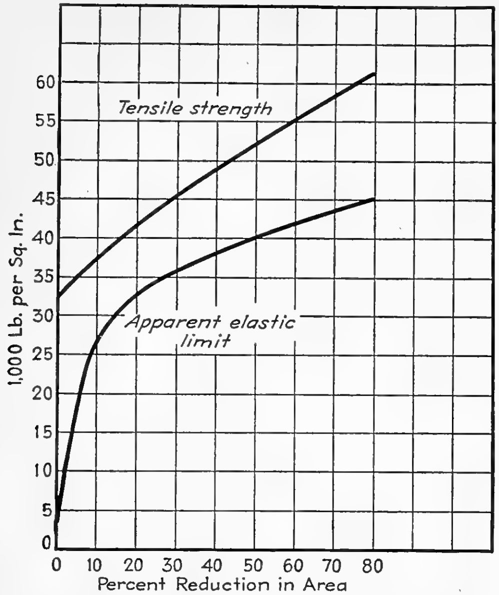


CHART 58.—The effect of cold drawing on the tensile strength and apparent elastic limit of leaded copper rod previously annealed to a grain size of 0.030 mm. (99.00 % copper, 1.00 % lead) (rod under 1 in. in diameter).

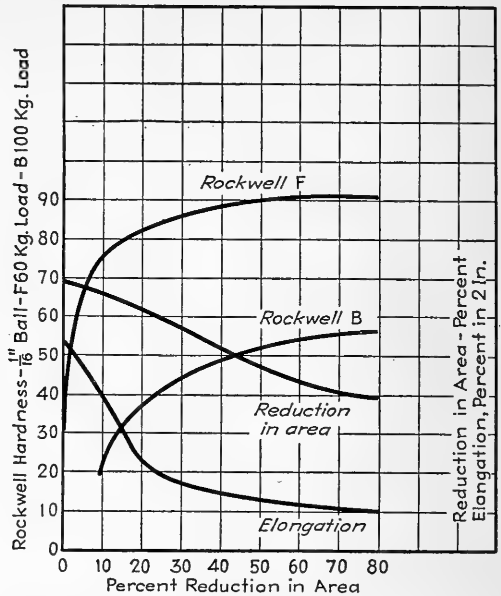


CHART 59.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in. and percentage reduction of area of leaded copper rod previously annealed to a grain size of 0.030 mm. (rod under 1 in. in diameter).

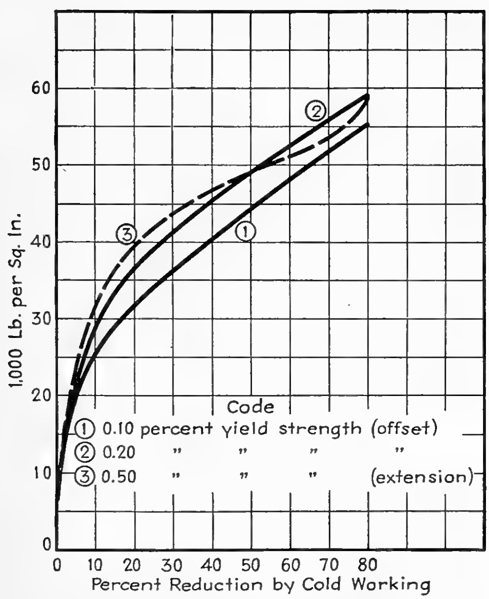


CHART 60.—The effect of cold drawing on the yield strength of leaded copper rod previously annealed to a grain size of 0.030 mm. (rod under 1 in. in diameter).

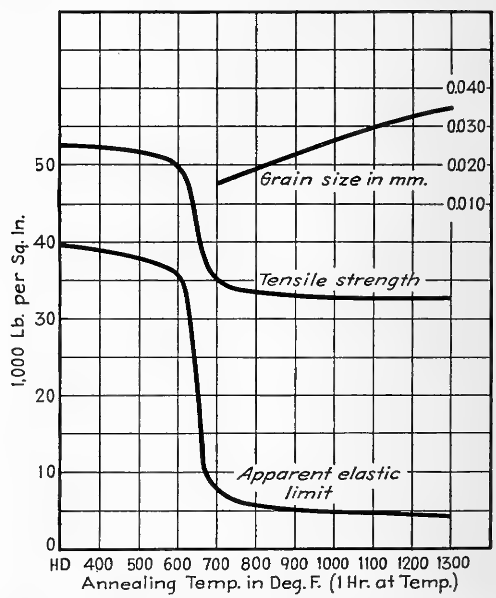


CHART 61.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of leaded copper rod previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.030 mm. (rod under 1 in. in diameter).

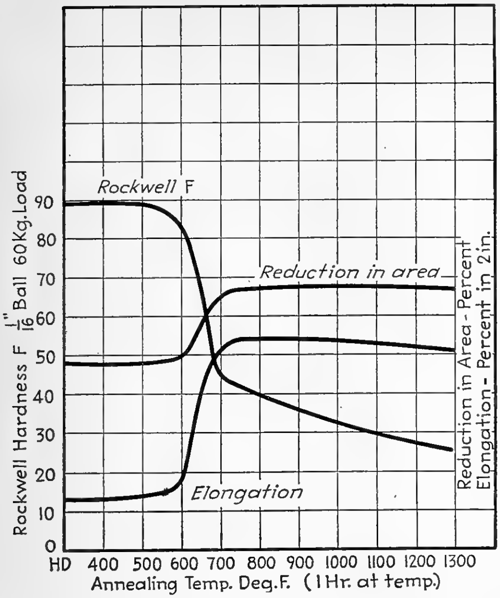


CHART 62.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., percentage reduction of area of leaded copper rod previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.030 mm. (rod under 1 in. in diameter).

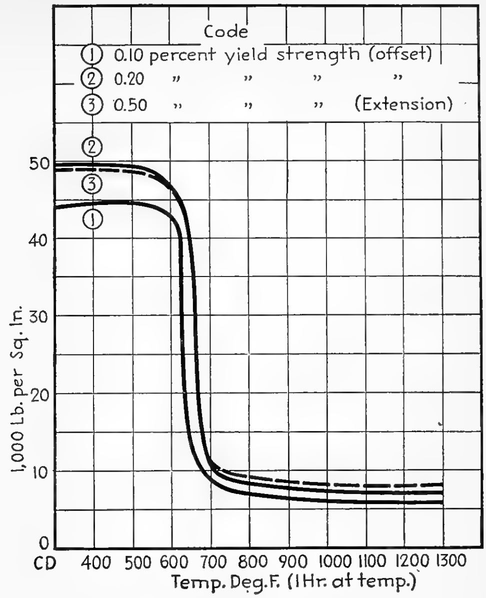


CHART 63.—The effect of annealing on the yield strength of leaded copper rod previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.030 mm. (rod under 1 in. in diameter).

TABLE 8
TELLURIUM COPPER
GENERAL DATA—ROD
Copper, balance; tellurium, 0.45%

Property	Hard[a]	Soft[b]	Forgings hot
Tensile strength, p.s.i. (000 omitted)	53	32	33–35
Apparent elastic limit, p.s.i. (000 omitted)	42	5	4–9
Yield strength, 0.5% extension, p.s.i. (000 omitted)	49	7	6–12
Yield strength, 0.2% offset, p.s.i. (000 omitted)	50	7	5–11
Yield strength, 0.1% offset, p.s.i. (000 omitted)	45	7	4–8
Elongation, % in 2 in.	7	40	40–43
Reduction of area, %	22	46	50–30
Rockwell hardness F, 1/16-in. ball, 60-kg. load	86	40	30–45
Rockwell hardness B, 1/16-in. ball, 100-kg. load	48	..	
Modulus of elasticity, lb. per sq. in.	16,000,000		
Melting point, °F	1980		
Coefficient of expansion, per °C. from 25–300°C	0.0000177		
Electrical conductivity, % I.A.C.S., 68°F	98		
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F	221		
Density, lb. per cu. in.	0.323		
Forging range, °F	1250–1450		
Forging quality	Good		
Type structure	Two phase, alpha + copper telluride		

[a] Refers to rod cold-drawn 50%; rod under 1 in. diameter ready-to-finish grain size 0.025 mm.
[b] Refers to 1100°F. anneal (1 hr. at temperature).

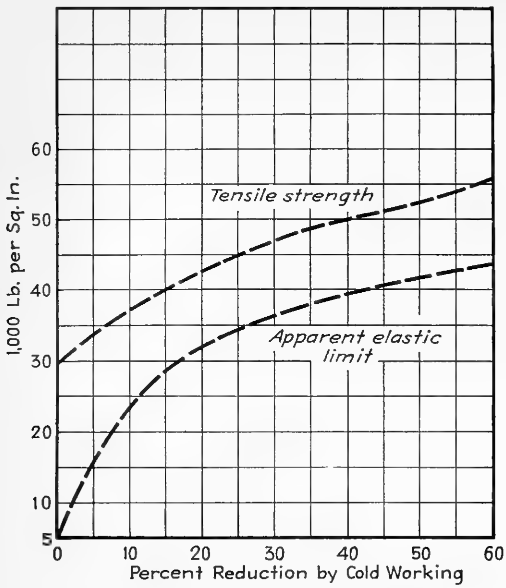


CHART 64.—The effect of cold drawing on the tensile strength and apparent elastic limit of tellurium copper rod previously annealed to a grain size of 0.025 mm. (0.45 % tellurium, balance copper) (rod under 1 in. in diameter).

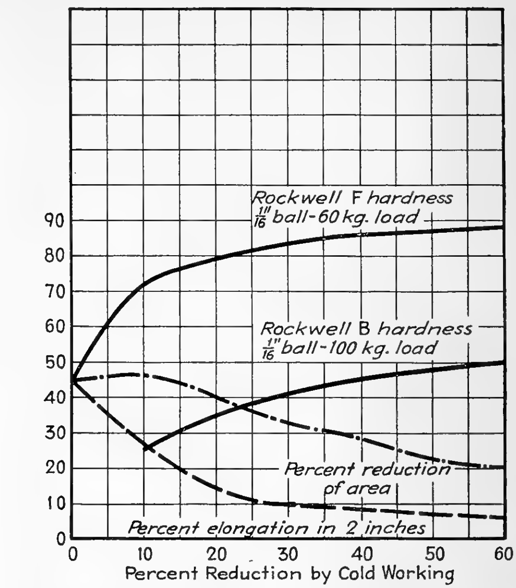


CHART 65.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of tellurium copper rod previously annealed to a grain size of 0.025 mm. (0.45 % tellurium, balance copper) (rod under 1 in. in diameter).

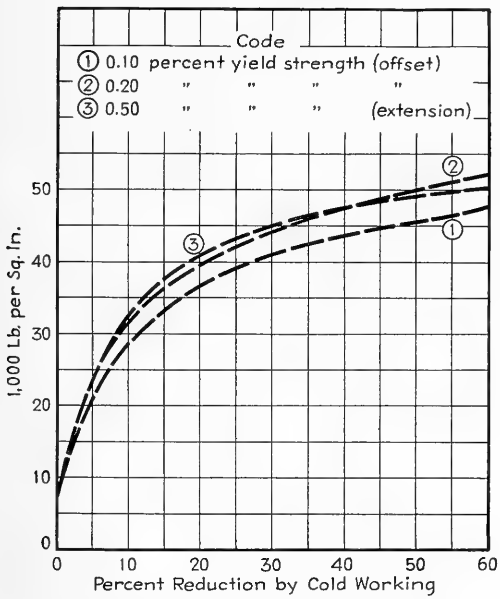


CHART 66.—The effect of cold drawing on the yield strength of tellurium copper rod previously annealed to a grain size of 0.025 mm. (0.045 % tellurium, balance copper) (rod under 1 in. in diameter).

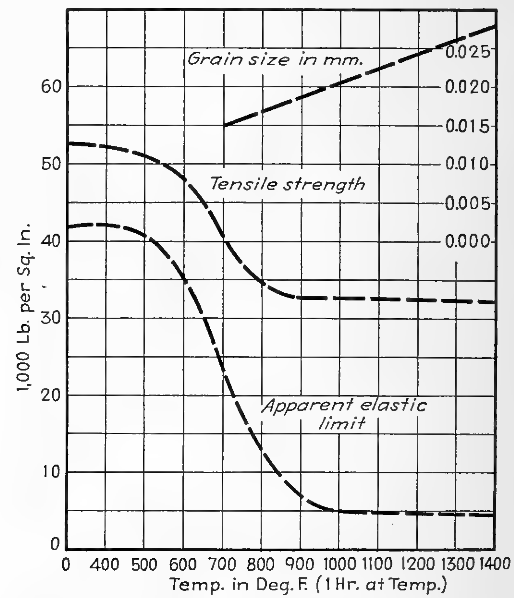


CHART 67.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of tellurium copper rod previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.025 mm. (0.45 % tellurium, balance copper) (rod under 1 in. in diameter).

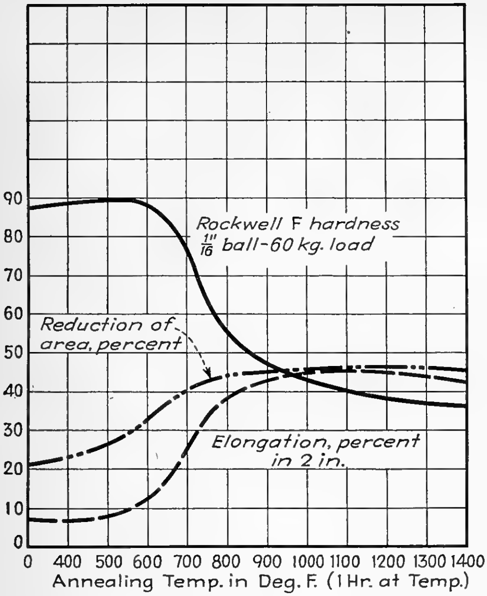


CHART 68.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of tellurium copper rod previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.025 mm. (0.45 % tellurium, balance copper) (rod under 1 in. in diameter).

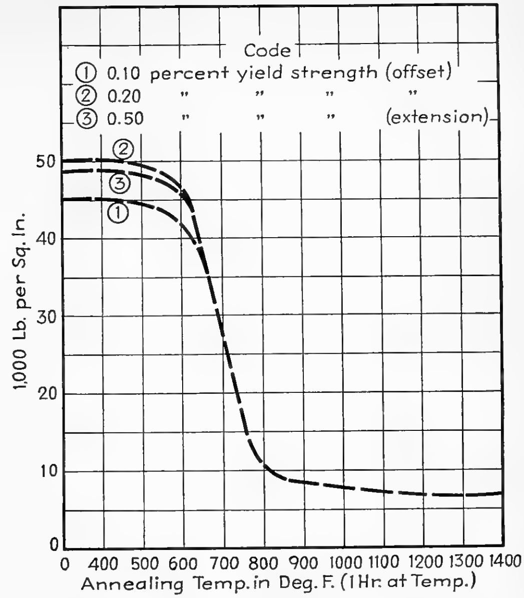


CHART 69.—The effect of annealing on the yield strength of tellurium copper rod previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.025 mm. (0.45 % tellurium, balance copper) (rod under 1 in. in diameter).

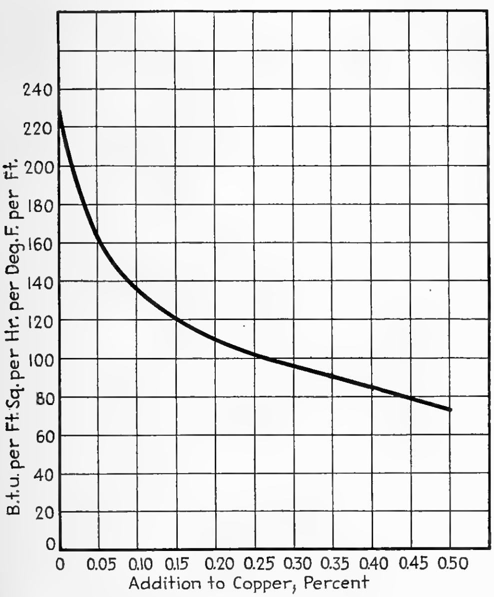


CHART 70.—The effect of phosphorus on the thermal conductivity of copper annealed at 1832°F. for 1 hour and quenched in water based on data by Hanson and Rogers.[4]

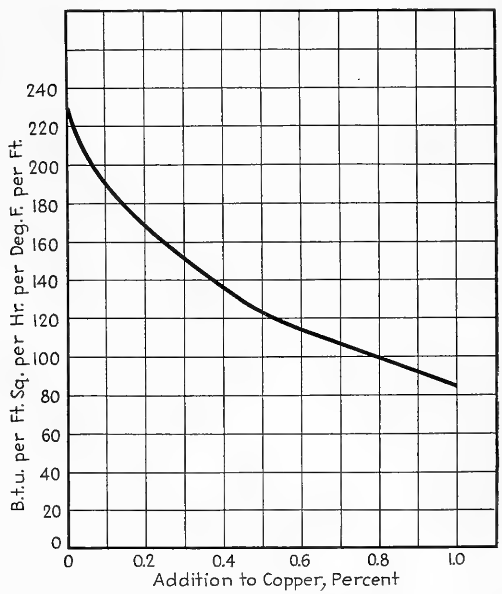


CHART 71.—The effect of iron on the thermal conductivity of copper based on data by Hanson and Rogers.[4]

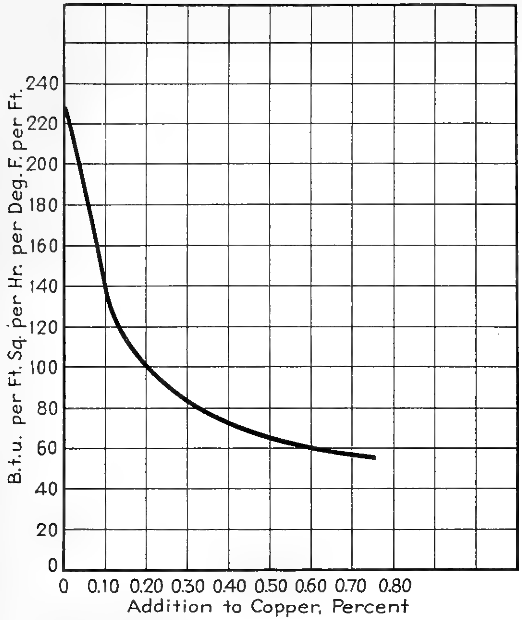


Chart 72.—The effect of arsenic on the thermal conductivity of copper based on data by Hanson and Rogers.[4]

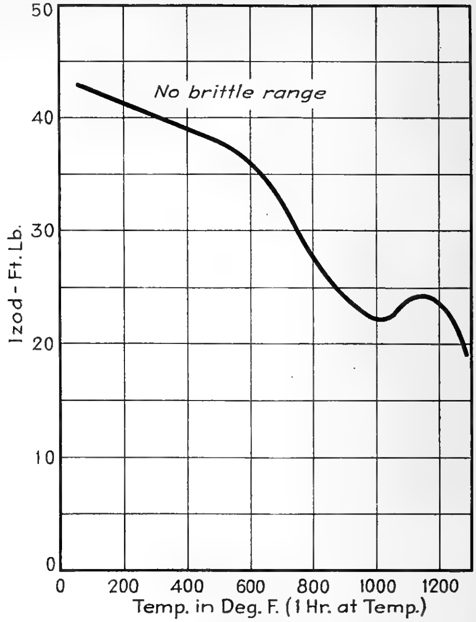


Chart 73.—The effect of elevated temperatures on the Izod impact strength of an annealed 99 % copper, 1 % zinc alloy based on data by Bunting.[5]

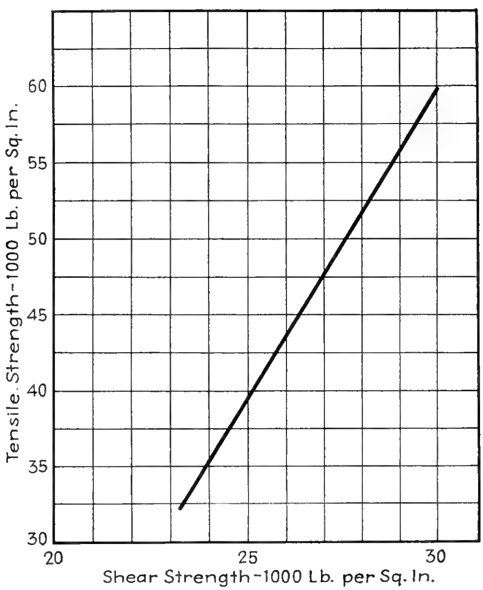


Chart 74.—Conversion chart for determination of shear strength of the coppers when tensile strength is known. Accurate to ±5 per cent.[86]

CHAPTER II

THE BRASSES

The most widely used and the best-known copper-base alloys are those with zinc known as "the brasses." Copper and zinc together form a complete series of solid solutions. As zinc is added to copper, tensile properties increase, electrical and thermal properties decrease, and some diminution of resistance to the action of most corrosive media results.

Brasses are commonly used in applications where it is desired to improve upon some specific characteristic of copper, and where such improvement may be effected at a sacrifice only of such characteristics of copper as are unimportant in respect to the particular application at hand.

Commonly, certain mill products and certain manufactured products may be produced at lower cost if, instead of copper, certain of the brasses are used. Obviously therefore, cost frequently is the consideration that leads to the use of brass rather than copper for a given product.

In general the brasses offer mechanical properties superior to those of copper; the advantage in this respect being gained at a sacrifice of both electrical and thermal conductivities.

There are two broad classifications of the alloys of copper and zinc: one containing from 64 to 99 per cent of copper, consisting of a single phase and known as "alpha" brasses; the other containing from 55 to 64 per cent of copper, containing two phases and known as the "alpha-beta" brasses. The alloys of copper and zinc containing less than 55 per cent of copper, owing to the predominance of the beta phase, are brittle and of no commercial significance.

ALPHA BRASSES

Cold Working.—The alpha brasses are exceptionally ductile and malleable at room temperature and can be cold-worked by any of the commercial methods such as deep drawing, spinning, stamping, forming, cold rolling, cold heading, flaring, and upsetting.

As the brasses are cold-worked, they become increasingly hard; the degree of hardness being dependent on the amount of cold work and the copper content of the alloy. The alpha brasses containing in excess of 85 per cent of copper have work-hardening properties similar to those of copper. Those containing between 64 and 85 per cent of copper work-harden less rapidly than those of higher copper content. Because of this property these brasses are used extensively for applications requiring successive drawing operations without intermediate anneals.

Annealing.—After cold-working operations, the brasses can be rendered malleable or ductile again by heat-treatment at temperatures ranging from 700 to 1400°F., depending upon the properties desired.

Since the alpha brasses are single-phase alloys, they are not susceptible of hardening by heat-treatment.

Hot Working.—Those alpha brasses containing between 64 and 80 per cent of copper possess relatively poor hot-working properties. In order to hot-roll or hot-forge these alloys successfully the utmost care must be taken to keep lead, a natural impurity of most zinc, to a trace. (The presence of even 0.03 per cent of lead causes these alloys to crack at any hot-working temperature.) Brasses of this group are best hot-worked at temperatures in excess of 1350°F.; the best results are secured if all hot working is done within the range of 1350 to 1550°F.

The alpha brasses containing 80 per cent or more of copper have hot-working properties comparable to those of copper, which is extremely plastic through a wide temperature range. However, as in the case of copper, care must be exercised to control the lead to within very close limits. As a general rule, if these brasses do not contain in excess of 0.01 per cent of lead, they can be hot-forged, hot-rolled, or otherwise hot-worked without any difficulty.

Physical Properties—General.—In the alpha range, tensile properties increase with increasing zinc content, which is also accompanied by a change of color from red through gold to the green yellows and a progressive diminution of electrical and thermal conductivites.

Corrosion Resistance.—Alpha brasses are, for the most part, adversely affected by the same substances and the same conditions that have an adverse effect on copper. In some instances they may be corroded by substances, particularly those which might be termed "active chemical reagents," that do not affect copper to any appreciable extent. An exception to this generality is that in resisting the corrosive attack of sulphides the brasses, on the whole, are better than copper, and their superiority in that respect becomes more marked as the zinc content increases. Further, it is of particular interest that in combating the corrosion of sea water certain of the brasses, *e.g.*, 85-15 brass (known as "rich low" or "red brass") gives materially better service in respect to withstanding corrosion than copper itself.

Brasses containing less than 85 per cent of copper, when exposed to certain media, frequently fail in a characteristic manner termed "dezincification." Failures of this kind are identified by the appearance of spongy areas of copper in the form of layers or so-called "plugs" on the affected surface. This spongy copper is a consequence of the solution of fractions of the alloy in the media and a redeposition of the copper by chemical displacement. Arsenic, antimony, and phosphorus in small fractional percentages are demonstrably effective in repressing or inhibiting dezincification in the alpha brasses.

Brass that contains less than 85 per cent of copper may under certain conditions fail by stress-corrosion cracking or, as it is more commonly called, "season cracking." Conditions that favor this form of failure are the presence of internal stress or stress gradients produced by cold-working operations followed by exposure to mild atmospheric corrosion. The presence of traces of ammonia in the atmosphere is said to favor this form of corrosion. Season cracking can be effectively prevented by relief annealing below the recrystallization temperature.

A type of failure closely associated with season cracking and known as "fire cracking" occurs when susceptible brasses in a stressed condition are suddenly exposed to elevated temperatures. The presence of lead in the brass decreases the resistance to this type of failure by promoting greater intercrystalline weakness. In order to avoid this form of failure it is common practice to bring stressed materials up to the annealing temperature gradually rather than precipitantly.

In the fabrication of susceptible rod alloys it is common practice to flex or spring the rods prior to annealing, to counteract tensile stresses produced during fabrication, and thus reduce liability to fire cracking.

Following is a table of the more important commercial alpha brasses:

Most common name	Copper, %	Zinc, %
Gilding metal	95	5
Commercial "bronze"	90	10
Rich low brass or red brass	85	15
Low brass	80	20
Spring brass	75	25
70-30 or cartridge brass	70	30
Deep drawing	68	32
Common high brass (2 and 1)	66	34
Tubular rivet brass	65	35
Brass rod	64	36

The alloy of copper and zinc containing 95 per cent of copper is known as *gilding metal.* It is an extremely easy alloy to cold-work and flows readily in the intricate dies used for jewelry, emblems, plaques, and coining operations. It can be readily spun, drawn, forged, and upset. Its hot-working properties are comparable to those of copper. This alloy has slightly higher tensile properties and about the same ductility as copper but its thermal and electrical properties are lower.

Gilding metal is used extensively in the jewelry and emblem industry because of its excellent cold-working properties and its golden color. It is also an excellent base for articles that are to be gold-plated or finished to a high polish in their natural color. This alloy is commercially available in all common wrought forms. Physical and general mechanical properties of the most common form—strip—are given in Table 1 on page 30. Charts 1 to 13 on pages 30 to 33 give in greater detail the effect of cold working and annealing on its mechanical properties.

Brass with 90 per cent of copper through long usage has become known as *commercial bronze.* It has excellent cold-working properties and can be readily spun, drawn, forged, and upset. Its hot-working properties are very similar to those of copper.

Commercial bronze is used in the manufacture of costume jewelry, compacts, weatherstripping, stamped hardware, forgings, screws, rivets, and various ammunition components. Because of its attractive color it is used to a limited extent in architectural metalwork. The alloy is fabricated as sheet, strip, plate, rod, wire, bar, and tube. Physical and general mechanical properties of the more common forms (strip and rod) are given in Table 2 on page 34. Detailed mechanical property data are given in Charts 14 to 35 on pages 35 to 40.

Rich low brass, or *red brass,* has excellent cold-working properties and can be cold-worked to a greater extent than copper, owing to a better combination of strength and ductility. It is widely used for severe cold-drawing, stamping, or spinning operations. Red brass can be hot-worked commercially at temperatures in excess of 1350°F. when the lead content is less than 0.02 per cent. However, red brass is not so plastic at elevated temperatures as the other commercial brasses and for that reason is seldom used for forgings or for parts requiring fabrication through hot working.

Red brass has excellent corrosion-resisting properties, in many cases superior to those of copper. When in contact with salt or brackish waters it offers better resistance than copper itself and it is used successfully under conditions of operation that cause the higher zinc alloys to fail through dezincification.

Rich low brass is used extensively in the construction of automotive radiators, in the manufacture of tube and pipe for oil refineries and utilities, and in the field of domestic and industrial plumbing. This alloy is commonly fabricated in sheet, strip, plate, rod, bar, wire, and tube. Physical and general mechanical properties are shown in Table 3 on page 41 for the more common products (sheet and strip, rod and tube). Charts 36 to 58 on pages 42 to 47 give more detailed information.

Low brass has hot- and cold-working properties similar to rich low brass. Its corrosion-resisting properties are generally the same as those of the latter. Under certain severe conditions it may dezincify or fail by season cracking.

This alloy is used for flexible hose, bellows, clock dials, and numerous drawn and stamped parts. It is usually fabricated in sheet, strip, rod, wire, bar, and tube. Its physical and general mechanical properties are given in Table 4 on page 48 for the common forms (strip, rod, and tube). Charts 59 to 77 on pages 49 to 53 show in greater detail the influence of cold working and annealing on the mechanical properties of this alloy.

Spring brass containing 75 per cent of copper has excellent cold-working properties and can be readily fabricated by spinning, drawing, forging, and upsetting. It is not generally hot-worked as its hot plastic range is extremely narrow. Spring brass is suitable for forming into springs where loads are not excessive and where corrosion resistance is important. It is commonly fabricated into sheet and strip. Its physical and general mechanical properties are given in Table 5 on page 54. Charts 78 to 91 on pages 54 to 57 show more detailed information.

70-30, or cartridge, brass, deep-drawing, 2 and 1, and common high brass are known generally as the *high brasses.* These alloys possess the optimum combinations of strength and ductility. They all have excellent cold-working properties and can be readily spun, drawn, forged, and upset. As a general rule they are not fabricated by hot-working processes as the range in which they are hot plastic is very narrow.

Since the operations in which these alloys are used require excellent ductility, those elements which have an adverse influence on this property are very carefully controlled. Iron because of its hardening action and lead because of its influence on fire cracking are usually limited to 0.05 per cent, maximum. Such impurities as phosphorus, antimony, bismuth, nickel, chromium, and aluminum are kept to a trace or less.

Since alloys in this copper range are susceptible to "season cracking," it is common practice to relief-anneal, at low temperatures, formed parts that are to be used under conditions of mild corrosion.

High brasses are used for the manufacture of pins, rivets, eyelets, snap fasteners, automobile radiator cores, heating units, musical instruments, automobile lamp bodies and reflectors, cartridge cases and clips, electrical sockets, lamp bases, and many other drawn or formed shapes. The high brasses are available in sheet and strip, rod, wire, bar, and tube. Their physical and general mechanical properties for the common forms (strip and rod) are shown in Tables 6 to 9 on pages 58 to 76. Detailed data are given in Charts 92 to 158 on pages 59 to 78.

ALPHA-BETA BRASSES

Hot Working.—The alpha-beta brasses, *i.e.*, those containing from 64 to 55 per cent copper, are much easier to hot-work than the alpha; the ease of hot working increasing as the copper content decreases. Although lead is virtually insoluble in the alpha brasses and as such interferes with hot rolling, there is reason to believe that the beta phase will hold up to 1 per cent of lead in solution as it is possible to hot-work by any process alpha-beta brasses containing this amount of lead. The alpha-beta brasses are most commonly fabricated by hot processes since they are most plastic under these conditions.

Cold Working.—The alpha-beta brasses become increasingly difficult to cold-work as the copper content decreases. Those alloys containing less than about 58 per cent of copper are considered commercially unsuited for any cold-working operations. The poor cold-working properties of the alpha-beta brasses are caused by the presence of the beta phase. The brasses containing between 60 and 62 per cent of copper are suitable for parts requiring light cold-working properties. Cold-working properties improve progressively as the copper content increases to 64 per cent, at which point the beta phase disappears and the characteristic properties of the alpha range are encountered.

Annealing.—Like the alpha brasses, the alpha-beta brasses can be rendered soft after cold-working operations by annealing within the temperature range of 700 to 1400°F. depending upon the properties required. The alpha-beta brasses, however, can be hardened slightly by quenching from the annealing temperature. The hardening is produced by the formation of a greater amount of beta in the alloy than would be produced by air or furnace cooling.

Physical Properties—General.—The alpha-beta brasses possess the highest tensile properties and the lowest ductility of any of the copper-zinc alloys. Both of these properties are affected by the ratio of the beta phase to the alpha phase. Alloys of the lowest copper content, because of the greater percentage of beta phase, are the strongest and least ductile. The alpha-beta brasses with the higher copper content approach the alpha brasses containing 64 per cent of copper in ductility and strength.

At the appearance of the beta phase an increase in electrical and thermal properties over those of the low-copper alpha brasses is effected. *Muntz metal* containing 60 per cent of copper, the most important of the alpha-beta brasses, has an electrical conductivity slightly higher than that of 70-30 brass.

Muntz metal, known also as "yellow metal," has extremely good hot-working properties, being hot plastic over a wide temperature range. It possesses the highest tensile strength and lowest ductility of the brasses and consequently only light cold-working operations are possible with it.

Muntz metal is widely used in architectural work for panel sheets, grilles, door stiles, and so forth. It is also used for tube sheets and baffle and support plates in heat exchangers. It also has been used for condenser tubes and as pipe for domestic and industrial plumbing. It is fabricated in sheet and strip, plate, rod, bar, and tube. Its physical and general mechanical properties are given in Table 10 on page 79. Charts 159 to 186 on pages 80 to 86 show the range of properties that can be secured.

TABLE 1
GILDING METAL
Copper, 94.59%; iron, trace; zinc, balance

Property	Hard[a]	Soft[b]
Tensile strength,[c] p.s.i. (000 omitted)	58–63	36–38
Elongation,[c] % in 2 in.	4	45
Apparent elastic limit,[c] p.s.i. (000 omitted)	48–55	5–9
Yield strength, 0.5% extension, p.s.i. (000 omitted)	54–58	8–13
Yield strength, 0.2% offset, p.s.i. (000 omitted)	54–60	8–13
Yield strength, 0.1% offset, p.s.i. (000 omitted)	51–57	8–13
Rockwell hardness F, 1/16-in. ball, 60-kg. load[c]	95–100	52–63
Rockwell hardness B, 1/16-in. ball, 100-kg. load[c]	62–73	0–8
Rockwell hardness G, 1/16-in. ball, 150-kg. load[c]	21–38	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load[c]	81–83	63
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load[c]	58–66	21
Young's modulus of elasticity, p.s.i.	15,000,000	
Melting point, °F.	1950	
Density, lb. per cu. in.	0.320	
Coefficient of expansion, per °C. from 25–300°C.	0.0000181	
Electrical conductivity,(87) % I.A.C.S., 68°F.	57	
Thermal conductivity,(87) B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	139	

[a] 6 B. & S. Nos., hard, 0.070–0.015 mm. grain size at ready-to-finish, respectively.
[b] Refers to 900°F. anneal (1 hr. at temperature).
[c] Apply to strip only (all tests conducted on 0.040-in. stock).

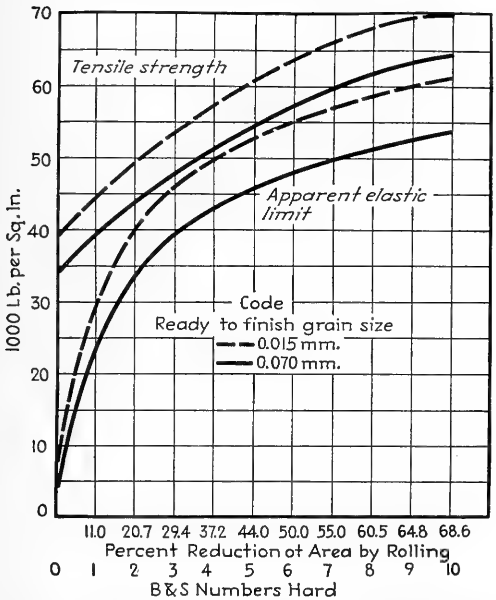


CHART 1.—The effect of cold rolling on the tensile strength and apparent elastic limit of gilding-metal strip, previously annealed to two different grain sizes, 0.015 and 0.070 mm. (94.59 % copper) (0.040-in. stock).

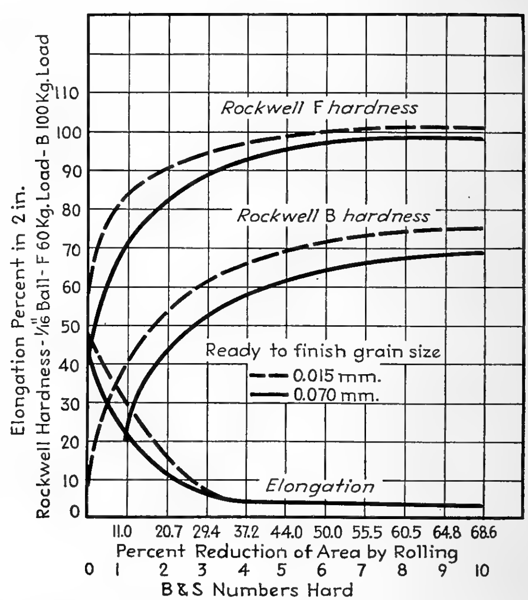


CHART 2.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of gilding-metal strip, previously annealed to two different grain sizes, 0.015 and 0.070 mm. (94.59 % copper) (0.040-in. stock).

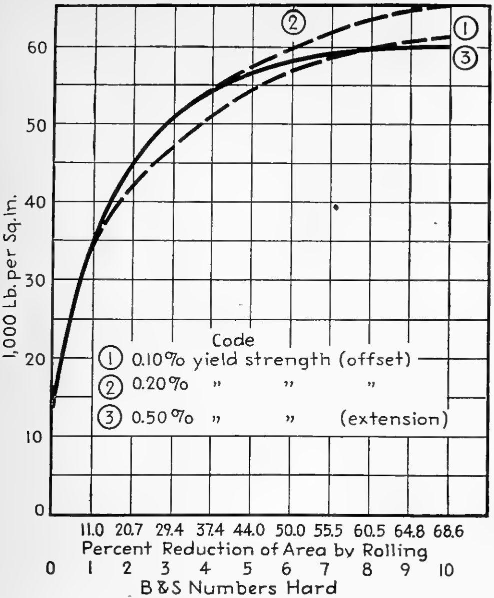


CHART 3.—The effect of cold rolling on the yield strengths of gilding-metal strip, previously annealed to a grain size of 0.015 mm. (94.59 % copper) (0.040-in. stock).

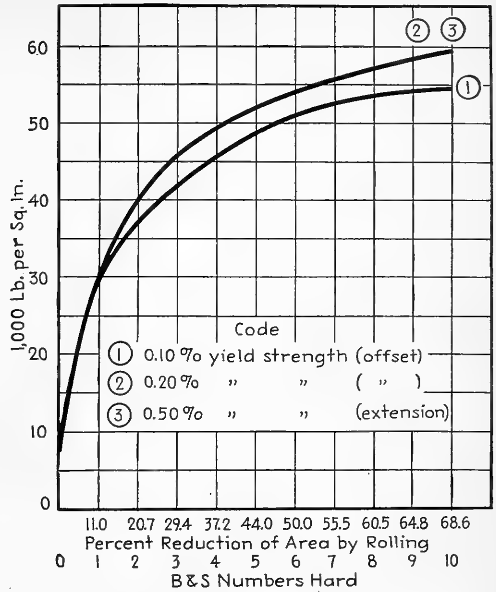


CHART 4.—The effect of cold rolling on the yield strengths of gilding-metal strip, previously annealed to a grain size of 0.070 mm. (94.59 % copper) (0.040-in. stock).

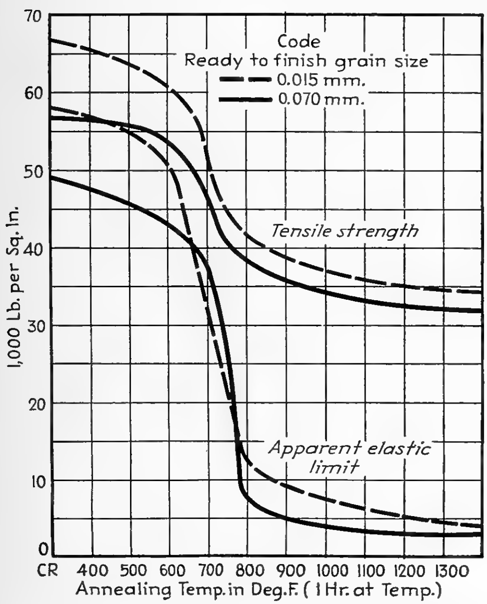


CHART 5.—The effect of annealing on the tensile strength and apparent elastic limit of gilding metal, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (94.59 % copper) (0.040-in. stock).

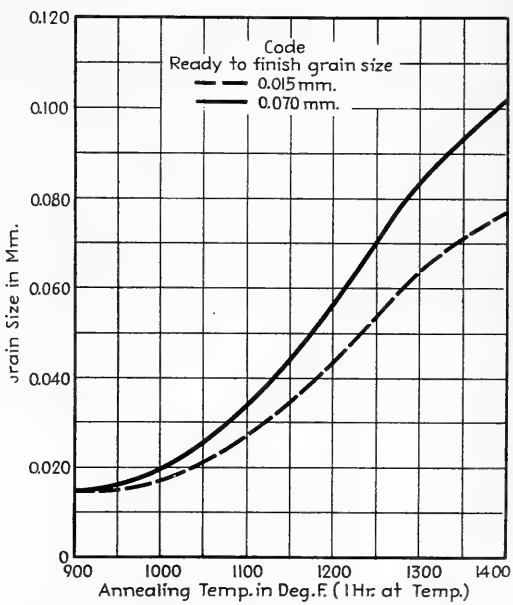


CHART 6.—The effect of annealing on the grain-growing characteristics of gilding metal, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (94.59 % copper) (0.040-in. stock).

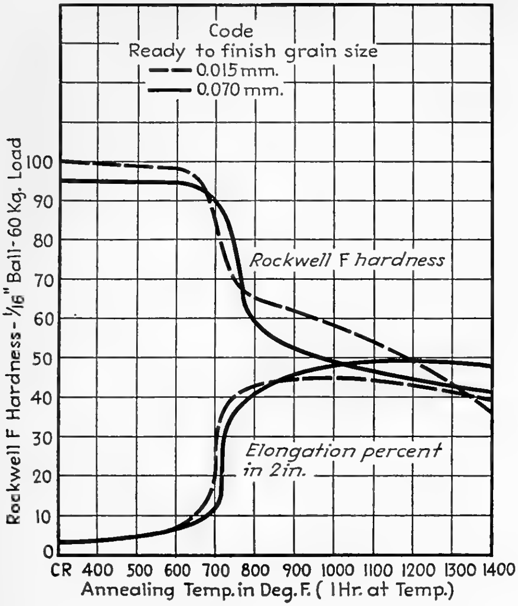


Chart 7.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of gilding-metal strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (94.59 % copper) (0.040-in. stock).

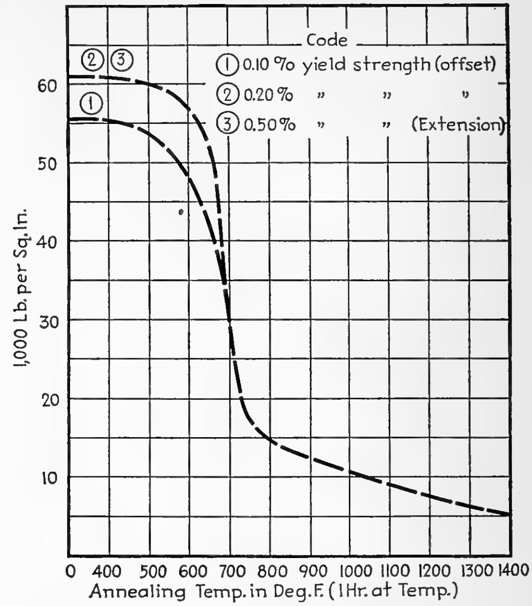


Chart 8.—The effect of annealing on the yield strength of gilding-metal strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (94.59 % copper) (0.040-in. stock).

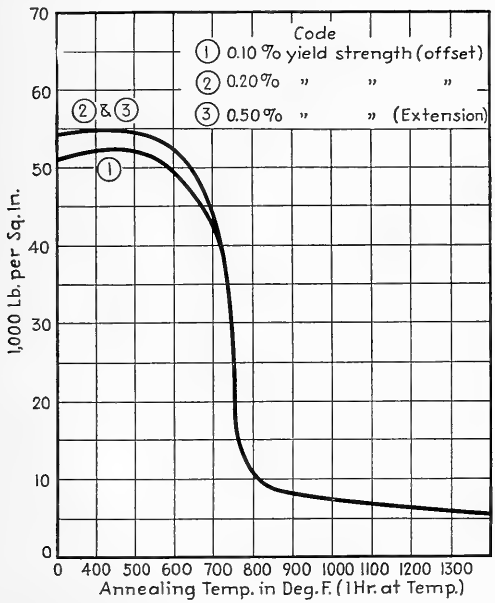


Chart 9.—The effect of annealing on the yield strength of gilding-metal strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.070 mm. (94.59 % copper) (0.040-in. stock).

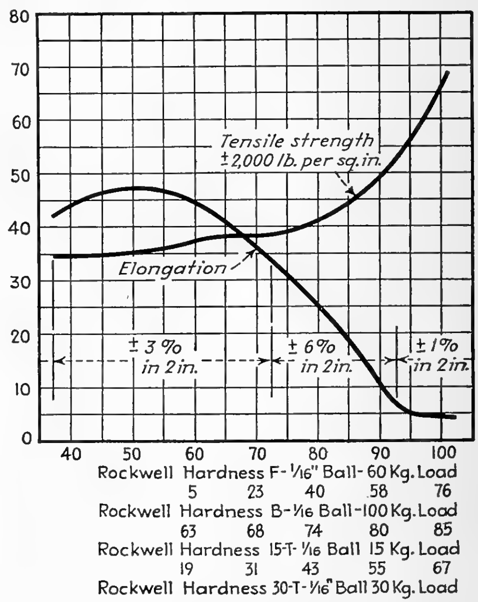


Chart 10.—This chart can be employed to determine the approximate tensile strength and percentage elongation of gilding-metal strip when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits (94.59 per cent copper).

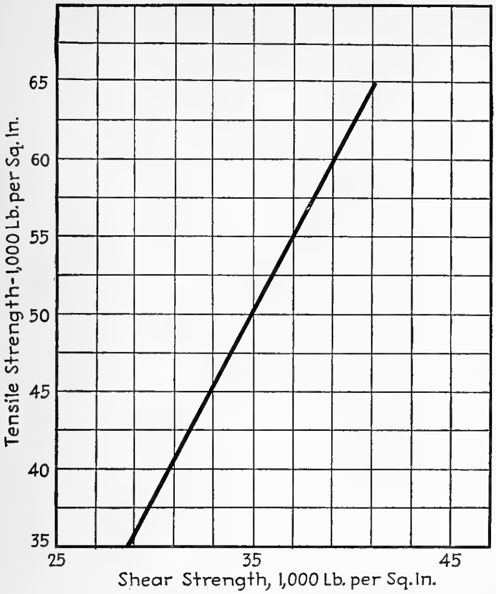


CHART 11.—Conversion chart for determination of shear strength of gilding metal (95.00 % copper, balance zinc) when tensile strength is known. Accurate to ±5 %.[86]

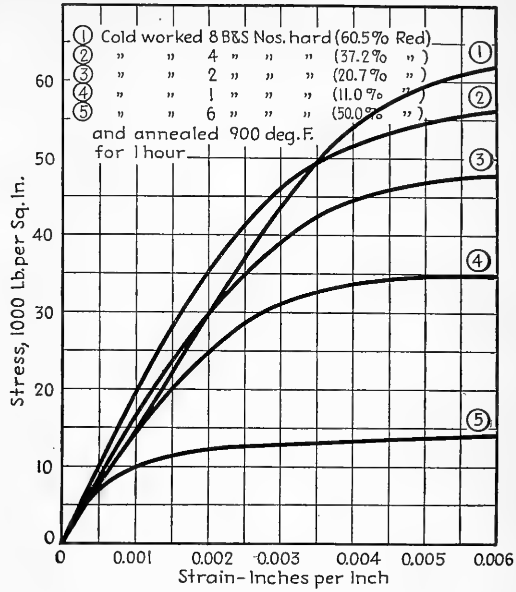


CHART 12.—The effect of cold-working on the stress-strain characteristics of gilding-metal strip (0.040-in. thick) having a ready-to-finish grain size of 0.015 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used (94.59 % copper).

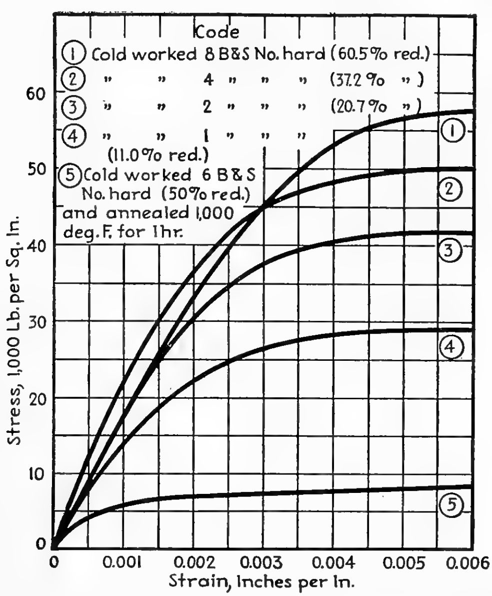


CHART 13.—The effect of cold working on the stress-strain characteristics of gilding-metal strip (0.040 in. thick) having a ready-to-finish grain size of 0.070 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used (94.59 % copper).

TABLE 2
COMMERCIAL BRONZE
GENERAL DATA—ROD
Copper, 89.99%; lead, trace; iron, trace; zinc, balance

Property	Hard[a]	Soft[b]	Forgings		
			Hot	Cold[c]	Cold[d]
Tensile strength, p.s.i. (000 omitted)	65	35	35–40	40–65	65
Apparent elastic limit, p.s.i. (000 omitted)	54	7	7–10	20–52	54
Yield strength, 0.5% extension, p.s.i. (000 omitted)	60	18	12–15	25–58	60
Yield strength, 0.2% offset, p.s.i. (000 omitted)	63	11	11–13	25–61	63
Yield strength, 0.1% offset, p.s.i. (000 omitted)	60	10	10–12	20–55	60
Elongation, % in 2 in.	18	56	60–50	48–19	19
Reduction of area, %	75	82	90–80	82–75	75
Endurance limit, p.s.i. (000 omitted)	18	12	12–16	12–16	18
Rockwell hardness F, 1/16-in. ball, 60-kg. load	97	55	50–60	69–97	97
Rockwell hardness B, 1/16-in. ball, 100-kg. load	68	..	.....	–65	67
Brinell hardness, 10-mm. ball, 500-kg. load	107	52	.....	62–102	103
Modulus of elasticity, p.s.i.	15,000,000				
Hot-forging range, °F.	1300–1450				
Hot-forging quality	Good				
Type structure	Single phase, alpha				

GENERAL DATA—STRIP
Copper, 89.74%; lead, nil; iron, trace; zinc, balance

Property	Hard[e]	Soft[f]
Tensile strength, p.s.i. (000 omitted)[g]	64–69	36–39
Elongation, % in 2 in.[g]	5	45
Apparent elastic limit, p.s.i. (000 omitted)[g]	53–57	8
Yield strength, 0.5% extension, p.s.i. (000 omitted)[g]	59–60	11–12
Yield strength, 0.2% offset, p.s.i. (000 omitted)[g]	62–64	11–12
Yield strength, 0.1% offset, p.s.i. (000 omitted)[g]	57–60	11–12
Rockwell hardness F, 1/16-in. ball, 60-kg. load[g]	100–103	59–62
Rockwell hardness B, 1/16-in. ball, 100-kg. load[g]	73–77	3–11
Rockwell hardness G, 1/16-in. ball, 150-kg. load[g]	38–44	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load[g]	85–86	62–64
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load[g]	66–68	17–23
Young's modulus of elasticity, p.s.i.	15,000,000	

PHYSICAL DATA

Melting point, °F	1913
Coefficient of expansion, per °C. from 25–300°C	0.0000182
Electrical conductivity,(87) % I.A.C.S., 68°F	43.6
Thermal conductivity,(87) B.t.u. per sq. ft. per ft. per hr. per °F., 68°F	108
Density, lb. per cu. in.	0.318

[a] Refers to rod cold-drawn 50%; rod under 1 in. in diameter with ready-to-finish grain size, 0.050 mm.
[b] Refers to 1200°F. anneal (1 hr.).
[c] Material cold-forged from soft rod (5–40% reduction of area).
[d] Material cold-forged from cold-worked condition (40%).
[e] 6 B. & S. Nos., hard, 0.070–0.015 mm. grain size at ready-to-finish, respectively.
[f] Refers to 1000°F. anneal (1 hr. at temperature).
[g] Refers to strip only (all tests conducted on 0.040-in. stock).

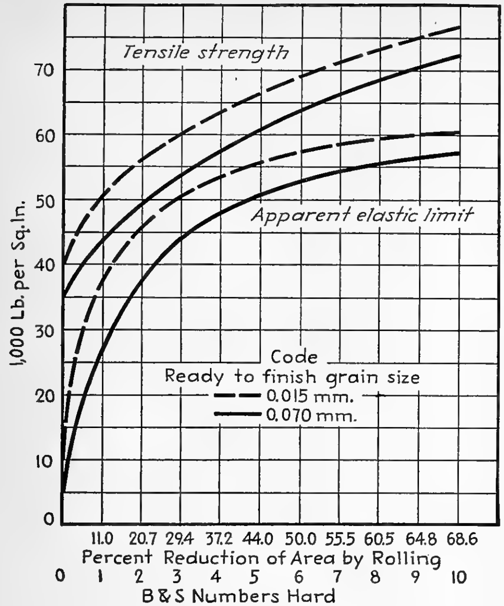


CHART 14.—The effect of cold rolling on the tensile strength and apparent elastic limit of commercial bronze (Government-gilding) strip, previously annealed to two different grain sizes, 0.015 and 0.070 mm. (89.74 % copper) (0.040-in. stock).

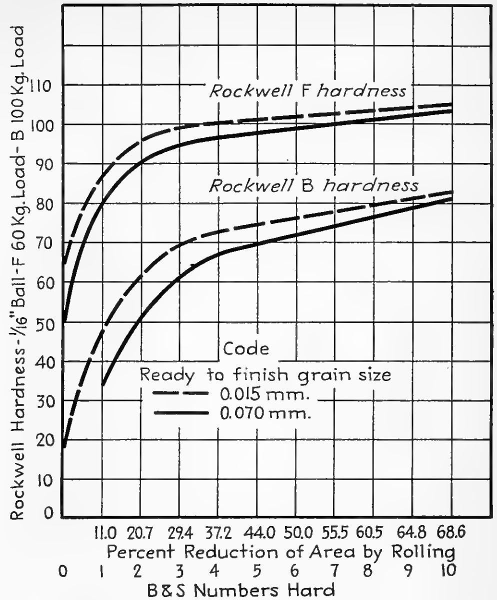


CHART 15.—The effect of cold rolling on the Rockwell hardness of commercial bronze (Government-gilding) strip, previously annealed to two different grain sizes, 0.015 and 0.070 mm. (89.74 % copper) (0.040-in. stock).

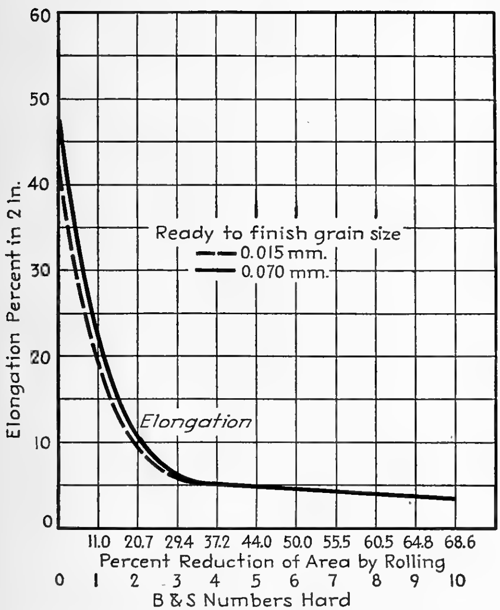


CHART 16.—The effect of cold rolling on the percentage elongation in 2 in. of commercial bronze (Government-gilding) strip, previously annealed to two different grain sizes, 0.015 and 0.070 mm. (89.74 % copper) (0.040-in. stock).

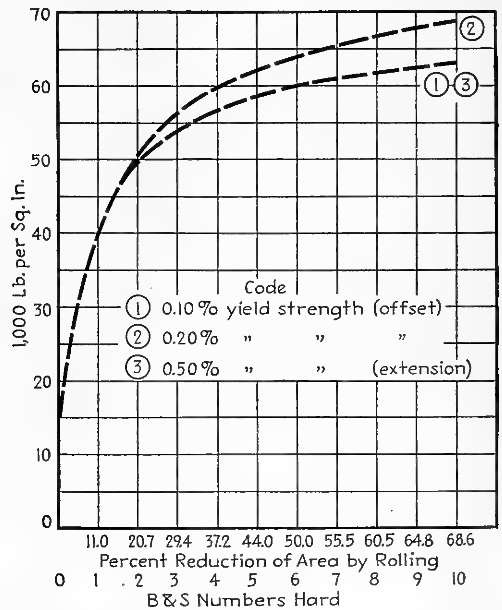


CHART 17.—The effect of cold rolling on the yield strengths of commercial bronze (Government-gilding) strip, previously annealed to a grain size of 0.015 mm. (89.74 % copper) (0.040-in. stock).

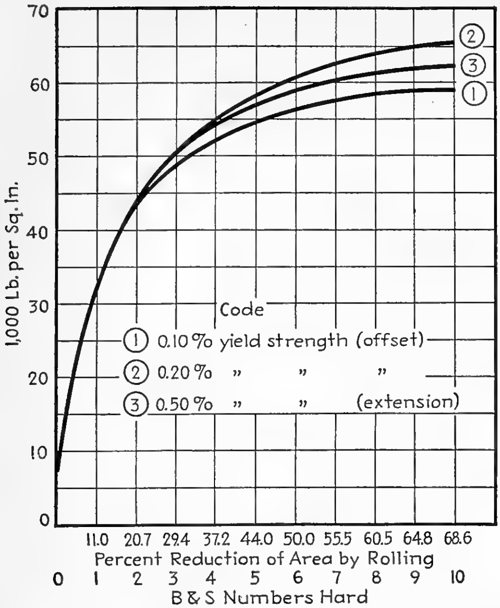


CHART 18.—The effect of cold rolling on the yield strengths of commercial bronze (Government-gilding) strip, previously annealed to a grain size of 0.070 mm. (89.74 % copper) (0.040-in. stock).

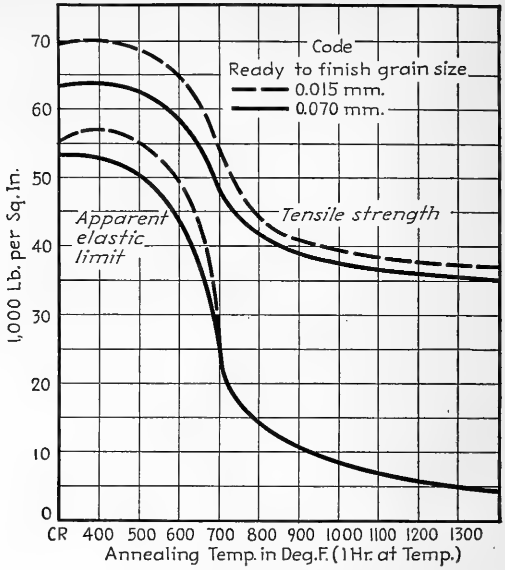


CHART 19.—The effect of annealing on the tensile strength and apparent elastic limit of commercial bronze (Government-gilding) strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (89.74 % copper) (0.040-in. stock).

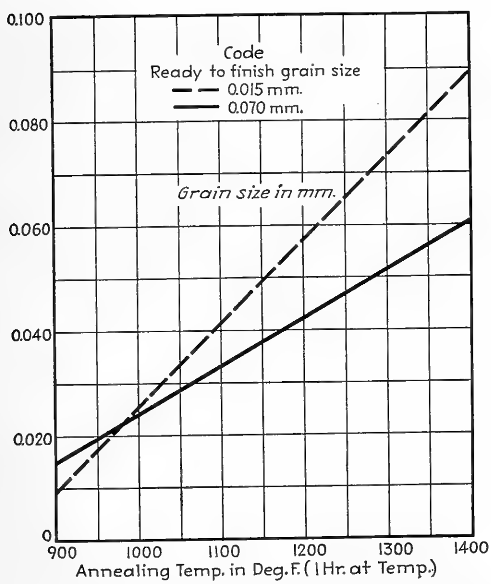


CHART 20.—The effect of annealing on the grain-growing characteristics of commercial bronze (Government-gilding) strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (89.74 % copper) (0.040-in. stock).

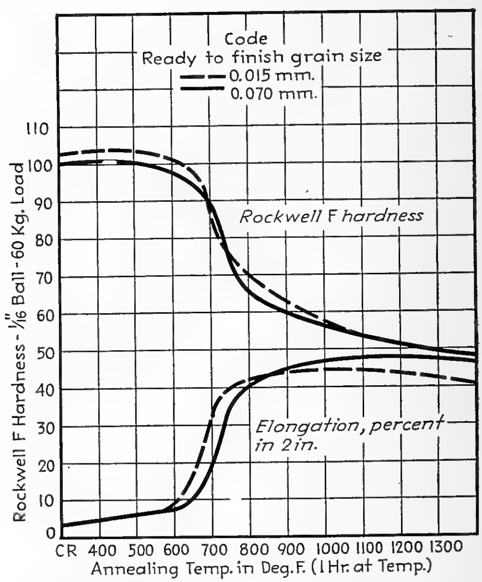


CHART 21.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of commercial bronze (Government-gilding) strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (89.74 % copper) (0.040-in. stock).

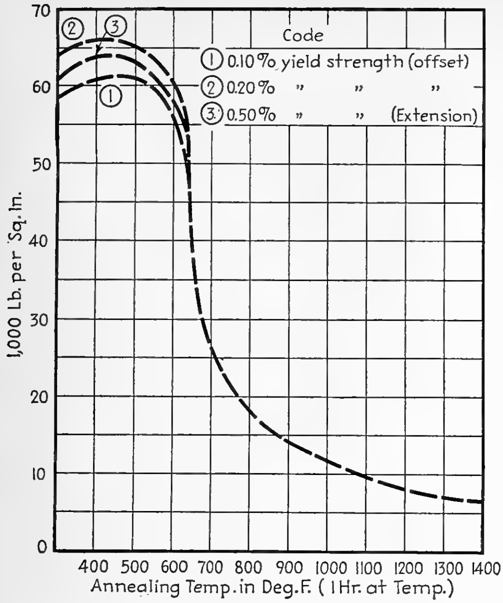


Chart 22.—The effect of annealing on the yield strength of commercial bronze (Government-gilding) strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (89.74 % copper) (0.040-in. stock).

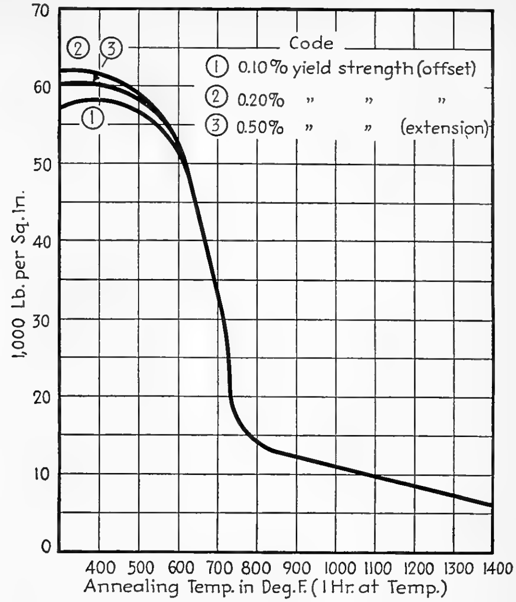


Chart 23.—The effect of annealing on the yield strength of commercial bronze (Government-gilding) strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.070 mm. (89.74 % copper) (0.040-in. stock).

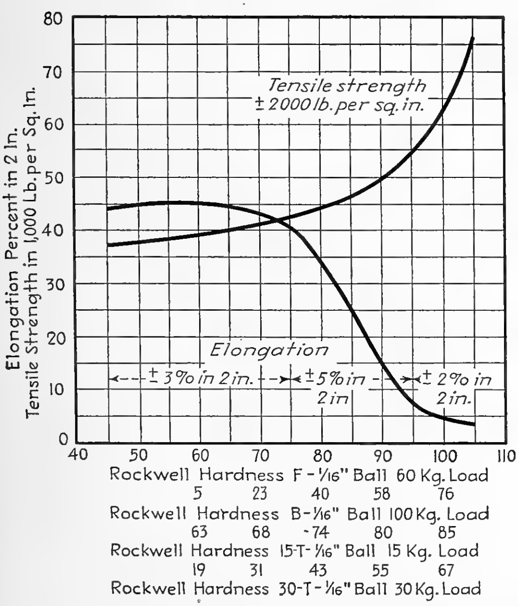


Chart 24.—This chart can be employed to determine the approximate tensile strength and percentage elongation of commercial bronze (Government-gilding strip (89.74 % copper) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

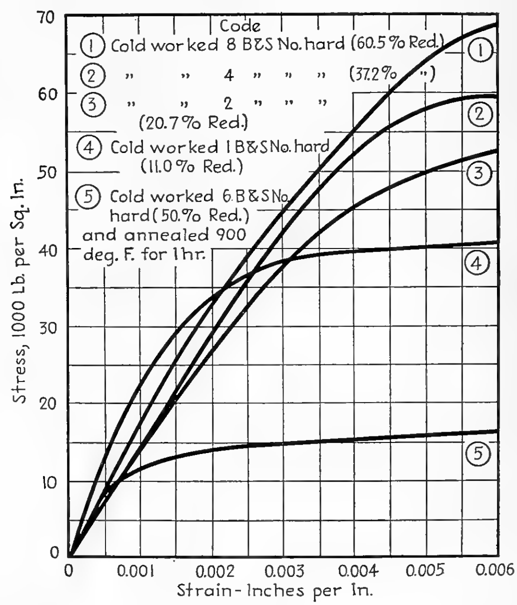


Chart 25.—The effect of cold working on the stress-strain characteristics of commercial bronze (Government-gilding) strip (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used (89.74 % copper).

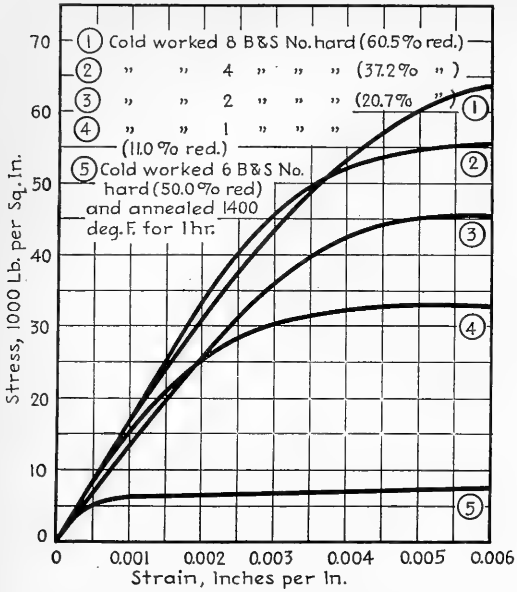


CHART 26.—The effect of cold working on the stress-strain characteristics of commercial bronze (Government-gilding) strip (0.040 in. thick) having a ready-to-finish grain size of 0.070 mm. (89.74 % copper); 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used.

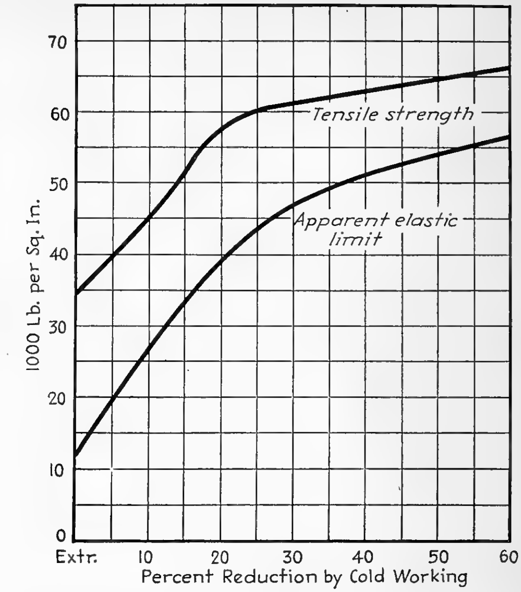


CHART 27.—The effect of cold drawing on the tensile strength and apparent elastic limit of commercial bronze (Government-gilding) rod, previously annealed to a grain size of 0.050 mm. (89.99 % copper) (rod under 1 in. in diameter).

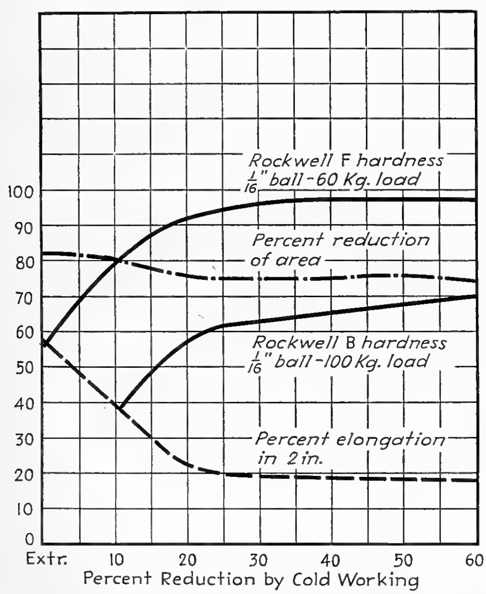


CHART 28.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of commercial bronze (Government-gilding) rod, previously annealed to a grain size of 0.050 mm. (89.99 % copper) (rod under 1 in. in diameter).

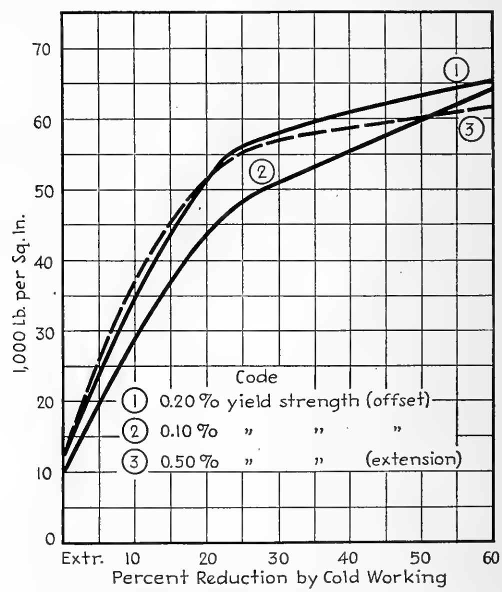


CHART 29.—The effect of cold drawing on the yield strength of commercial bronze (Government-gilding) rod, previously annealed to a grain size of 0.050 mm. (89.99 % copper) (rod under 1 in. in diameter).

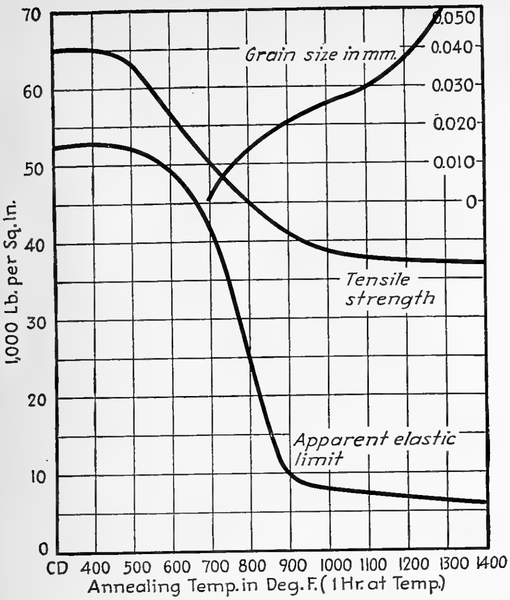


CHART 30.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of commercial bronze (Government-gilding) rod, previously cold-drawn 37 % (reduction of area) from material having a grain size of 0.050 mm. (89.99 % copper) (rod under 1 in. in diameter).

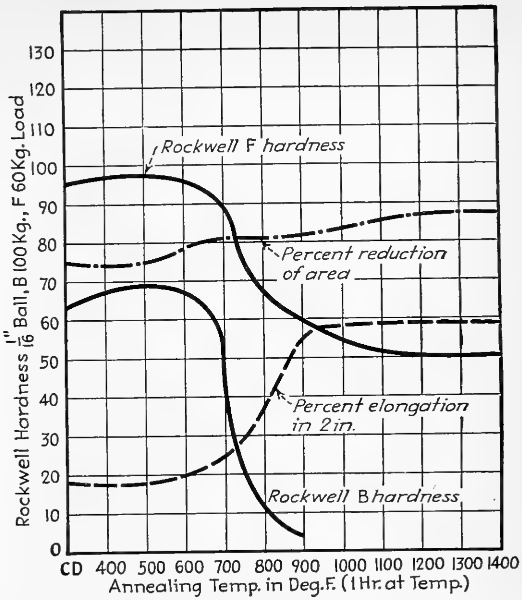


CHART 31.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., percentage reduction of area of commercial bronze (Government-gilding) rod, previously cold-drawn 37 per cent (reduction of area) from material having a grain size of 0.050 mm. (89.99 % copper) (rod under 1 in. in diameter).

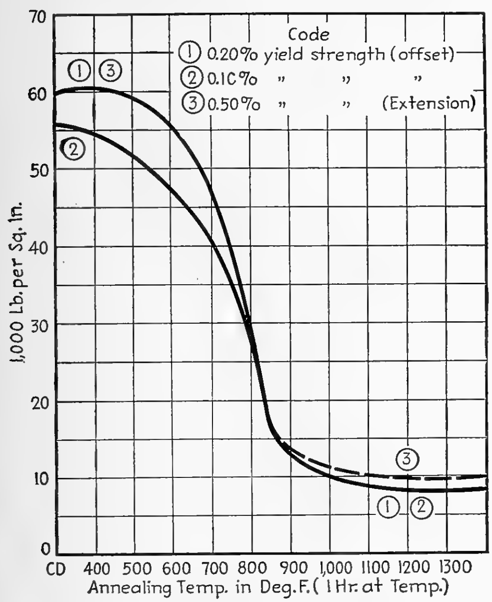


CHART 32.—The effect of annealing on the yield strength of commercial bronze (Government-gilding) rod, previously cold-drawn 37 per cent (reduction of area) from material having a grain size of 0.050 mm. (89.99 % copper) (rod under 1 in. in diameter).

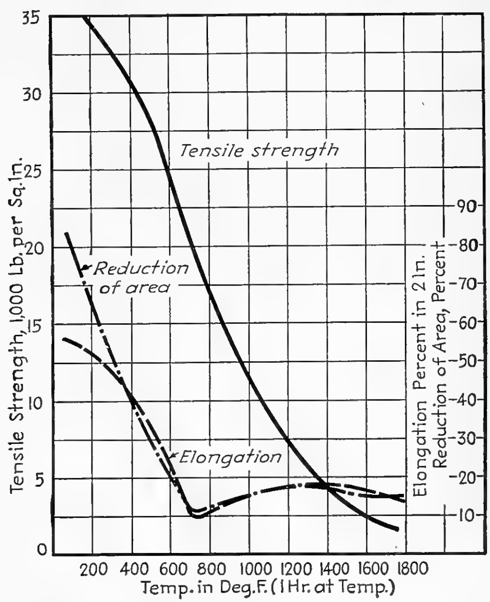


CHART 33.—The effect of elevated temperature on tensile strength, reduction of area, and percentage elongation in 2 in. of commercial bronze rod (89.99 % copper), previously annealed to a grain size of 0.030 mm. according to W. B. Price[7] (rod under 1 in. in diameter).

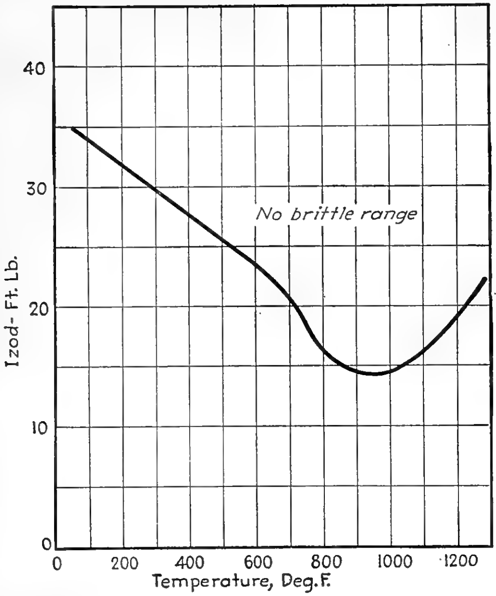


CHART 34.—The effect of elevated temperature on the Izod-impact strength of annealed commercial bronze (90.00 % copper) according to D. Bunting.[5]

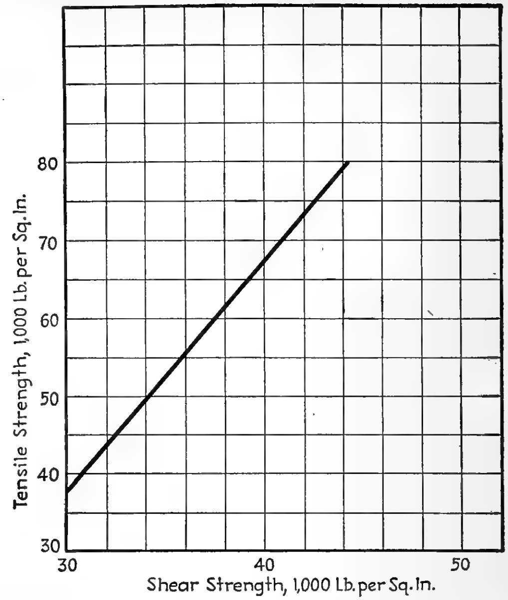


CHART 35.—Conversion chart for determination of shear strength of commercial bronze (90.00 % copper, balance zinc) when tensile strength is known. Accurate to ±5 %.[86]

FOOTNOTES FOR TABLE 3

[a] Refers to rod cold-drawn 50 %; rod under 1 in. in diameter with a ready-to-finish grain size, 0.050 mm.
[b] Refers to 1050°F. for 1 hr.
[c] Material cold-forged from soft rod (5–40 % reduction of area).
[d] Material cold-forged from cold-worked condition (40 %).
[e] 6 B. & S. Nos., hard, 0.070–0.015 grain size at ready-to-finish, respectively.
[f] Refers to 1100°F. anneal (1 hr. at temperature).
[g] Apply to strip only (all tests conducted on 0.040-in. stock).
[h] Extruded, reduced, and cold-drawn to ¾ by 0.049 in.
[i] 950°F. anneal for 1 hr.

TABLE 3
RICH LOW BRASS (RED BRASS)

General Data—Rod

Copper, 85.68%; lead, trace; iron, trace; zinc, balance

Property	Rod		Forgings		
	Hard[a]	Soft[b]	Hot	Cold[c]	Cold[d]
Tensile strength, p.s.i. (000 omitted)	75	37	37–42	42–68	72
Apparent elastic limit, p.s.i. (000 omitted)	60	8	8–12	18–50	56
Yield strength, 0.5% extension, p.s.i. (000 omitted)	64	14	14–18	25–57	67
Yield strength, 0.2% offset, p.s.i. (000 omitted)	72	14	14–16	22–54	68
Yield strength, 0.1% offset, p.s.i. (000 omitted)	67	12	12–15	24–62	62
Elongation, % in 2 in.	55	18	60–50	47–20	18
Reduction of area, %	80	72	85–80	80–74	72
Endurance limit, p.s.i. (000 omitted)	20	14	.....	14–18	20
Rockwell hardness F, 1/16-in. ball, 60-kg. load	100	59	48–68	70–98	100
Rockwell hardness B, 1/16-in. ball, 100-kg. load	78	..	18	75	78
Brinell hardness, 10-mm. ball, 500-kg. load	126	54	60	63–120	126
Modulus of elasticity, p.s.i.	15,000,000				
Hot-forging range, °F.	1350–1500				
Hot-forging quality	Fair				
Type structure	Single phase, alpha				

General Data—Strip

Copper, 85.42%; lead, nil; iron, trace; zinc, balance

Property	Hard[e]	Soft[f]
Tensile strength, p.s.i. (000 omitted)[g]	74–82	38–40
Elongation, % in 2 in.[g]	4	43
Apparent elastic limit, p.s.i. (000 omitted)[g]	52–63	7–8
Yield strength, 0.5% extension, p.s.i. (000 omitted)[g]	61–64	10
Yield strength, 0.2% offset, p.s.i. (000 omitted)[g]	67–73	10
Yield strength, 0.1% offset, p.s.i. (000 omitted)[g]	62–66	10
Rockwell hardness F, 1/16-in. ball, 60-kg. load[g]	104–107	55–57
Rockwell hardness B, 1/16-in. ball, 100-kg. load[g]	82–86	
Rockwell hardness G, 1/16-in. ball, 150-kg. load[g]	53–59	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load[g]	87–89	
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load[g]	72–74	
Young's modulus of elasticity, p.s.i.	15,000,000	

General Data—Tube

Copper, 85.01%; lead, trace; iron, trace; zinc, balance

Property	Hard[h]	Soft[i]
Tensile strength, p.s.i. (000 omitted)	89	45
Elongation, % in 2 in.	4	43
Apparent elastic limit, p.s.i. (000 omitted)	85	15
Rockwell hardness F, 1/16-in. ball, 60-kg. load	108	60

Physical Data

Melting point, °F.	1870
Coefficient of expansion, per °C. from 25–300°C.	0.0000187
Electrical conductivity,[87] % I.A.C.S., 68°F.	34.7
Thermal conductivity,[87] B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	87
Density, lb. per cu. in.	0.316

Available Creep Data[3]

Previous history: hot-rolled to 0.750 in. in diameter; grain size 0.030 mm.

Temperature, °F.	No measurable flow	Stress, p.s.i., required to produce designated rate of creep per 1,000 hr.		
		0.01%	0.10%	1.00%
400	7,500	8,800	12,000	17,000
600	Approaching zero	1,000	2,600	6,800

See p. 40 for table footnotes.

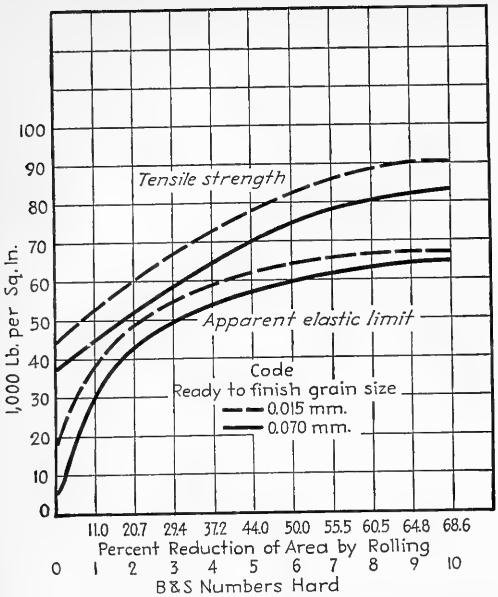


Chart 36.—The effect of cold rolling on the tensile strength and apparent elastic limit of rich low-brass strip, previously annealed to two different grain sizes, 0.015 and 0.070 mm. (85.42 % copper) (0.040-in. stock).

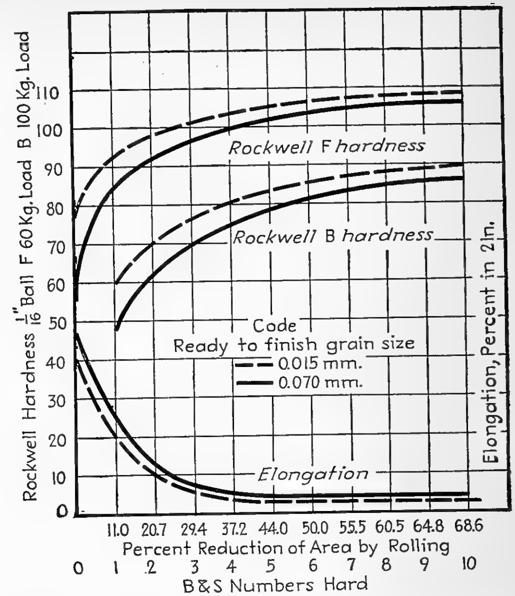


Chart 37.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of rich low-brass strip, previously annealed to two different grain sizes, 0.015 and 0.070 mm. (85.42 % copper) (0.040-in. stock).

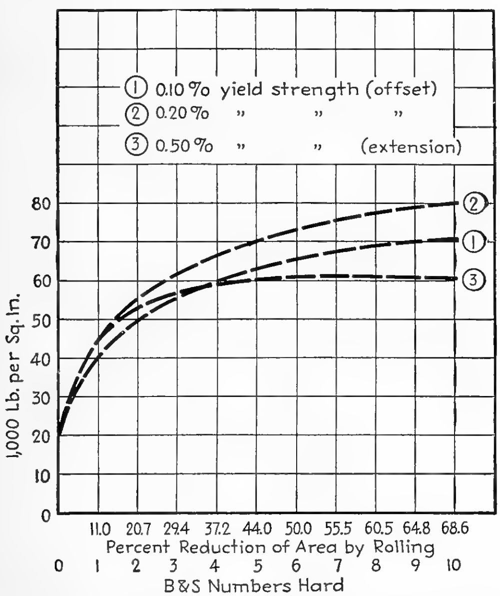


Chart 38.—The effect of cold rolling on the yield strengths of rich low-brass strip, previously annealed to a grain size of 0.015 mm. (85.42 % copper) (0.040-in. stock).

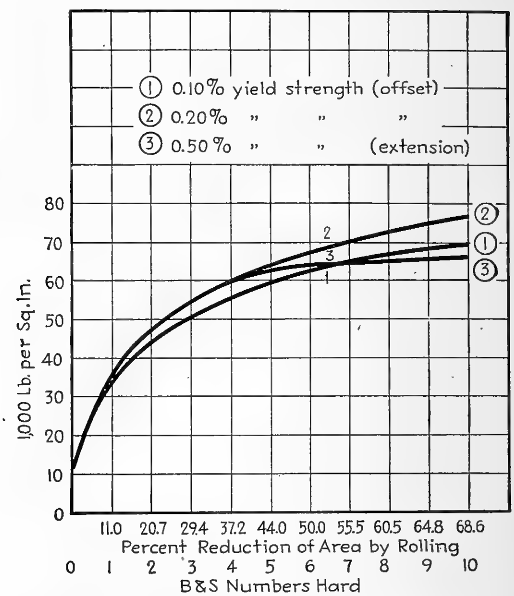


Chart 39.—The effect of cold rolling on the yield strengths of rich low-brass strip, previously annealed to a grain size of 0.070 mm. (85.42 % copper) (0.040-in. stock).

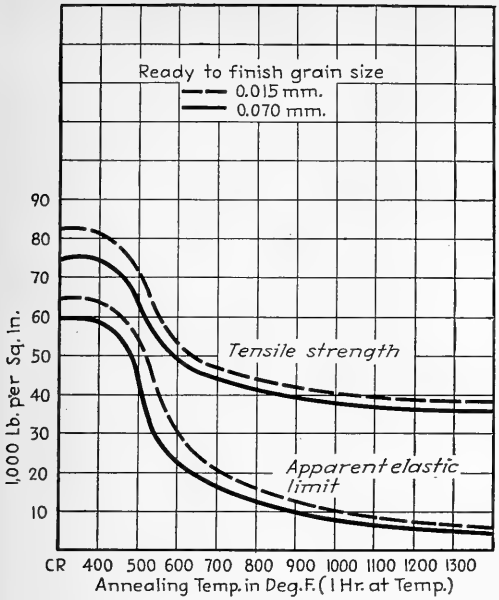


CHART 40.—The effect of annealing on the tensile strength and apparent elastic limit of rich low-brass strip previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (85.42 % copper) (0.040-in. stock).

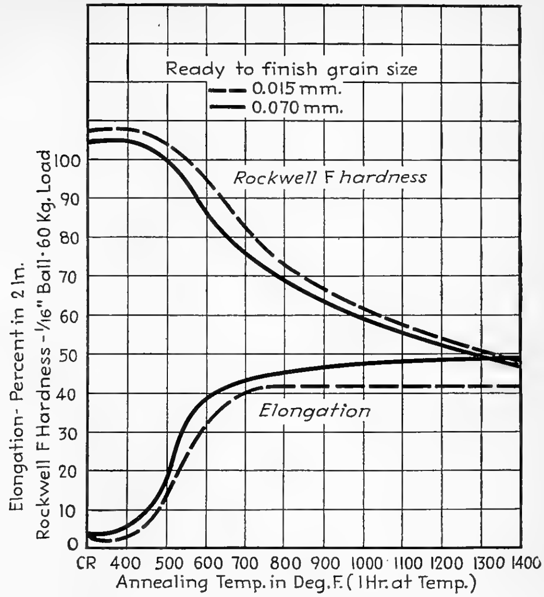


CHART 41.—The effect of annealing on the Rockwell hardness and percentage of elongation in 2 in. of rich low-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (85.42 % copper) (0.040-in. stock).

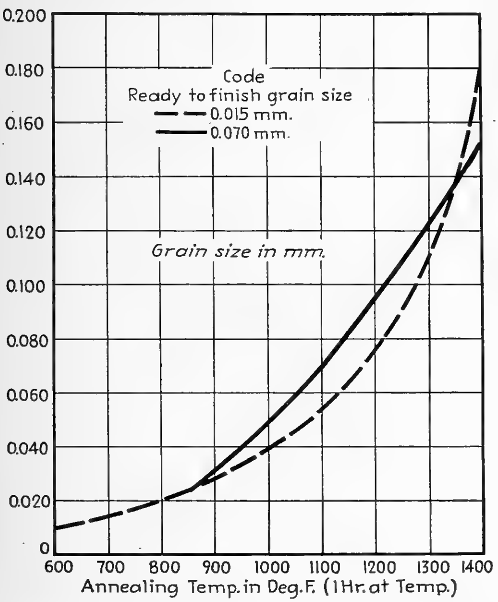


CHART 42.—The effect of annealing on the grain-growing characteristics of rich low-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (85.42 % copper) (0.040-in. stock).

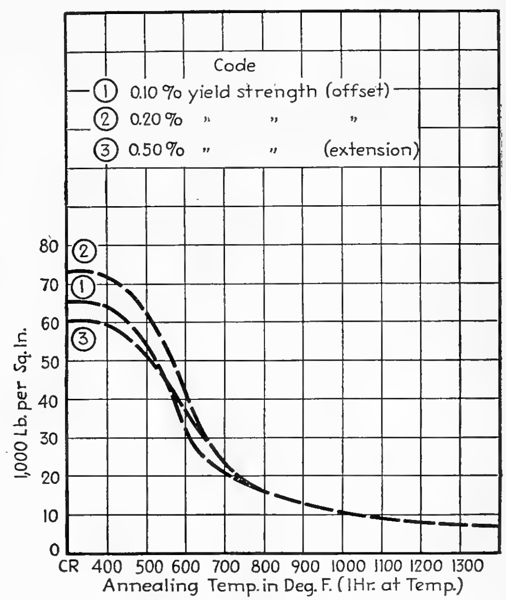


CHART 43.—The effect of annealing on the yield strength of rich low-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (85.42 % copper) (0.040-in. stock).

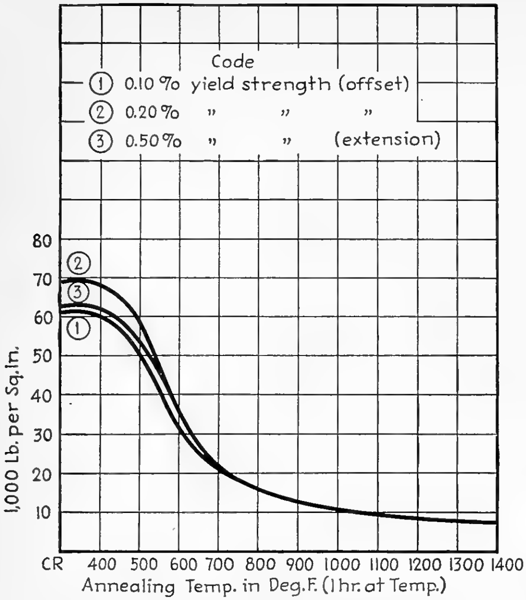


CHART 44.—The effect of annealing on the yield strength of rich low-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.070 mm. (85.42 % copper) (0.040-in. stock).

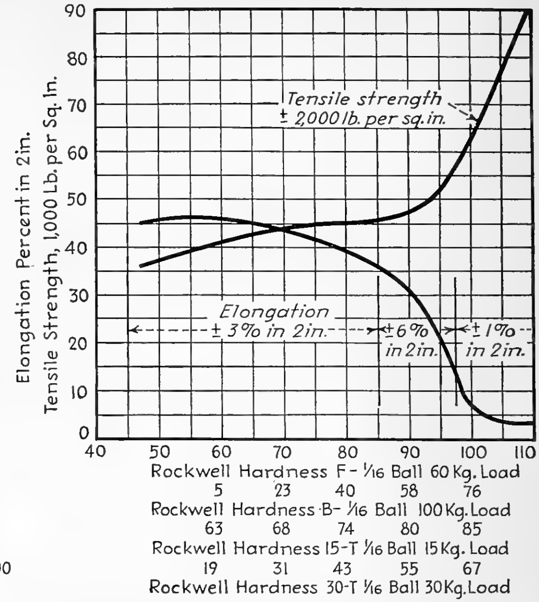


CHART 45.—This chart can be employed to determine the approximate tensile strength and percentage elongation of rich low-brass strip (85.42 % copper) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

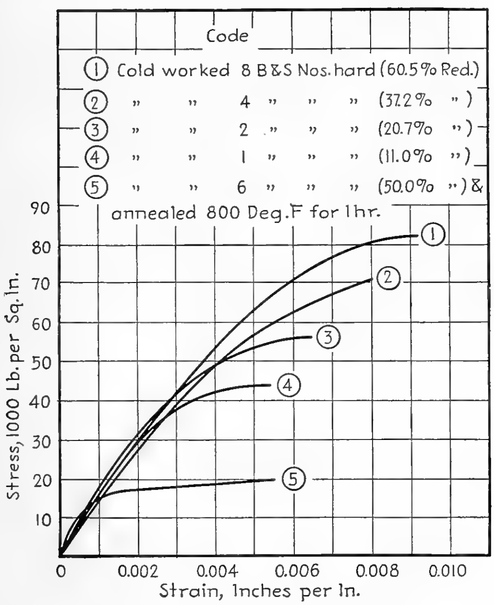


CHART 46.—The effect of cold working on the stress-strain characteristics of rich low-brass strip (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm. (85.42 % copper); 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used.

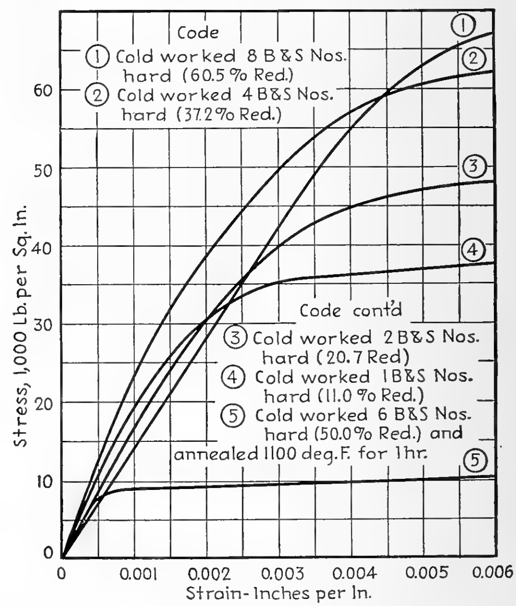


CHART 47.—The effect of cold working on the stress-strain characteristics of rich low-brass strip (0.040 in. thick) having a ready-to-finish grain size of 0.070 mm. (85.42 % copper); 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used.

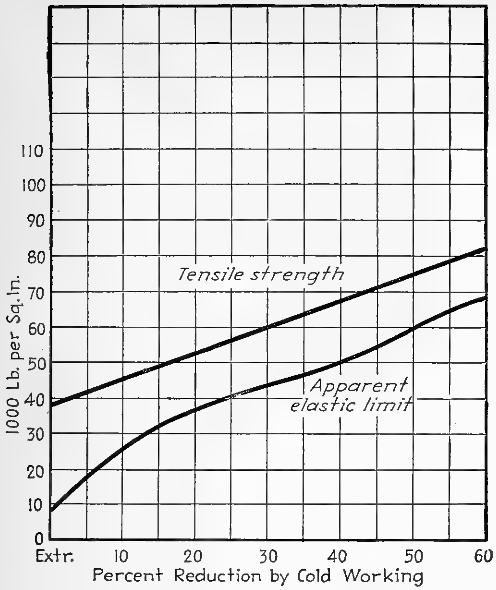


CHART 48.—The effect of cold drawing on the tensile strength and apparent elastic limit of rich low-brass rod, previously annealed to a grain size of 0.050 mm. (85.68 % copper) (rod under 1 in. in diameter).

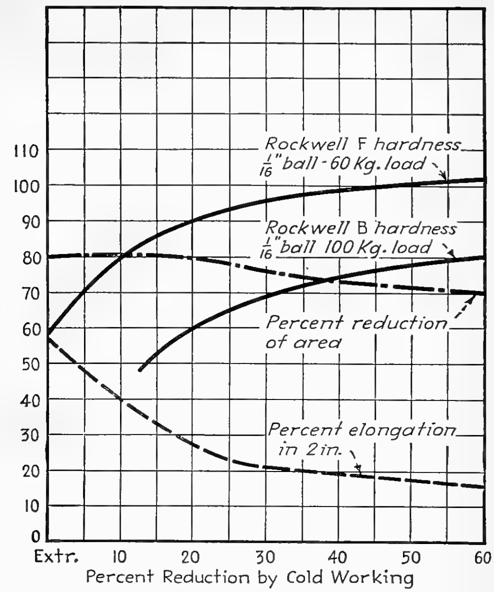


CHART 49.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of rich low-brass rod, previously annealed to a grain size of 0.050 mm. (85.68 % copper) (rod under 1 in. in diameter).

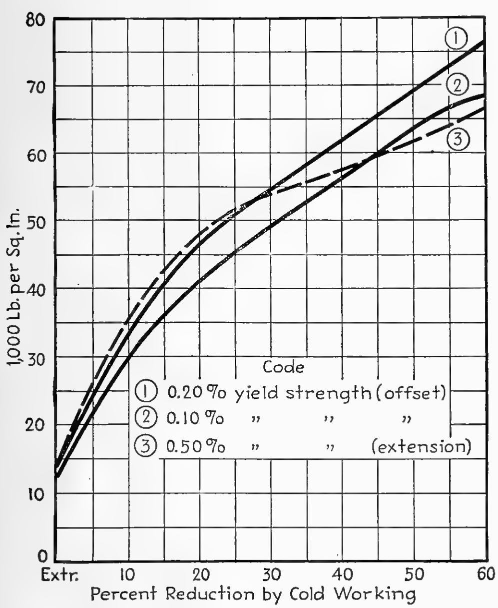


CHART 50.—The effect of cold drawing on the yield strength of rich low-brass rod, previously annealed to a grain size of 0.050 mm. (85.68 % copper) (rod under 1 in. in diameter).

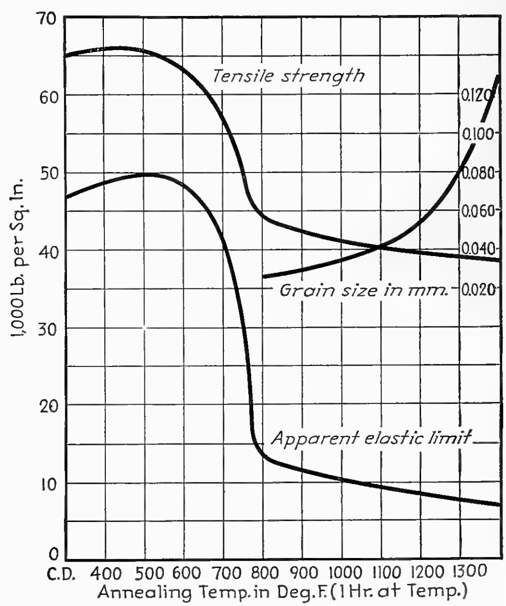


CHART 51.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of rich low-brass rod, previously cold-drawn 37 per cent (reduction of area) from material having a grain size of 0.050 mm. (85.68 % copper) (rod under 1 in. in diameter).

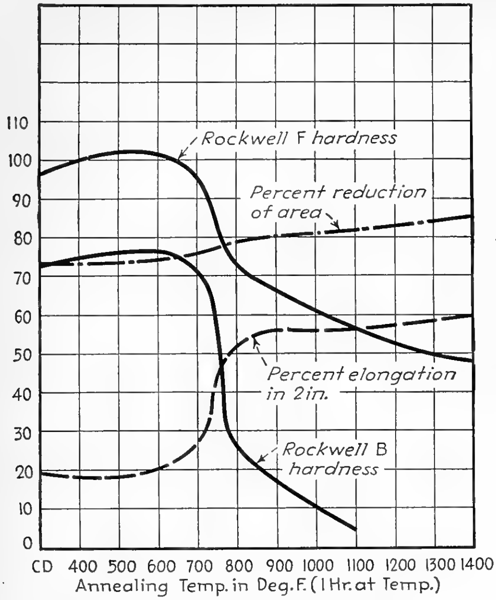


CHART 52.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of rich low-brass rod, previously cold-drawn 37 per cent (reduction of area) from material having a grain size of 0.050 mm. (85.68 % copper) (rod under 1 in. in diameter).

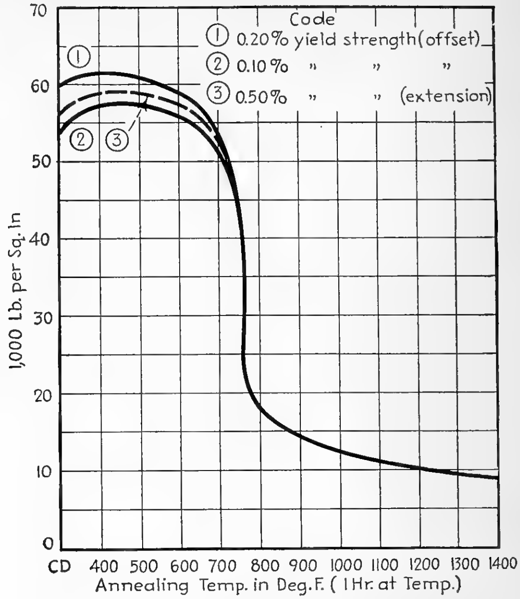


CHART 53.—The effect of annealing on the yield strength of rich low-brass rod, previously cold-drawn 37 per cent (reduction of area) from material having a grain size of 0.050 mm. (85.68 % copper) (rod under 1 in. in diameter).

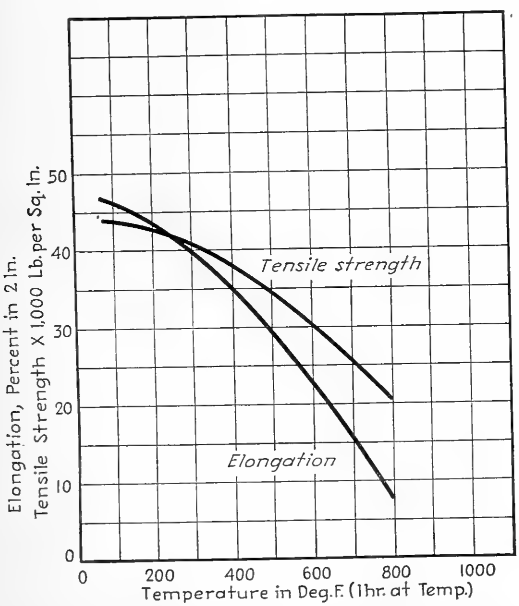


CHART 54.—The effect of elevated temperatures on the tensile strength and percentage elongation in 2 in. of 85-15 brass rod according to W. H. Bassett.[10]

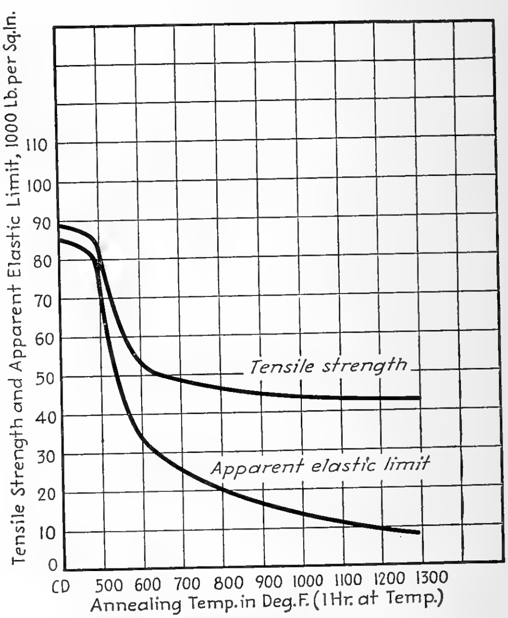


CHART 55.—The effect of annealing on the tensile strength and apparent elastic limit of 85-15 brass condenser tube, previously cold-drawn 65 per cent (reduction of area) from a grain size of 0.050 mm. (85.01 % copper).

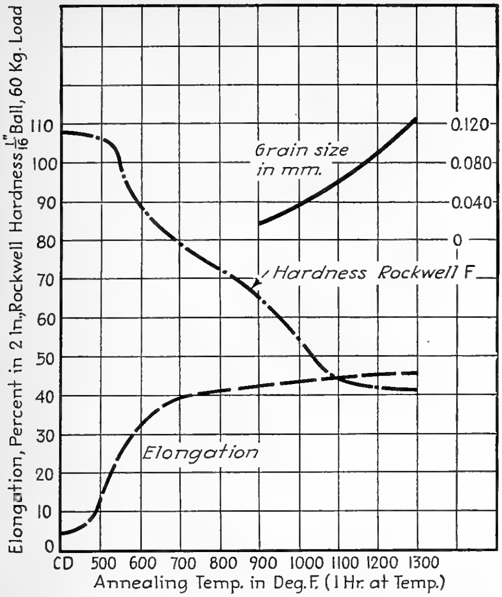


CHART 56.—The effect of annealing on percentage elongation in 2 in., Rockwell hardness, and grain size of 85-15 brass condenser tube, previously cold-drawn 65 per cent (reduction of area) from a grain size of 0.050 mm. (85.01 % copper).

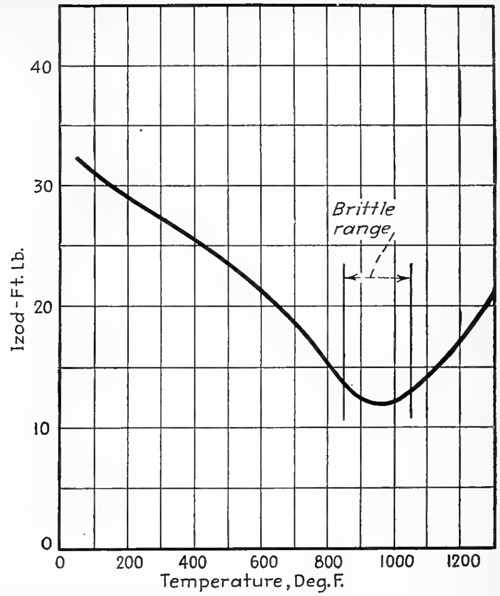


CHART 57.—The effect of elevated temperature on the Izod-impact strength of an annealed 87 % copper-zinc alloy according to D. Bunting.[5]

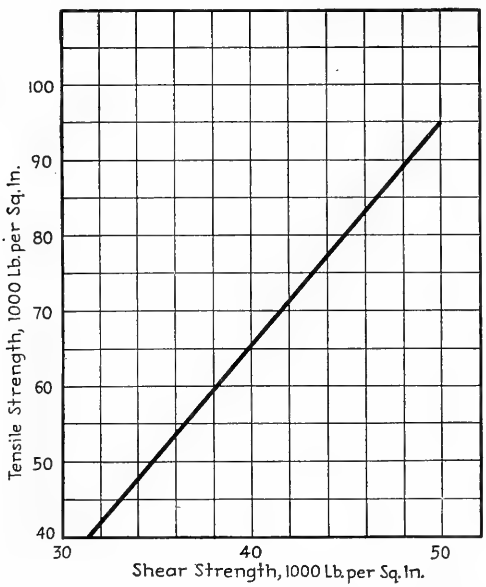


CHART 58.—Conversion chart for determination of shear strength of red brass (85 % copper, balance zinc) when tensile strength is known. Accurate to ±5 %.[86]

TABLE 4
LOW BRASS
General Data—Rod
Copper, 80.95%; lead, trace; tin, trace; zinc, balance

Property	Rod		Forgings		
	Hard[a]	Soft[b]	Hot	Cold[c]	Cold[d]
Tensile strength, p.s.i. (000 omitted)	75	44	42–48	47–80	85
Apparent elastic limit, p.s.i. (000 omitted)	52	9	7–14	20–50	55
Yield strength, 0.5% extension, p.s.i. (000 omitted)	56	13	10–19	25–58	65
Yield strength, 0.2% offset, p.s.i. (000 omitted)	68	13	10–19	25–70	85
Yield strength, 0.1% offset, p.s.i. (000 omitted)	59	12	9–17	20–65	80
Elongation, % in 2 in.	18	65	65–58	30–15	15
Reduction of area, %	70	80	82–80	80–65	60
Endurance limit, p.s.i. (000 omitted)	22	15			
Rockwell hardness F, 1/16-in. ball, 60-kg. load	103	60	45–70	70–104	105
Rockwell hardness B, 1/16-in. ball, 100-kg. load	80	9	24	81	82
Brinell hardness, 10-mm. ball, 500-kg. load	130	56	63	63–133	135
Modulus of elasticity, p.s.i.	15,000,000				
Forging range, °F.	1250–1450				
Forging quality	Good				
Type structure	Single phase, alpha				

General Data—Strip[e]
Copper, 80.41%; lead, trace; iron, trace; tin, nil; zinc, balance

Property	Hard[f]	Soft[g]
Tensile strength, p.s.i. (000 omitted)	91	46
Elongation, % in 2 in.	6	49
Apparent elastic limit, p.s.i. (000 omitted)	69	13
Yield strength, 0.5% extension, p.s.i. (000 omitted)	65	14
Yield strength, 0.2% offset, p.s.i. (000 omitted)	74	14
Yield strength, 0.1% offset, p.s.i. (000 omitted)	61	14
Rockwell hardness F, 1/16-in. ball, 60-kg. load	108	60
Rockwell hardness B, 1/16-in. ball, 100-kg. load	88	2
Rockwell hardness G, 1/16-in. ball, 150-kg. load	63	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	89	62
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	75	17

General Data—Tube
Copper, 79.74%; zinc, balance; lead, trace; iron, trace; tin, nil

Property	Hard[h]	Soft[i]
Tensile strength, p.s.i. (000 omitted)	98	48
Elongation, % in 2 in.	2	43
Apparent elastic limit, p.s.i. (000 omitted)	76	19
Rockwell hardness F, 1/16-in. ball, 60-kg. load	109	58

Physical Data

Melting point, °F.	1832
Coefficient of expansion, per °C. from 25–300°C.	0.0000191
Electrical conductivity,[87] % I.A.C.S., 68°F.	32
Thermal conductivity,[87] B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	81
Density, lb. per cu. in.	0.313

[a] Refers to rod cold-drawn 37%; rod under 1 in. in diameter with a ready-to-finish grain size, 0.050 mm.
[b] Refers to a 1100°F. anneal (1 hr.).
[c] Material cold-forged from soft rod (5–40% reduction of area).
[d] Material cold-forged from cold-worked condition (40%).
[e] Apply to strip only (all tests conducted on 0.040-in. stock).
[f] 6 B. & S. Nos., 0.015 mm. grain size at ready-to-finish.
[g] Cold-rolled 4 B. & S. Nos.; refer to 1000°F. anneal.
[h] Cold-drawn to 13/16 by 0.049 in.
[i] Refers to 1000°F. anneal.

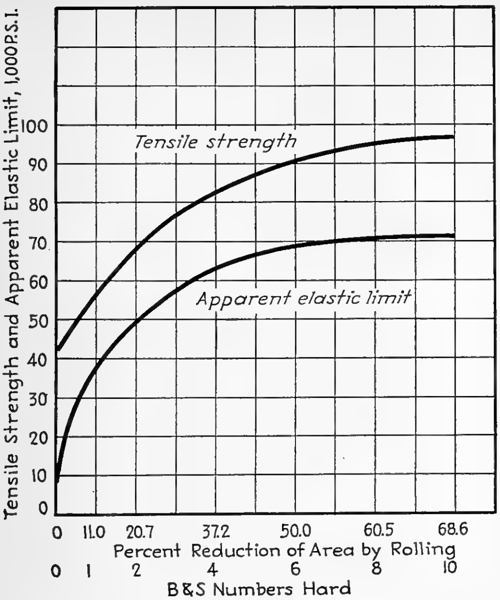


CHART 59.—The effect of cold rolling on the tensile strength and apparent elastic limit of low-brass (80-20) strip, previously annealed to a grain size of 0.020 mm. (80.41 % copper) (0.040-in. stock).

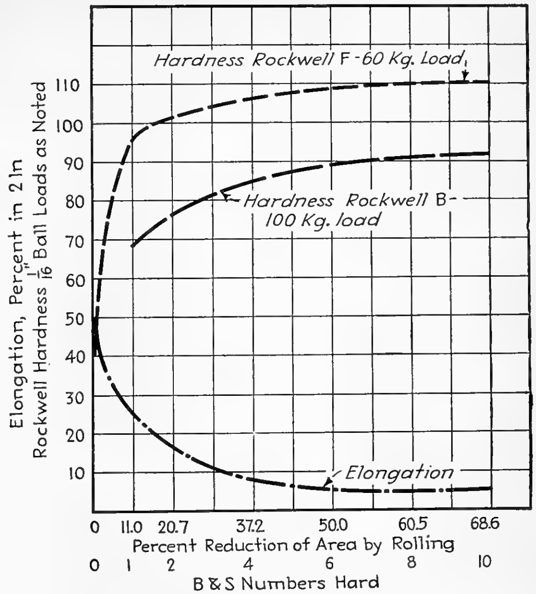


CHART 60.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of low-brass (80-20) strip, previously annealed to a grain size of 0.020 mm. (80.41 % copper) (0.040-in. stock).

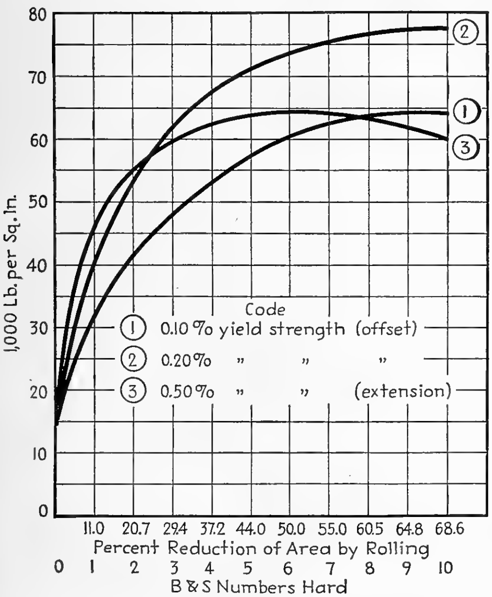


CHART 61.—The effect of cold rolling on the yield strength of low-brass (80-20) strip, previously annealed to a grain size of 0.020 mm. (80.41 % copper) (0.040-in. stock).

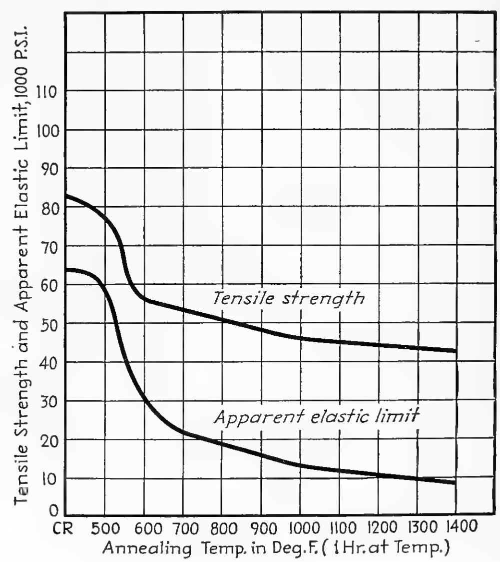


CHART 62.—The effect of annealing on the tensile strength and apparent elastic limit of low-brass (80-20) strip, previously cold-rolled 4 B. & S. Nos. (37 per cent reduction of area) from a grain size of 0.020 mm. (80.41 % copper) (0.040-in. stock).

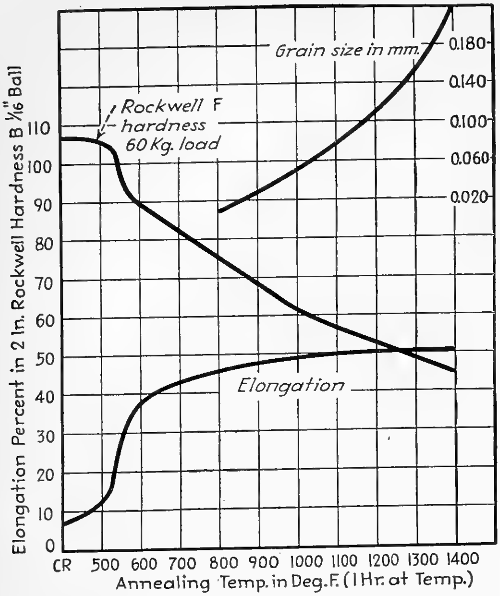


Chart 63.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and grain size of low-brass (80-20) strip, previously cold-rolled 4 B. & S. Nos. (37 per cent reduction of area) from a grain size of 0.020 mm. (80.41 % copper) (0.040-in. stock).

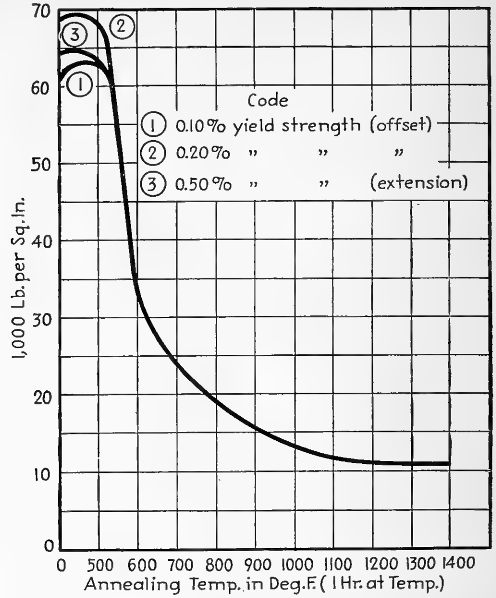


Chart 64.—The effect of annealing on the yield strength of low-brass (80-20) strip, previously cold-rolled 4 B. & S. Nos. (37 per cent reduction of area) from a grain size of 0.020 mm. (80.41 % copper) (0.040-in. stock).

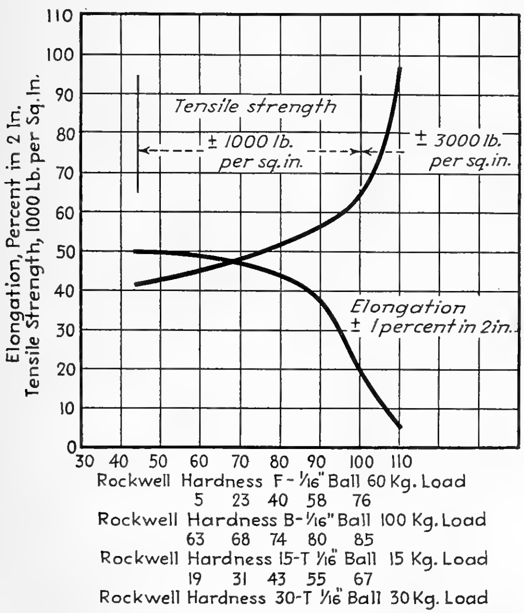


Chart 65.—This chart can be employed to determine the approximate tensile strength and percentage elongation of low-brass (80-20) strip (80.41 % copper) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

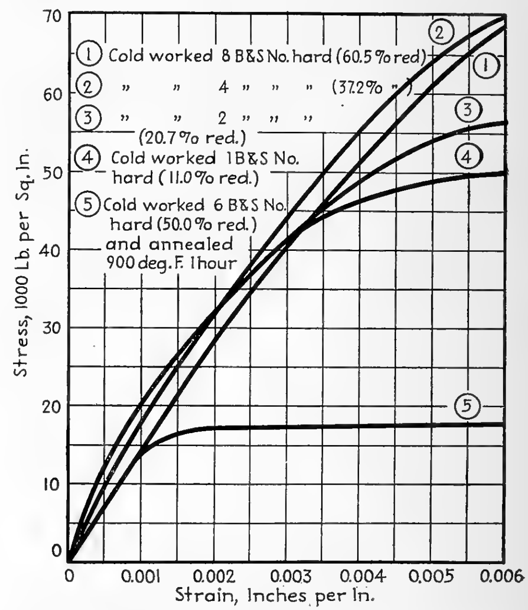


Chart 66.—The effect of cold working on the stress-strain characteristics of low-brass (80-20) strip (0.040 in. thick) having a ready-to-finish grain size of 0.020 mm. (80.41 % copper); 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used.

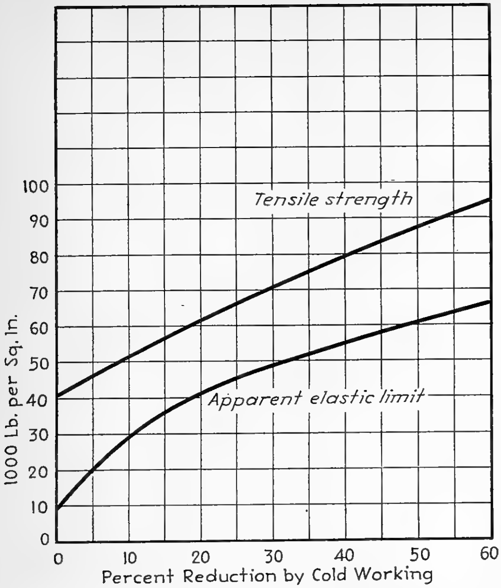


CHART 67.—The effect of cold drawing on the tensile strength and apparent elastic limit of low-brass rod, previously annealed to a grain size of 0.060 mm. (80.95 % copper) (rod under 1 in. in diameter).

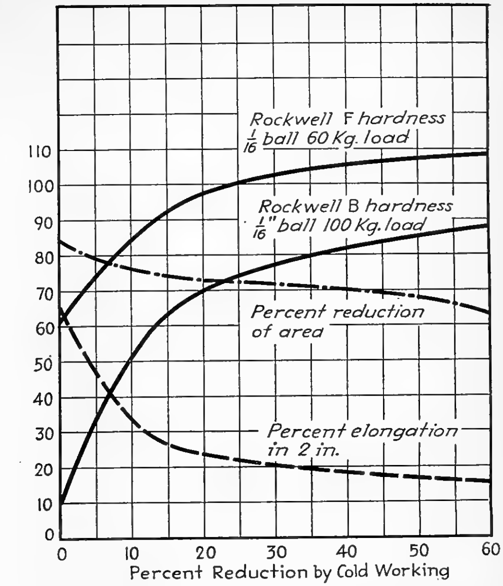


CHART 68.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of low-brass rod, previously annealed to a grain size of 0.060 mm. (80.95 % copper) (rod under 1 in. in diameter).

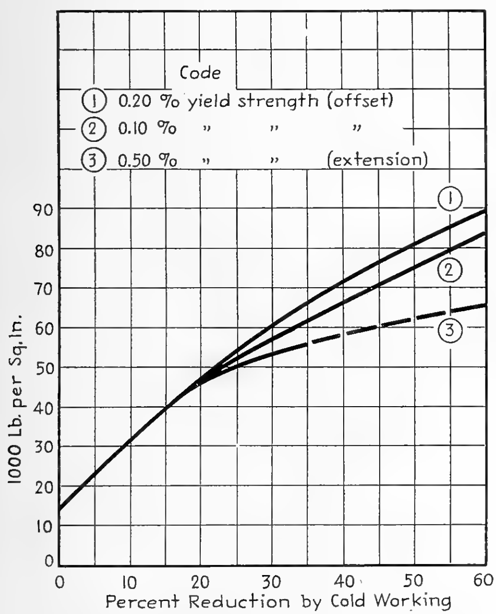


CHART 69.—The effect of cold drawing on the yield strength of low-brass rod, previously annealed to a grain size of 0.060 mm. (80.95 % copper) (rod under 1 in. in diameter).

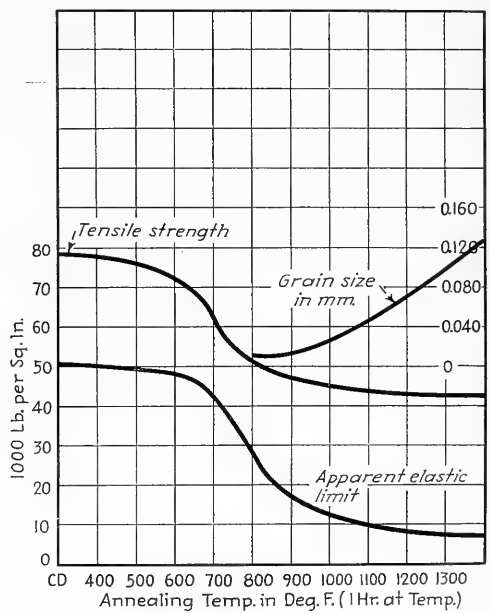


CHART 70.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of low-brass rod, previously cold-drawn 37 per cent (reduction of area) from material having a grain size of 0.060 mm. (80.95 % copper) (rod under 1 in. in diameter).

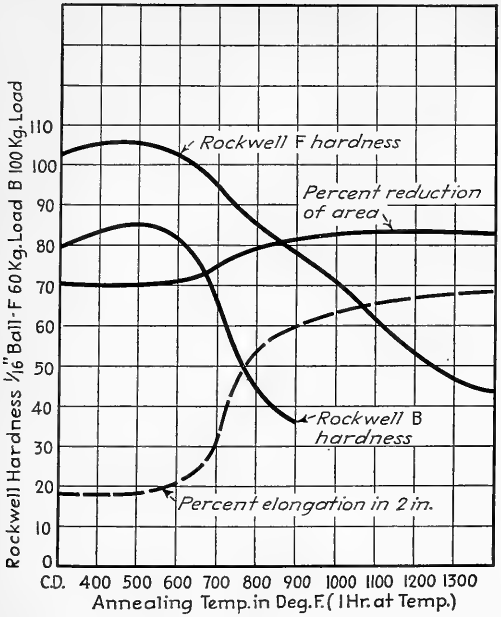


CHART 71.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of low-brass rod, previously cold-drawn 37 per cent (reduction of area) from material having a grain size of 0.060 mm. (80.95 % copper) (rod under 1 in. in diameter).

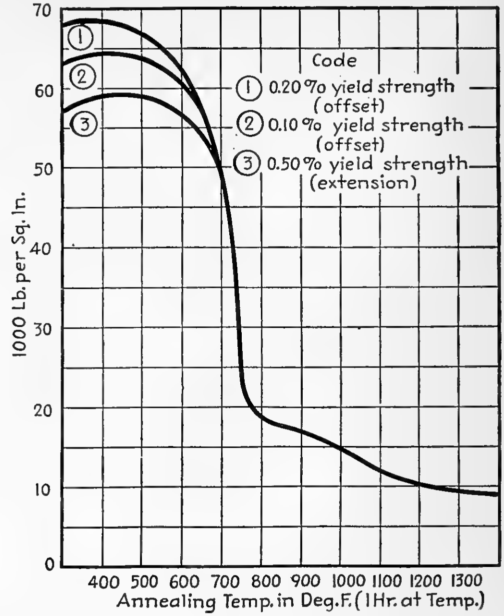


CHART 72.—The effect of annealing on the yield strength of low-brass rod, previously cold-drawn 37 per cent (reduction of area) from material having a grain size of 0.060 mm. (80.95 % copper) (rod under 1 in. in diameter).

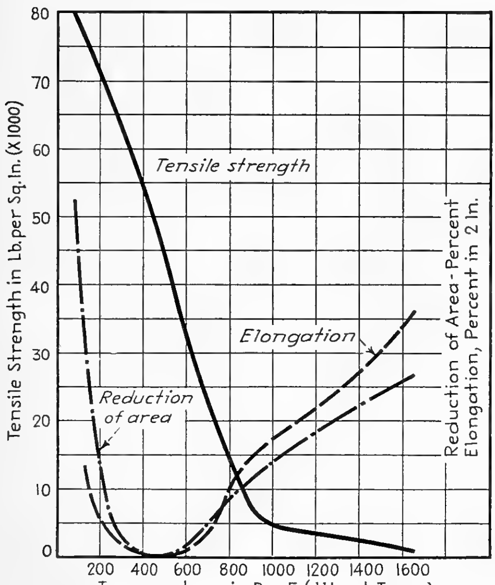


CHART 73.—The effect of elevated temperature on tensile strength, percentage reduction of area, and percentage elongation in 2 in. of 80-20 (low-brass) rod (80.12 % copper), previously cold-worked 30 per cent (reduction of area) according to W. B. Price.[7]

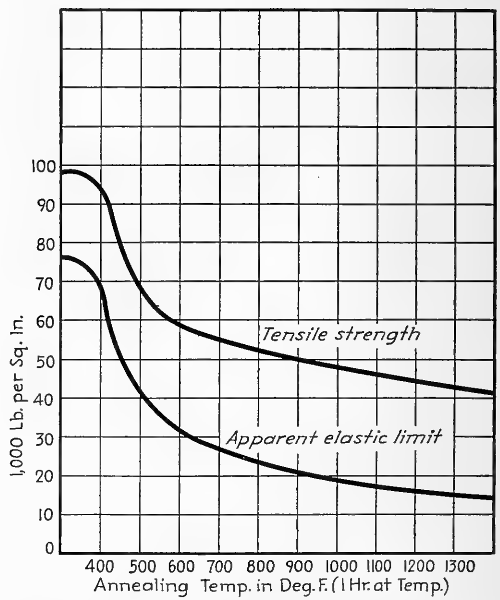


CHART 74.—The effect of annealing on the tensile strength and apparent elastic limit of 80-20 (low-brass) tubing, previously cold-worked 70 per cent (reduction of area) from a grain size of 0.025 mm. (79.74 % copper).

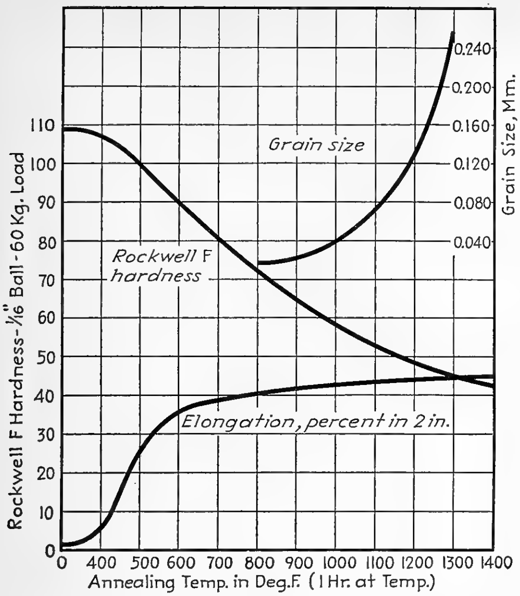


CHART 75.—The effect of annealing on the percentage elongation in 2 in., Rockwell hardness, and grain size of 80-20 (low-brass) tubing, previously cold-worked 70 per cent (reduction of area) from a grain size of 0.025 mm. (79.74 % copper).

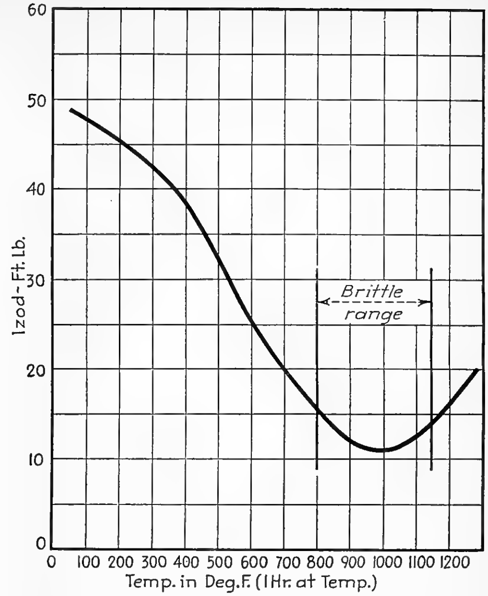


CHART 76.—The effect of elevated temperature on the Izod-impact strength of previously annealed 80-20 (low-brass) according to D. Bunting.[5]

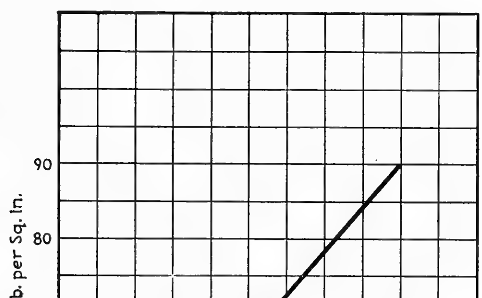


CHART 77.—Conversion chart for determination of shear strength of low brass (80 % copper, balance zinc) when tensile strength is known. Accurate to ± 5 %.[86]

TABLE 5
SPRING BRASS
GENERAL DATA—STRIP[a]
Copper, 74.69%; lead, trace; iron, trace; zinc, balance

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	84–97	45–49
Elongation, % in 2 in.	5–7	58–66
Apparent elastic limit, p.s.i. (000 omitted)	64–68	6–13
Yield strength, 0.5% extension, p.s.i. (000 omitted)	61–67	15–17
Yield strength, 0.2% offset, p.s.i. (000 omitted)	73–82	15–17
Yield strength, 0.1% offset, p.s.i. (000 omitted)	67–73	15–17
Endurance limit, p.s.i. (000 omitted)	21	17
Rockwell hardness F, 1/16-in. ball, 60-kg. load	107–110	57–61
Rockwell hardness B, 1/16-in. ball, 100-kg. load	86–93	2–7
Rockwell hardness G, 1/16-in. ball, 150-kg. load	59–71	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	89–91	62–63
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	74–78	17–20
Young's modulus of elasticity, p.s.i.	15,000,000	
Melting point, °F.	1795	
Density, lb. per cu. in.	0.310	
Coefficient of expansion, per °C. from 25–300°C.	0.0000196	
Electrical conductivity, % I.A.C.S. at 20°C, 68°F.	30.0	
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	75	

[a] All tests conducted on 0.040-in. stock.
[b] 6 B. & S. Nos., hard, 0.095–0.015 mm. grain size at ready-to-finish, respectively.
[c] 1300°F. anneal for 1 hr.

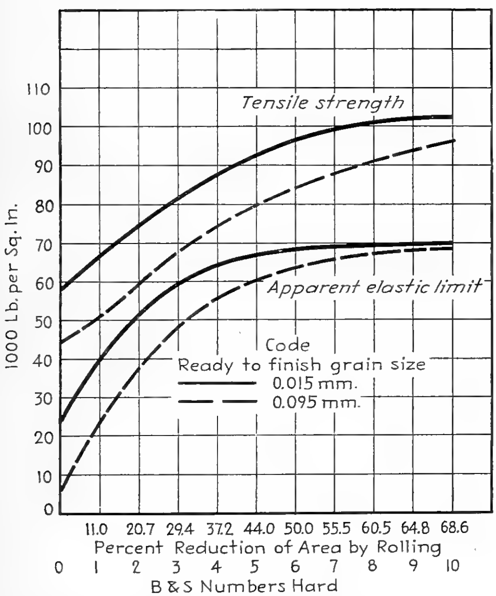


CHART 78.—The effect of cold rolling on the tensile strength and apparent elastic limit of spring-brass strip, previously annealed to two different grain sizes, 0.015 and 0.095 mm. (74.69 % copper) (0.040-in. stock).

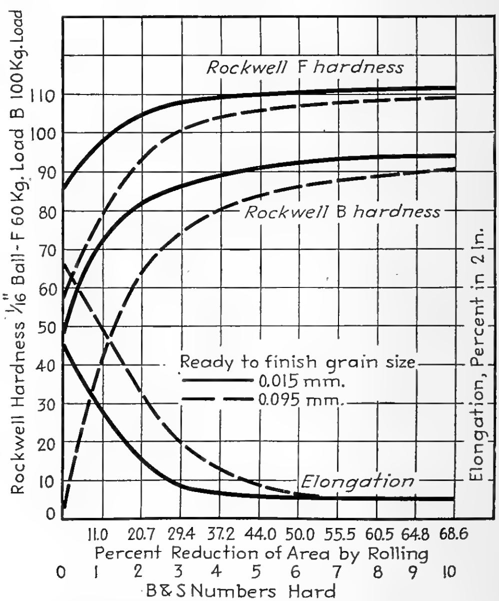


CHART 79.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of spring-brass strip, previously annealed to two different grain sizes, 0.015 and 0.095 mm. (74.69 % copper) (0.040-in. stock).

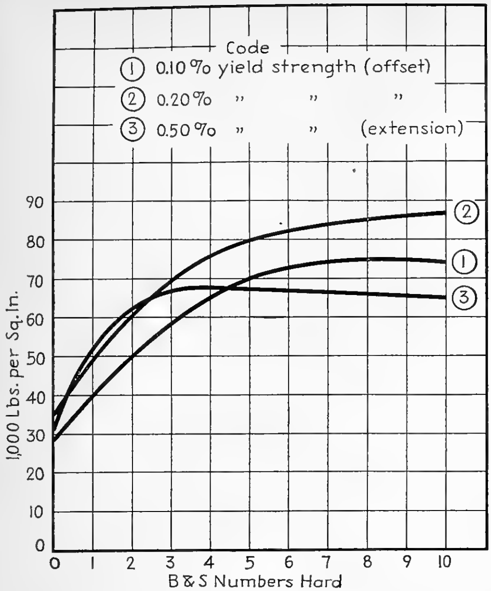


CHART 80.—The effect of cold rolling on the yield strengths of spring-brass strip, previously annealed to a grain size of 0.015 mm. (74.69 % copper) (0.040-in. stock).

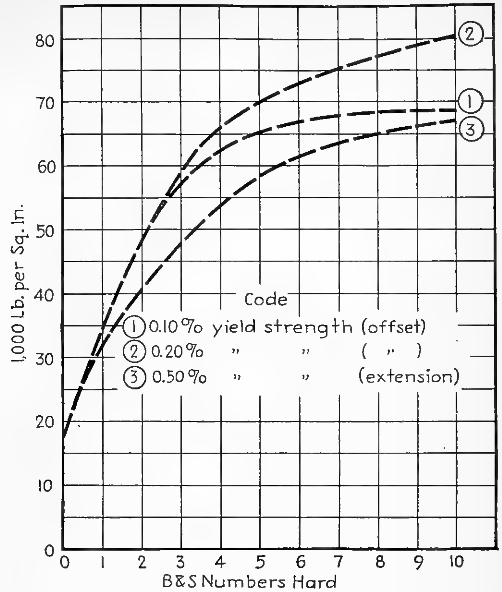


CHART 81.—The effect of cold rolling on the yield strengths of spring brass, previously annealed to a grain size of 0.095 mm. (74.69 % copper) (0.040-in. stock).

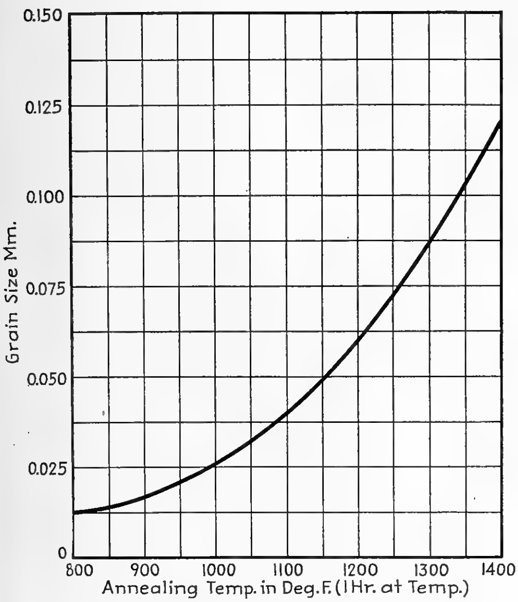


CHART 82.—The effect of annealing on the grain-growing characteristics of spring-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.095 mm. (74.69 % copper) (0.040-in. stock).

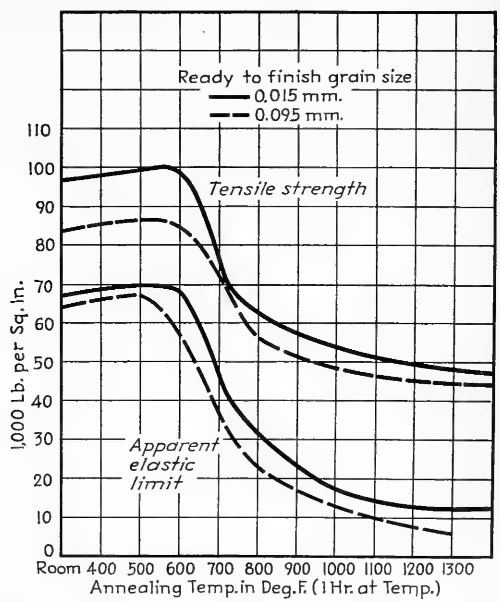


CHART 83.—The effect of annealing on the tensile strength and apparent elastic limit of spring-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 mm. and 0.095 mm. (74.69 % copper) (0.040-in. stock).

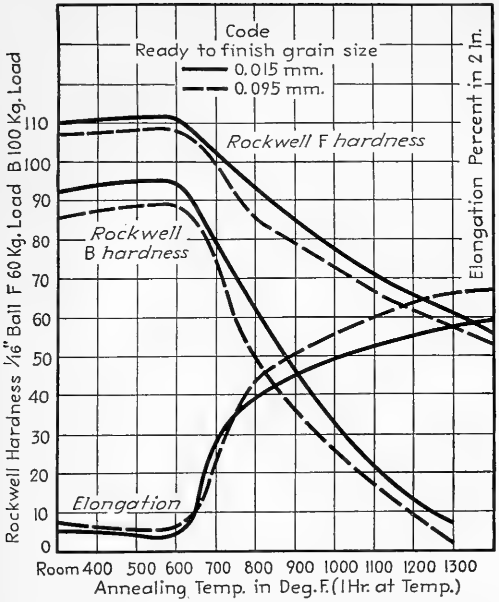


CHART 84.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of spring-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.095 mm. (74.69 % copper) (0.040-in. stock).

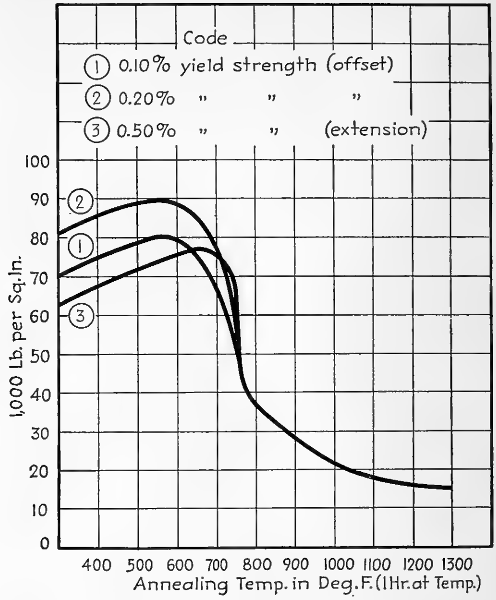


CHART 85.—The effect of annealing on the yield strength of spring-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (74.69 % copper) (0.040-in. stock).

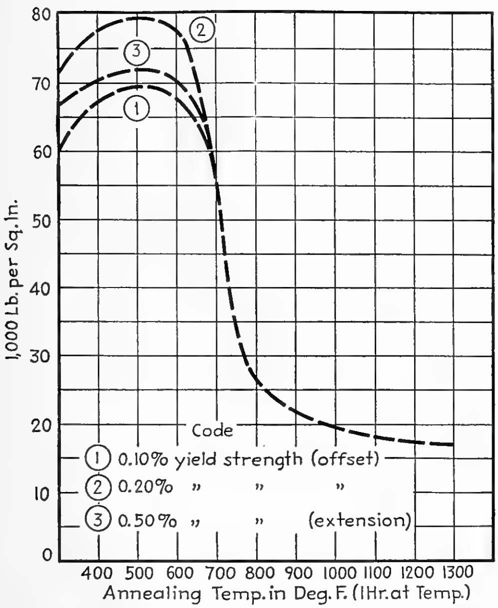


CHART 86.—The effect of annealing on the yield strength of spring-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.095 mm. (74.69 % copper) (0.040-in. stock).

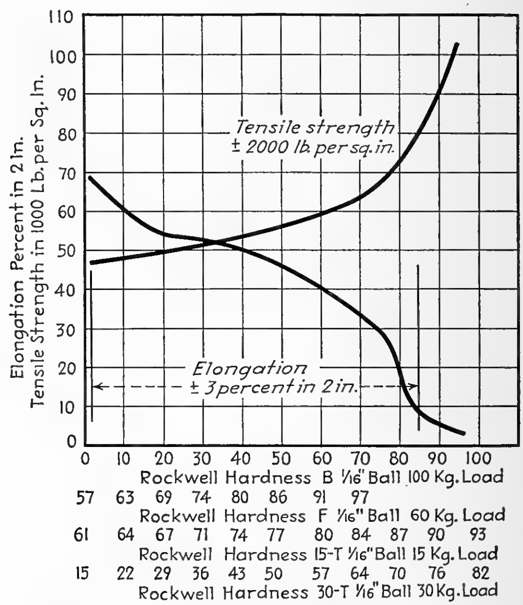


CHART 87.—This chart can be employed to determine the approximate tensile strength and percentage elongation of spring-brass strip (74.69 % copper) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

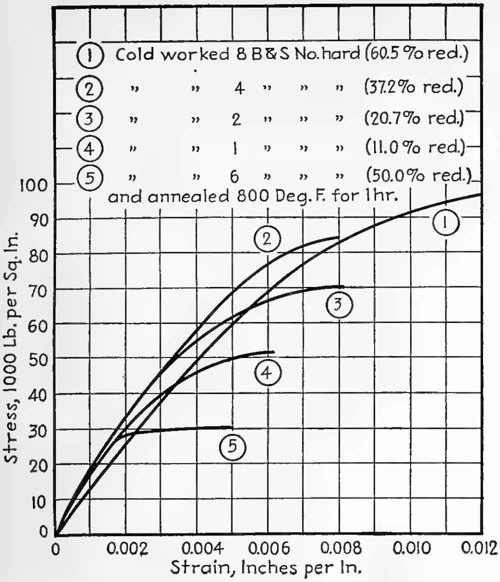


CHART 88.—The effect of cold rolling on the stress-strain characteristics of special spring-brass strip (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm. (74.69 % copper); 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used.

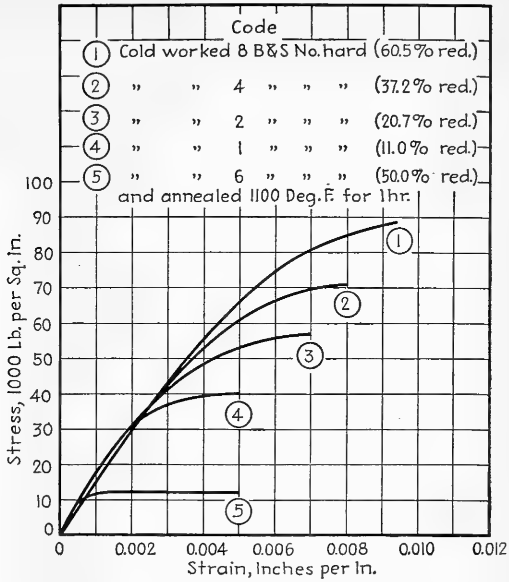


CHART 89.—The effect of cold rolling on the stress-strain characteristics of special spring-brass strip (0.040 in. thick) having a ready-to-finish grain size of 0.095 mm. (74.69 % copper); 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used.

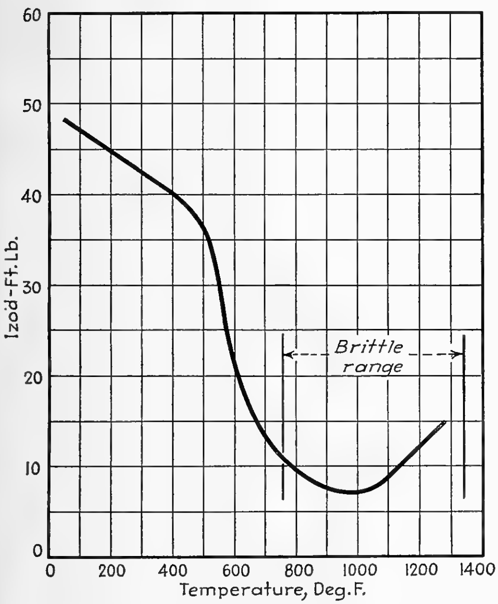


CHART 90.—The effect of temperature on the Izod-impact strength of previously annealed spring brass (75.00 % copper) according to D. Bunting.[6]

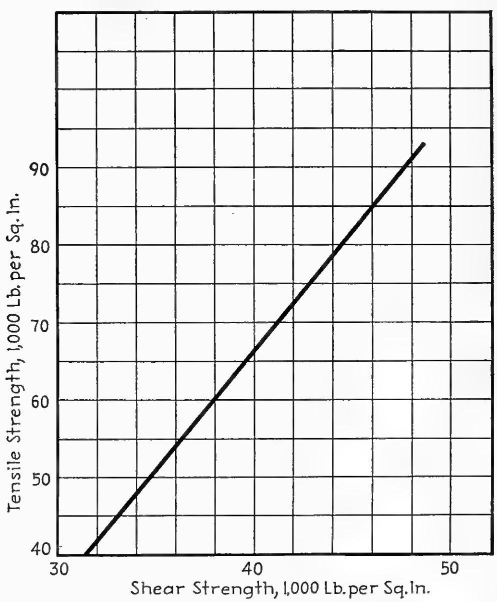


CHART 91.—Conversion chart for determination of shear strength of spring brass (75.00 % copper, balance zinc) when tensile strength is known. Accurate to ±5 %.[86]

TABLE 6

70–30 OR CARTRIDGE BRASS

GENERAL DATA—ROD

Copper, 70.26%; lead, nil; iron, nil; tin, nil; zinc, balance

Property	Rod		Forgings	
	Hard[a]	Soft[b]	Cold[c]	Cold[d]
Tensile strength, p.s.i. (000 omitted)	100	48	55–90	98
Apparent elastic limit, p.s.i. (000 omitted)	67	22	28–60	65
Yield strength, 0.5% extension, p.s.i. (000 omitted)	64	38	42–60	64
Yield strength, 0.2% offset, p.s.i. (000 omitted)	75	38	42–70	74
Yield strength, 0.1% offset, p.s.i. (000 omitted)	63	34	37–62	62
Elongation, % in 2 in.	14	55	50–15	
Reduction of area, %	60	75	73–62	
Endurance limit, p.s.i. (000 omitted)	22	17		
Rockwell hardness F, 1/16-in. ball, 60-kg. load	108	75	88–105	108
Rockwell hardness B, 1/16-in. ball, 100-kg. load	89	34	56–85	89
Brinell hardness, 10-mm. ball, 500-kg. load	154	70	90–142	154
Modulus of elasticity, p.s.i.	15,000,000			

GENERAL DATA—STRIP

Copper, 69.83%; lead, nil; iron, trace; zinc, balance

Property	Hard[e]	Soft[b]
Tensile strength, p.s.i. (000 omitted)[g]	86–97	45–48
Elongation, % in 2 in.[g]	4	48–64
Apparent elastic limit, p.s.i. (000 omitted)[g]	69–81	13
Yield strength, 0.5% extension, p.s.i. (000 omitted)[g]	67	13
Yield strength, 0.2% offset, p.s.i. (000 omitted)[g]	77–86	13
Yield strength 0.1% offset, p.s.i. (000 omitted)[g]	69–74	13
Rockwell hardness F, 1/16-in. ball, 60-kg. load[g]	108–111	60–61
Rockwell hardness B, 1/16-in. ball, 100-kg. load[g]	88–93	11–13
Rockwell hardness G, 1/16-in. ball, 150-kg. load[g]	63–71	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load[g]	89–91	64–65
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load[g]	75–78	23–24
Endurance Limit[g] (at 10^8 reversals):[1,6]		
Soft, p.s.i. (000 omitted)	16.5	
4 B. & S. Nos., hard, p.s.i. (000 omitted)	19.0	
8 B. & S. Nos., hard, p.s.i. (000 omitted)	22.0	
Young's modulus of elasticity, p.s.i.	15,000,000	

GENERAL DATA—TUBE

Copper, 69.74%; lead, trace; iron, trace; zinc, balance

Property	Hard[h]	Soft[i]
Tensile strength, p.s.i. (000 omitted)	95	51
Elongation, % in 2 in.	7	52
Apparent elastic limit, p.s.i. (000 omitted)	90	13
Rockwell hardness F, 1/16-in. ball, 60-kg. load	110	59

PHYSICAL DATA

Melting point, °F	1750
Coefficient of expansion, per °C. from 25–300°C.	0.0000199
Electrical conductivity, % I.A.C.S,[87] 68°F.	27.3
Thermal conductivity,[87] B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	70
Density	0.308
Type structure	Single phase, alpha

TABLE 6 (*Continued*)

AVAILABLE CREEP DATA[(3)]

Previous history: hot-rolled to 0.875 in. diameter, cold-drawn to 0.750 in. diameter.

Temperature °F.	No measurable flow	Stress, p.s.i., required to produce designated rate of creep per 1,000 hr.		
		0.01%	0.10%	1.00%
400	10,000	12,700	18,000	27,000
600	Approaches zero	290	850	2,150
800	Approaches zero		Approaches zero	

[a] Refers to rod under 1 in. in diameter and rod cold-drawn 50% with a ready-to-finish grain size, 0.045 mm.
[b] Refers to a 1100°F. anneal (1 hr.)
[c] Material cold-forged from soft rod (5–40% reduction of area).
[d] Material cold-forged from cold-worked condition (40%).
[e] 6 B. & S. Nos., hard, 0.070–0.015 grain size at ready-to-finish, respectively.
[f] Refers to 1100°F. anneal (1 hr. at temperature).
[g] Apply to strip only (all tests conducted on 0.040-in. stock).
[h] Extruded, reduced, and cold-drawn to ¾ by 0.049 in.
[i] 1000°F. anneal for 1 hr.

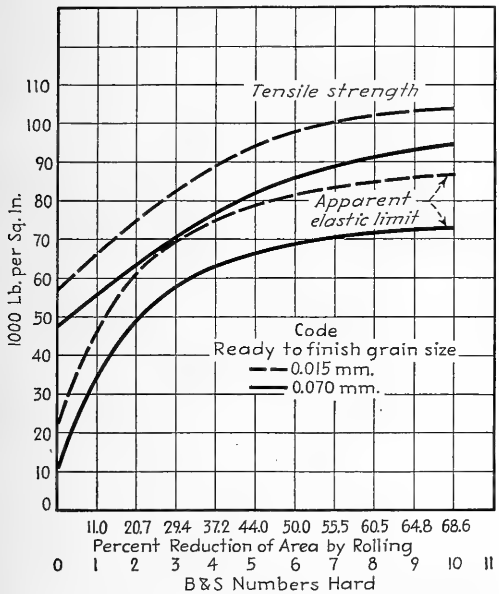


CHART 92.—The effect of cold rolling on the tensile strength and apparent elastic limit of 70-30 (cartridge brass) strip, previously annealed to two different grain sizes, 0.015 and 0.070 mm. (69.83% copper) (0.040-in. stock).

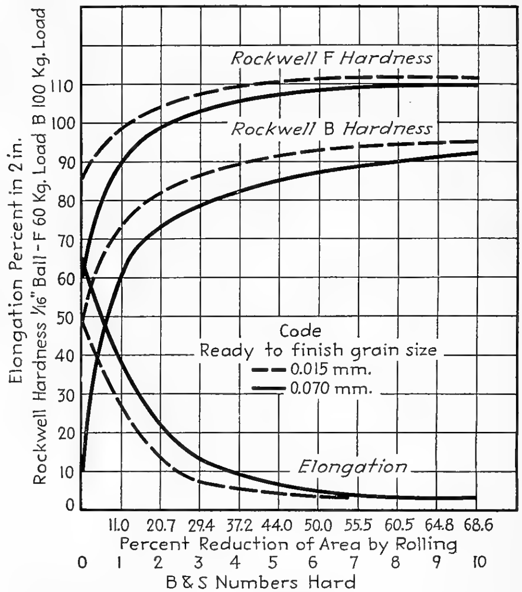


CHART 93.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of 70-30 (cartridge brass) strip, previously annealed to two different grain sizes, 0.015 and 0.070 mm. (69.83% copper) (0.040-in. stock).

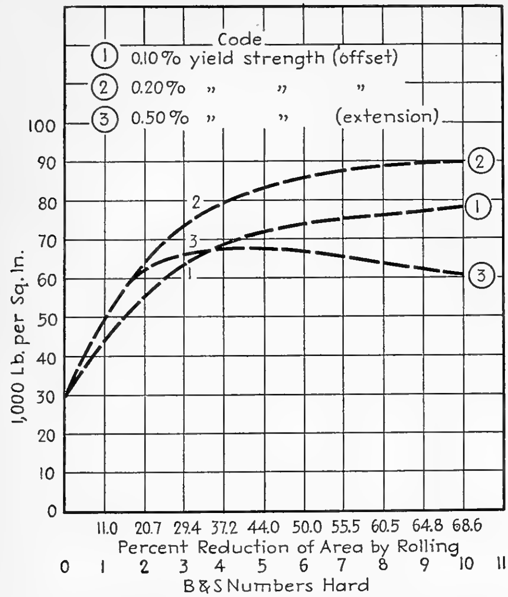


CHART 94.—The effect of cold rolling on the yield strengths of 70-30 (cartridge brass) strip, previously annealed to a grain size of 0.015 mm. (69.83 % copper) (0.040-in. stock).

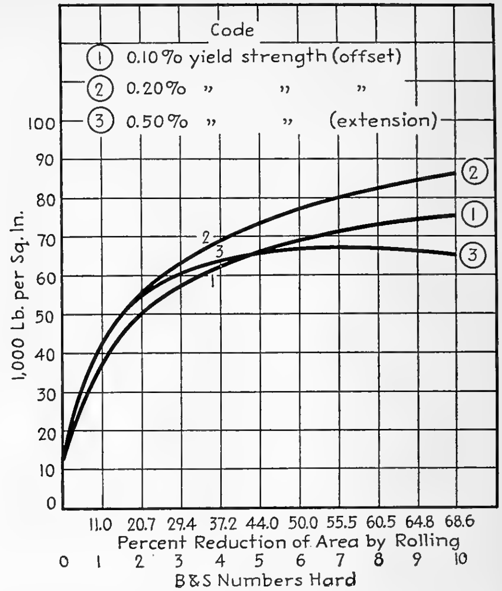


CHART 95.—The effect of cold rolling on the yield strengths of 70-30 (cartridge brass) strip, previously annealed to a grain size of 0.070 mm. (69.83 % copper) (0.040-in. stock).

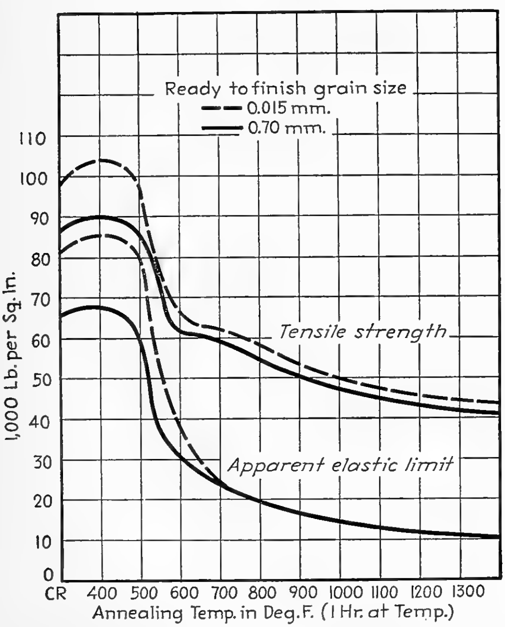


CHART 96.—The effect of annealing on the tensile strength and apparent elastic limit of 70-30 (cartridge brass) strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 mm. and 0.070 mm. (69.83 % copper) (0.040-in. stock).

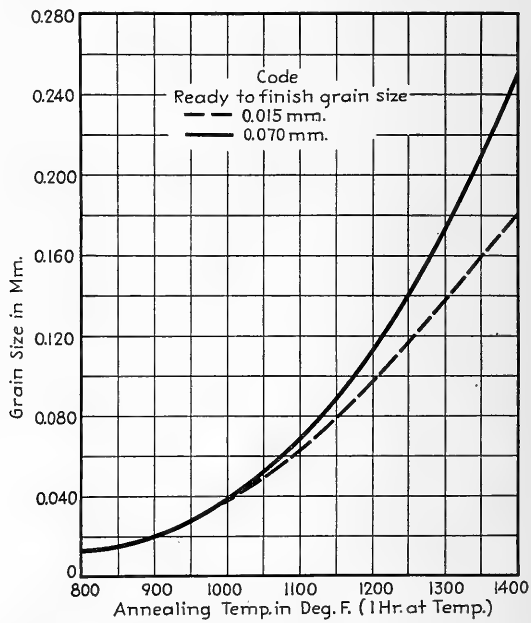


CHART 97.—The effect of annealing on the grain-growing characteristics of 70-30 (cartridge brass) strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (69.83 % copper) (0.040-in. stock).

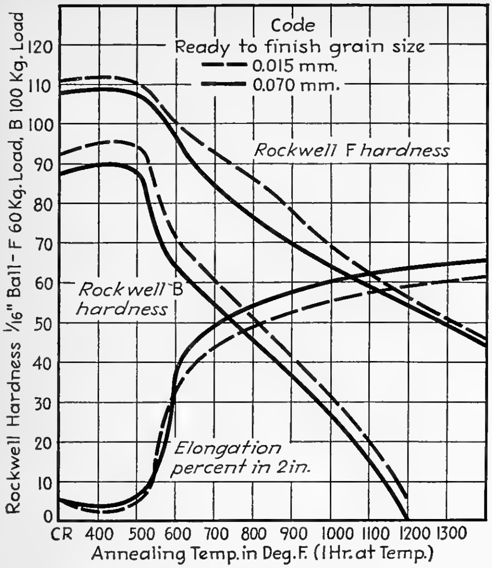


CHART 98.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of 70-30 (cartridge brass) strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (69.83 % copper) (0.040-in. stock).

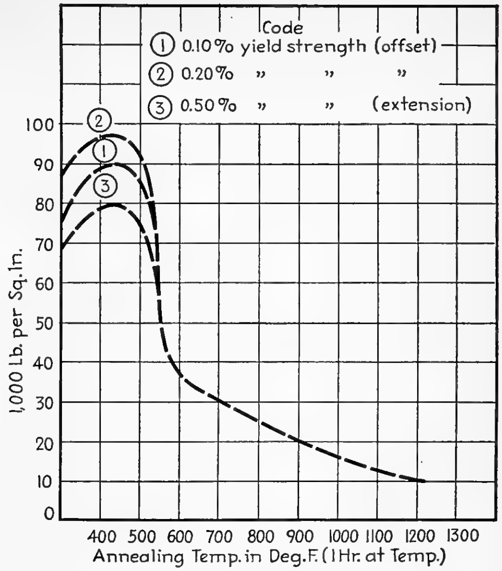


CHART 99.—The effect of annealing on the yield strength of 70-30 (cartridge brass) strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (69.83 % copper) (0.040-in. stock).

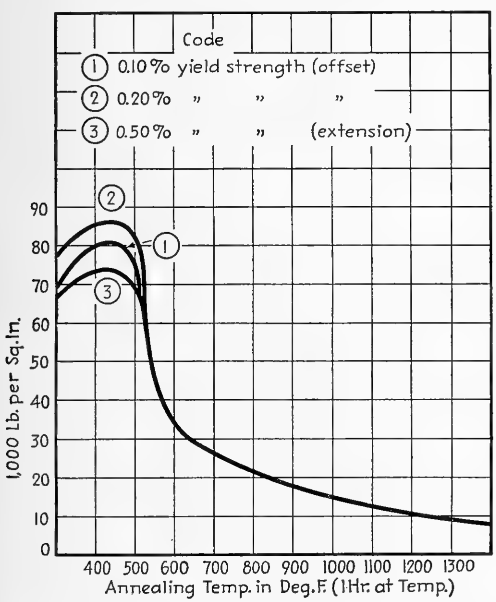


CHART 100.—The effect of annealing on the yield strength of 70-30 (cartridge brass) strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.070 mm. (69.83 % copper) (0.040-in. stock).

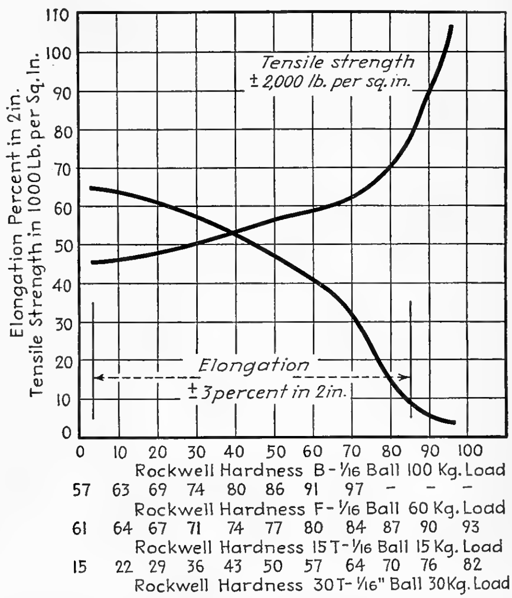


CHART 101.—This chart can be employed to determine the approximate tensile strength and percentage elongation of 70-30 (cartridge brass) strip (69.83 % copper) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

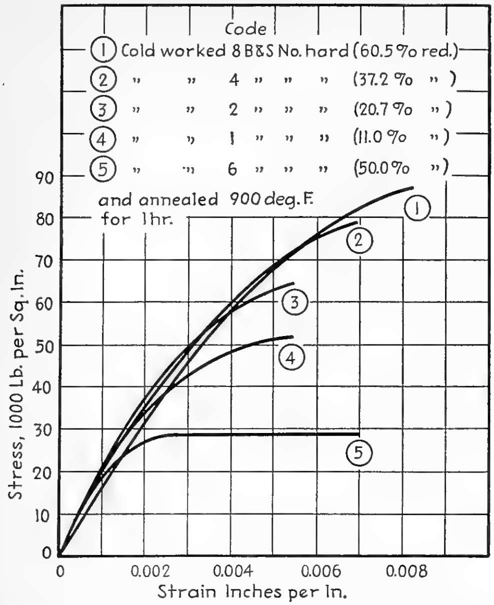


CHART 102.—The effect of cold working on the stress-strain characteristics of 70-30 (cartridge brass) strip (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm. (69.83 % copper); 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used.

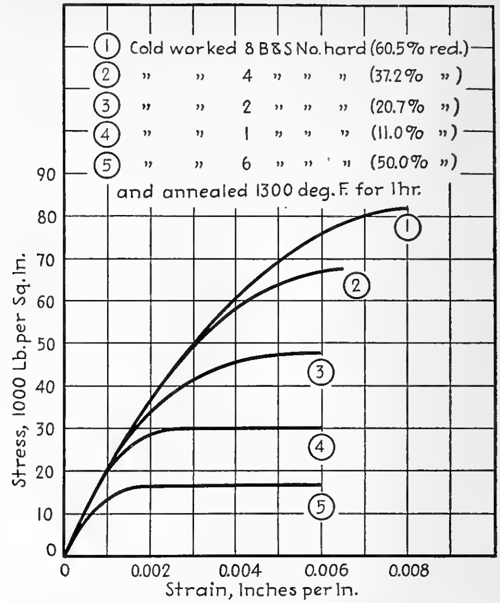


CHART 103.—The effect of cold working on the stress-strain characteristics of 70-30 (cartridge brass) strip (0.040 in. thick) having a ready-to-finish grain size of 0.070 mm. (69.83 % copper); 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used.

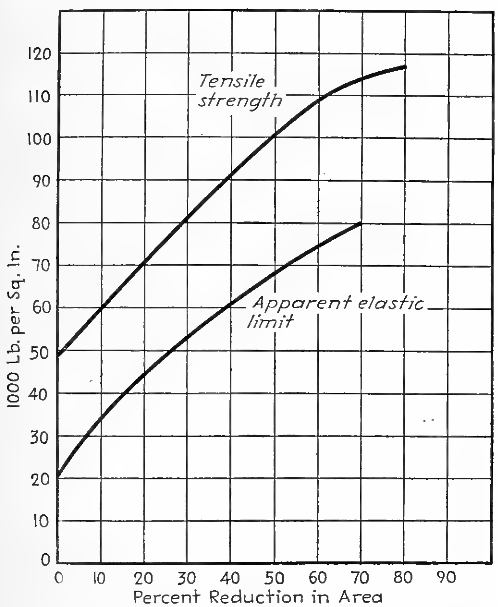


CHART 104.—The effect of cold drawing on the tensile strength and apparent elastic limit of 70-30 (cartridge brass) rod, previously annealed to a grain size of 0.045 mm. (70.26 % copper) (rod under 1 in. in diameter).

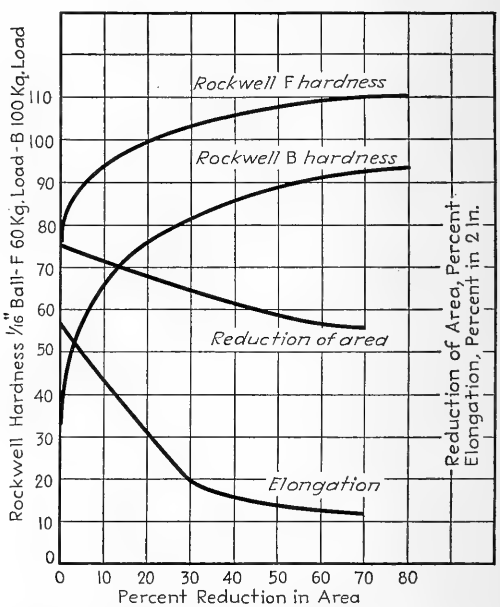


CHART 105.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of 70-30 (cartridge brass) rod, previously annealed to a grain size of 0.045 mm. (70.26 % copper) (rod under 1 in. in diameter).

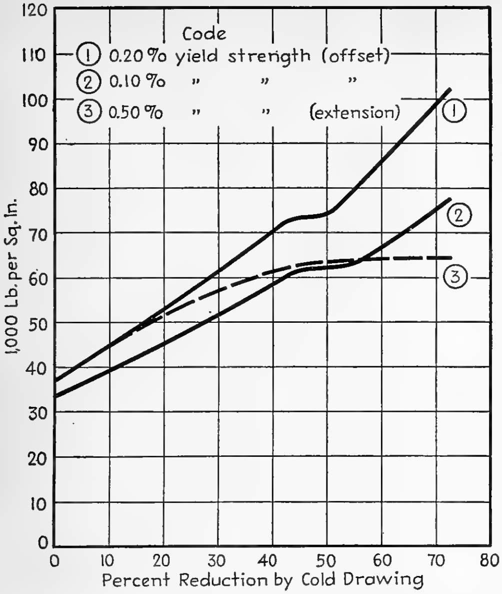


CHART 106.—The effect of cold drawing on the yield strength of 70-30 (cartridge brass) rod, previously annealed to a grain size of 0.045 mm. (70.26 % copper) (rod under 1 in. in diameter).

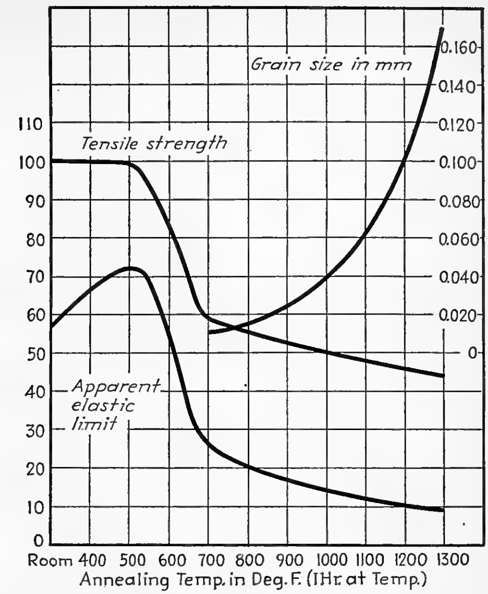


CHART 107.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of 70-30 (cartridge brass) rod, previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.045 mm. (70.26 % copper) (rod under 1 in. in diameter).

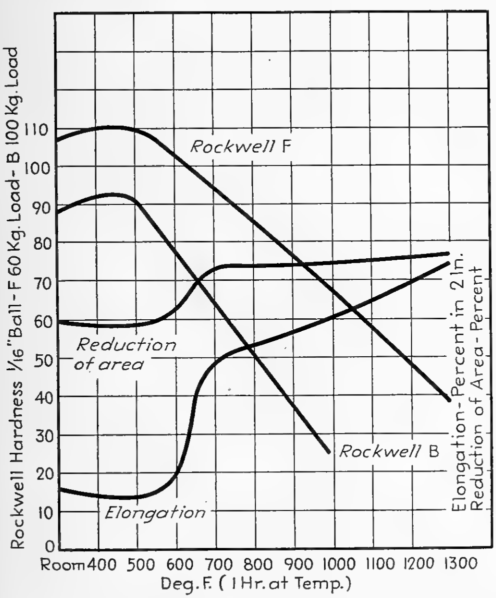


CHART 108.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of 70-30 (cartridge brass) rod, previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.045 mm. (70.26 % copper) (rod under 1 in. in diameter).

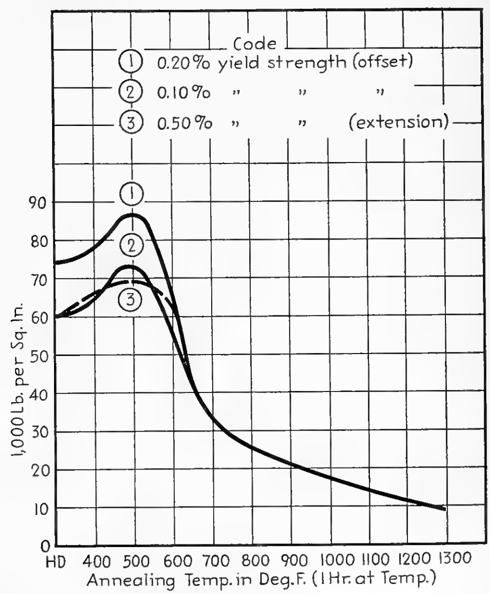


CHART 109.—The effect of annealing on the yield strength of 70-30 (cartridge brass) rod, previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.045 mm. (70.26 % copper) (rod under 1 in. in diameter).

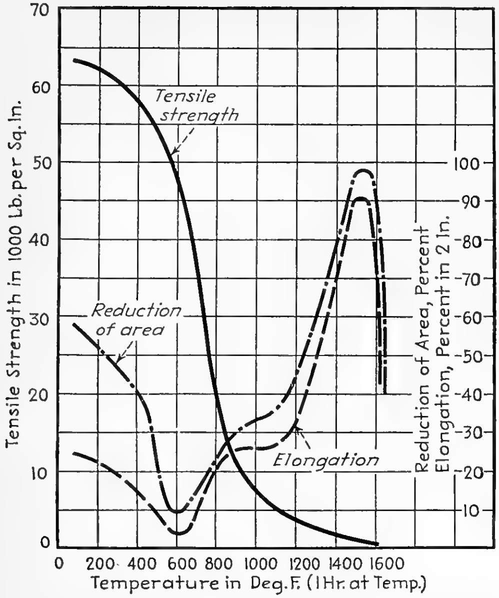


CHART 110.—The effect of elevated temperature on the tensile strength, reduction of area, and percentage elongation in 2 in. of 70-30 (cartridge brass) rod, previously cold-worked 20 per cent (reduction of area) (68.00 % copper) according to W. B. Price.[7]

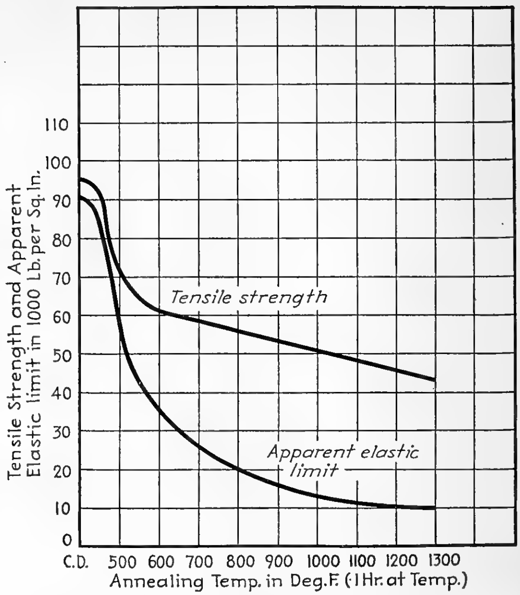


CHART 111.—The effect of annealing on the tensile strength and apparent elastic limit of 70-30 (cartridge brass) tube, previously cold-drawn 65 per cent (reduction of area) from a grain size of 0.050 mm. (69.74 % copper).

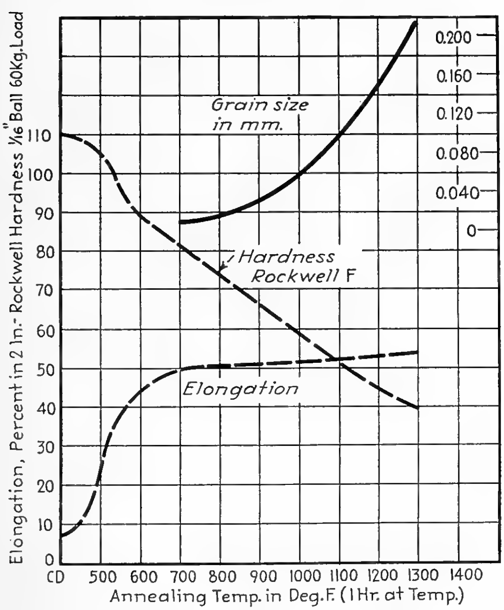


CHART 112.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and grain size of 70-30 (cartridge brass) tube, previously cold-drawn 65 per cent (reduction of area) from a grain size of 0.050 mm. (69.74 % copper).

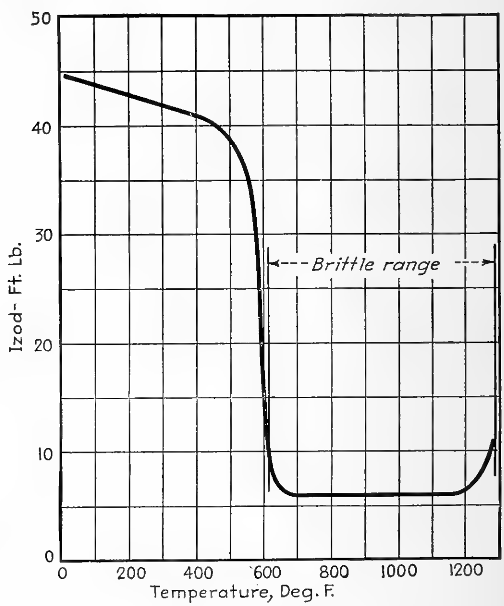


CHART 113.—The effect of elevated temperature on the Izod-impact strength of previously annealed 70-30 (cartridge brass) according to D. Bunting.[5]

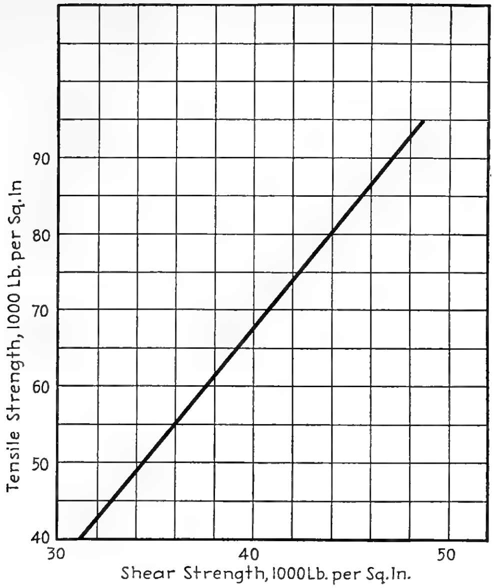


Chart 114.—Conversion chart for determination of shear strength of cartridge brass (70.00 % copper, balance zinc) when tensile strength is known. Accurate to ±5 %.[86]

TABLE 7
DEEP-DRAWING BRASS
General Data[a]—Strip
Analysis: copper, 68.41 %; lead, 0.01 %; iron, trace; zinc, balance

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	85–96	45–49
Apparent elastic limit, p.s.i. (000 omitted)	55–60	10
Yield strength, 0.5 % extension, p.s.i. (000 omitted)	64–65	11
Yield strength, 0.2 % offset, p.s.i. (000 omitted)	79–86	11–12
Yield strength, 0.1 % offset, p.s.i. (000 omitted)	70–77	11–12
Elongation, % in 2 in.	3	55–70
Rockwell hardness F, 1/16-in. ball, 60-kg. load	106–109	59
Rockwell hardness B, 1/16-in. ball, 100-kg. load	85–92	13
Rockwell hardness G, 1/16-in. ball, 150-kg. load	60–70	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	90–92	57–58
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	78–80	8–5
Endurance limit, p.s.i. (000 omitted)	21	17
Young's modulus of elasticity, lb. per sq. in.	15,000,000	
Melting point, °F.	1725	
Density, lb. per cu. in.	0.307	
Coefficient of expansion, per °C. from 25–300°C.	0.0000200	
Electrical conductivity, % I.A.C.S., 68°F.	27	
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	68	

[a] Apply to strip only (all tests conducted on 0.040-in. stock).
[b] Refers to 6 B. & S. Nos., hard, 0.100–0.015 mm. grain size at ready-to-finish.
[c] Refers to 1200°F. anneal (1 hr. at temperature).

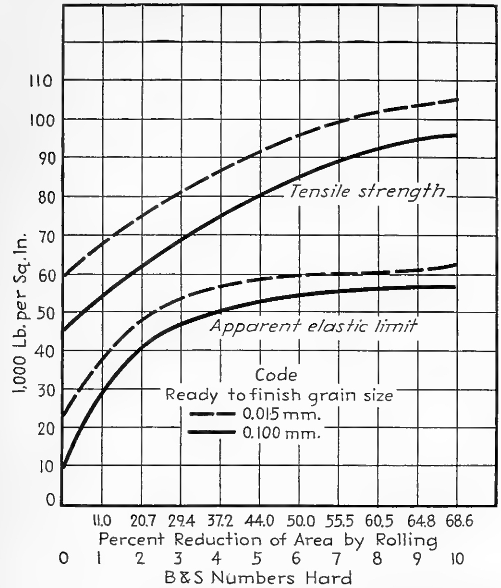


CHART 115.—The effect of cold rolling on the tensile strength and apparent elastic limit of deep-drawing brass strip, previously annealed to two different grain sizes, 0.015 and 0.100 mm. (68.41 % copper) (0.040-in. stock).

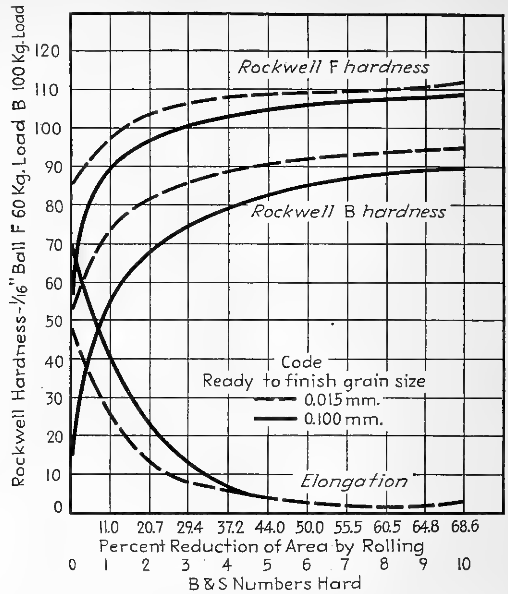


CHART 116.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of deep-drawing brass strip, previously annealed to two different grain sizes, 0.015 and 0.100 mm. (68.41 % copper) (0.040-in. stock).

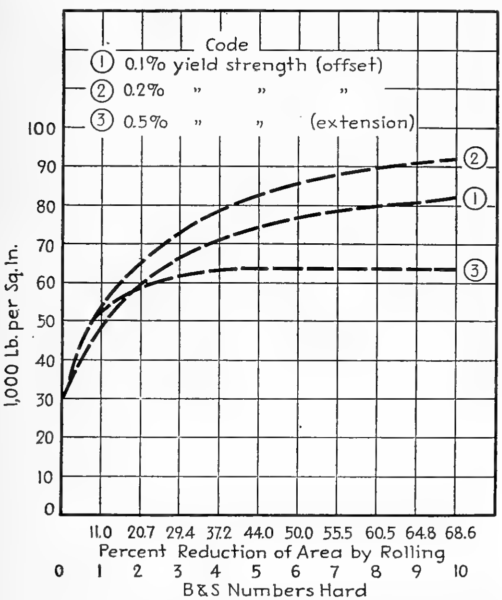


CHART 117.—The effect of cold rolling on the yield strengths of deep-drawing brass strip, previously annealed to a grain size of 0.015 mm. (68.41 % copper) (0.040-in. stock).

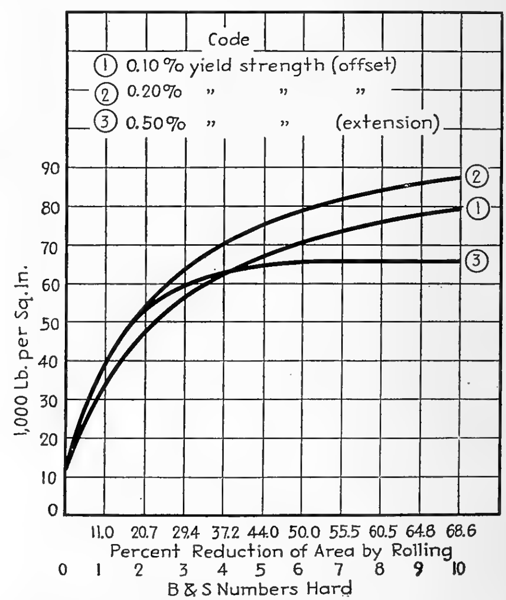


CHART 118.—The effect of cold rolling on the yield strengths of deep-drawing brass strip, previously annealed to a grain size of 0.100 mm. (68.41 % copper) (0.040-in. stock).

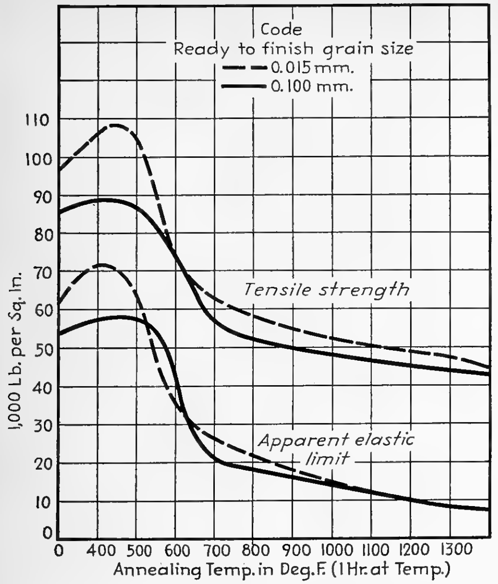


CHART 119.—The effect of annealing on the tensile strength and apparent elastic limit of deep-drawing brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.100 mm. (68.41 % copper) (0.040-in. stock).

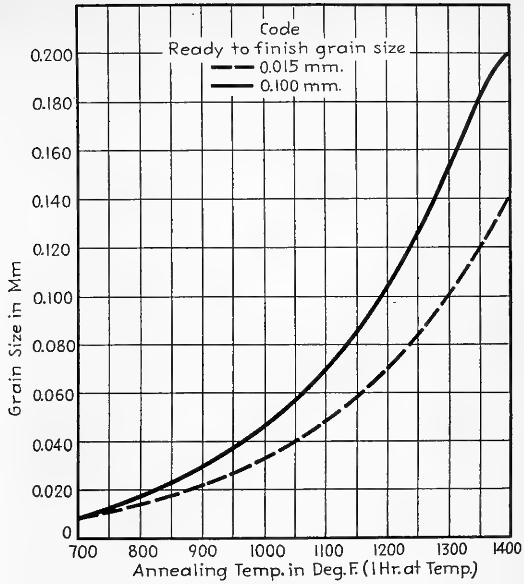


CHART 120.—The effect of annealing on the grain-growing characteristics of deep-drawing brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.100 mm. (68.41 % copper) (0.040-in. stock).

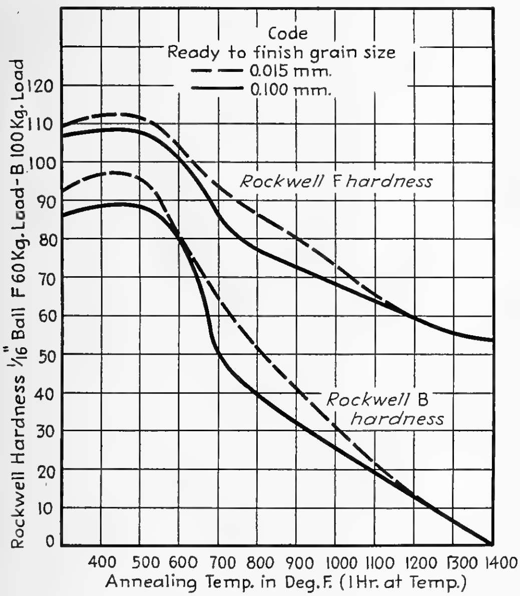


CHART 121.—The effect of annealing on the Rockwell hardness of deep-drawing brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.100 mm. (68.41 % copper) (0.040-in. stock).

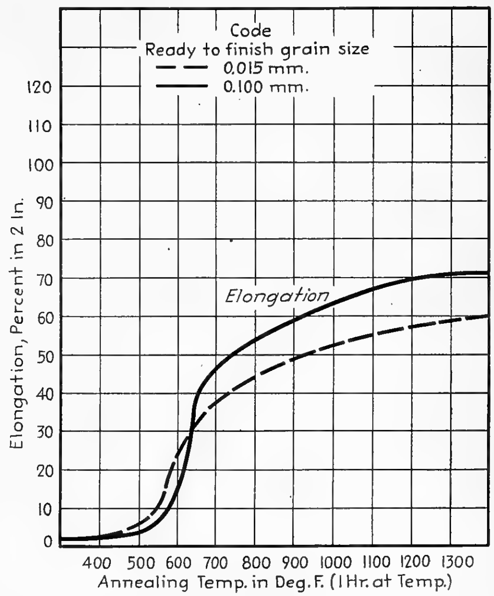


CHART 122.—The effect of annealing on the percentage elongation in 2 in. of deep-drawing brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.100 mm. (68.41 % copper) (0.040-in. stock).

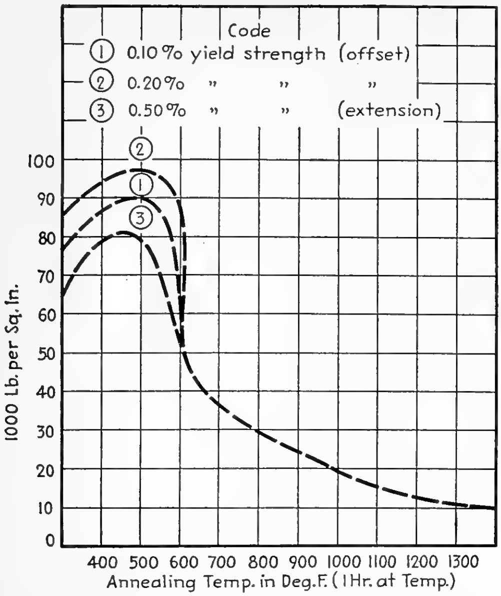


CHART 123.—The effect of annealing on the yield strength of deep-drawing brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (68.41 % copper) (0.040-in. stock).

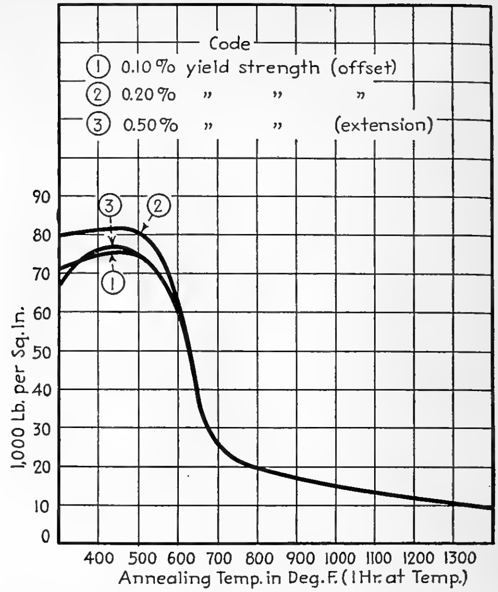


CHART 124.—The effect of annealing on the yield strength of deep-drawing brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.100 mm. (68.41 % copper) (0.040-in. stock).

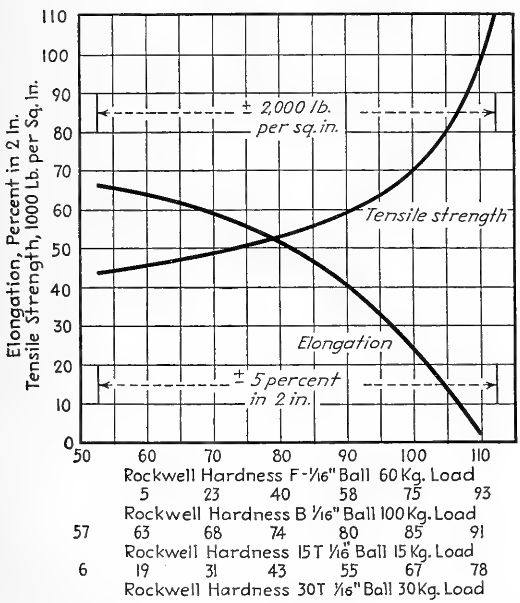


CHART 125.—This chart can be employed to determine the approximate tensile strength and percentage elongation of deep-drawing brass strip (68.41 % copper) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

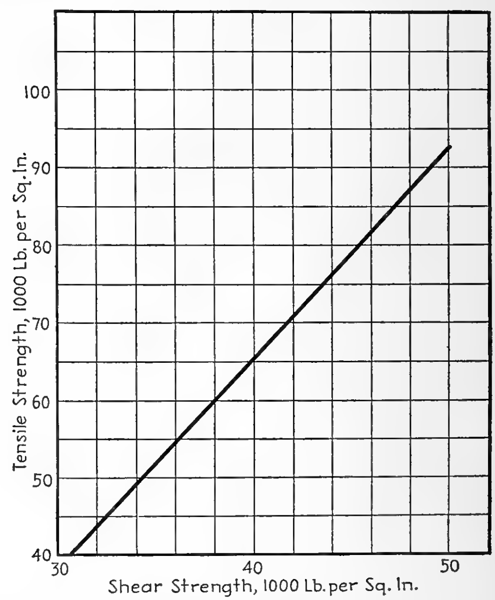


CHART 126.—Conversion chart for determination of shear strength of deep-drawing and spinning brass (68.00 % copper, balance zinc) when tensile strength is known. Accurate to ±5 %.[86]

TABLE 8

COMMON HIGH BRASS

GENERAL DATA—ROD

Copper, 64.87%; lead, trace; iron, trace; zinc, balance

Property	Rod		Forgings	
	Hard[a]	Soft[b]	Cold[c]	Cold[d]
Tensile strength, p.s.i. (000 omitted)	90	42	45–73	80
Apparent elastic limit, p.s.i. (000 omitted)	55	5	14–50	52
Yield strength, 0.5% extension, p.s.i. (000 omitted)	55	13	22–52	54
Yield strength, 0.2% offset, p.s.i. (000 omitted)	65	13	22–62	63
Yield strength, 0.1% offset, p.s.i. (000 omitted)	59	11	20–57	57
Elongation, % in 2 in.	60	15	52–18	17
Reduction of area, %	65	78	75–68	66
Endurance limit, p.s.i. (000 omitted)	21	16		
Rockwell hardness F, 1/16-in. ball, 60-kg. load	104	60	76–102	103
Rockwell hardness B, 1/16-in. ball, 100-kg. load	82	8	34–79	81
Brinell hardness, 10-mm. ball, 500-kg. load	136	56	70–128	135
Modulus of elasticity. p.s.i.	15,000,000			

GENERAL DATA—STRIP[e]

Copper, 66.49%; lead, 0.04%; iron, 0.02%; zinc, balance

Property	Hard[f]	Soft[g]
Tensile strength, p.s.i. (000 omitted)	84–93	44–46
Elongation, % in 2 in.	5	63–70
Apparent elastic limit, p.s.i. (000 omitted)	54–58	10
Yield strength, 0.5% extension, p.s.i. (000 omitted)	59–61	11
Yield strength, 0.2% offset, p.s.i. (000 omitted)	70–73	11
Yield strength, 0.1% offset, p.s.i. (000 omitted)	61–62	11
Rockwell hardness F, 1/16-in. ball, 60-kg. load	108–111	57–60
Rockwell hardness B, 1/16-in. ball, 100-kg. load	87–92	0–5
Rockwell hardness G, 1/16-in. ball, 150-kg. load	61–69	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	89–91	63
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	75–78	19
Endurance limit (at 10^8 reversals):(1,6)		
Soft, p.s.i. (000 omitted)	13.5	
4 B. & S. Nos., p.s.i. (000 omitted)	15	
8 B. & S. Nos., hard, p.s.i. (000 omitted)	17.5	
10 B. & S. Nos., hard, p.s.i. (000 omitted)	20	
Young's modulus of elasticity, p.s.i.	14,000,000	
Melting point, °F	1700	
Density, lb. per cu. in.	0.306	

PHYSICAL DATA

Melting point, °F	1700
Coefficient of expansion, per °C. from 25–300°C	0.0000202
Electrical conductivity,(87) % I.A.C.S., 68°F	26.4
Thermal conductivity,(87) B.t.u. per sq. ft. per ft. per hr. per °F., 68°F	69
Density, lb. per cu. in.	0.306
Forging range, °F	
Type structure	Single phase, alpha

[a] Refers to rod under 1 in. in diameter and cold-drawn 50% with a ready-to-finish grain size of 0.040 mm.
[b] Refers to 1050°F. anneal (1 hr.).
[c] Material cold-forged from soft rod (5–40%) reduction of area).
[d] Material cold-forged from cold-worked condition (40%).
[e] All tests conducted on 0.040-in. stock.
[f] 6 B. & S. Nos., hard, 0.070–0.015 mm. grain size at ready-to-finish, respectively.
[g] Refer to 1100°F. anneal (1 hr. at temperature).

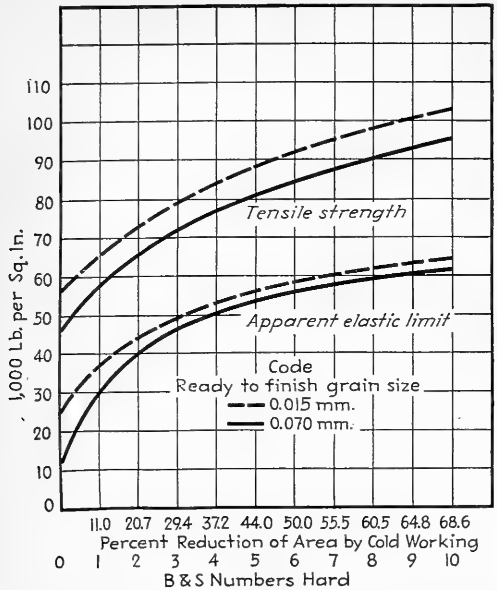


CHART 127.—The effect of cold rolling on the tensile strength and apparent elastic limit of common high-brass strip, previously annealed to two different grain sizes, 0.015 and 0.070 mm. (66.49 % copper) (0.040-in. stock).

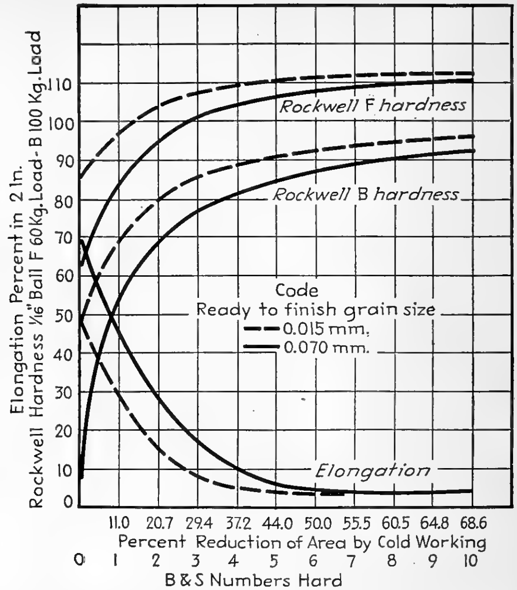


CHART 128.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of common high-brass strip, previously annealed to two different grain sizes, 0.015 and 0.070 mm. (66.49 % copper) (0.040-in. stock).

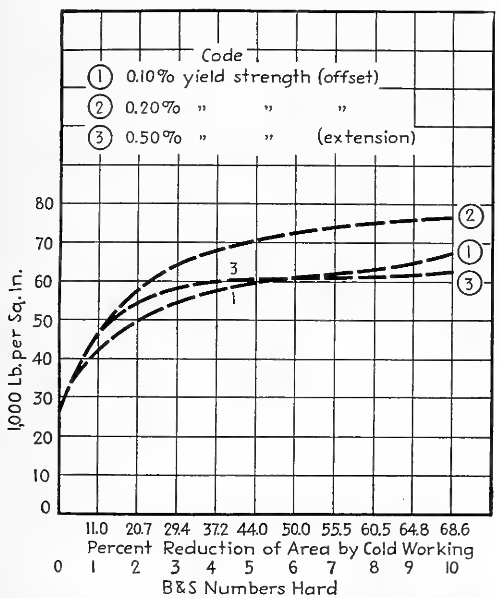


CHART 129.—The effect of cold rolling on the yield strengths of common high-brass strip, previously annealed to a grain size of 0.015 mm. (66.49 % copper) (0.040-in. stock).

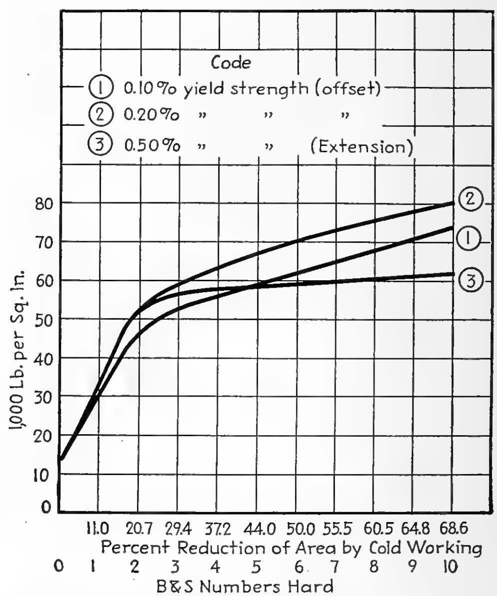


CHART 130.—The effect of cold rolling on the yield strengths of common high-brass strip, previously annealed to a grain size of 0.070 mm. (66.49 % copper) (0.040-in. stock).

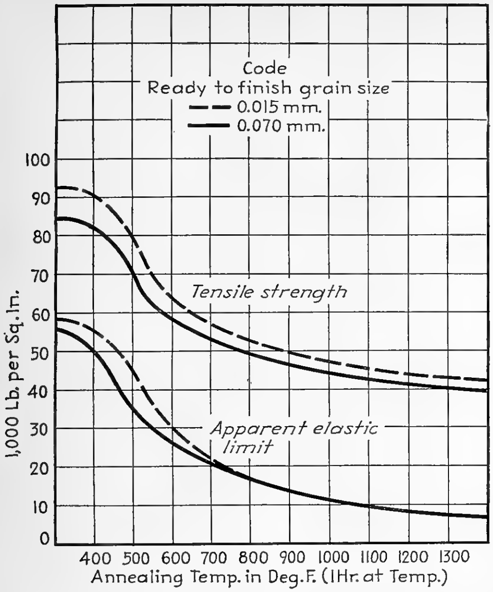


CHART 131.—The effect of annealing on the tensile strength and apparent elastic limit of common high-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (66.49 % copper) (0.040-in. stock).

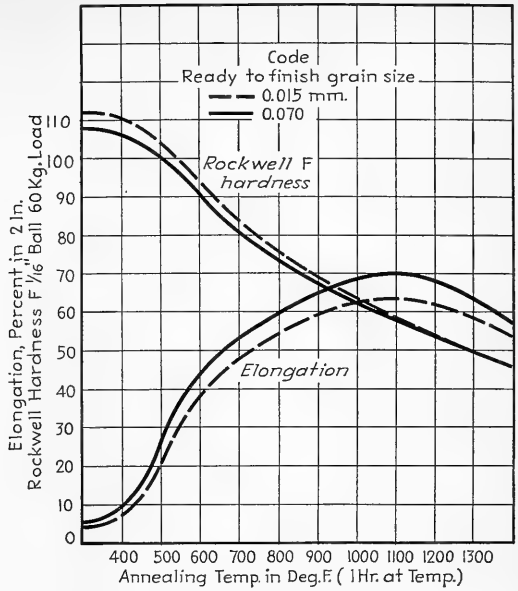


CHART 132.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of common high-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (66.49 % copper) (0.040-in. stock).

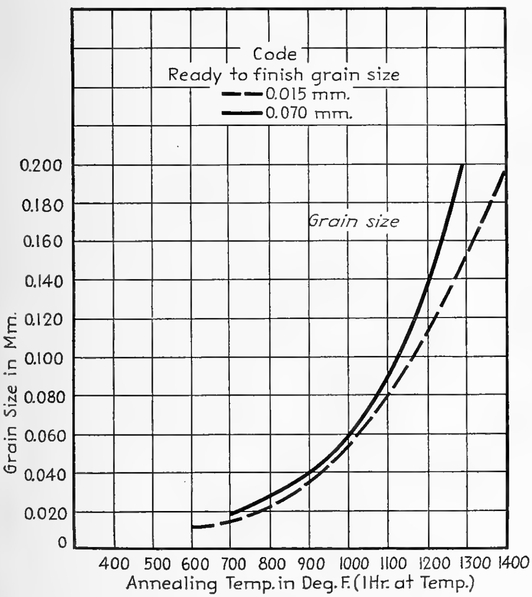


CHART 133.—The effect of annealing on the grain-growing characteristics of common high-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (66.49 % copper) (0.040-in. stock).

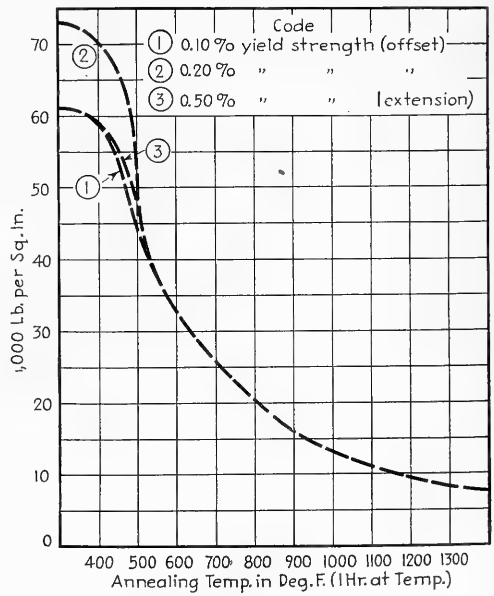


CHART 134.—The effect of annealing on the yield strength of common high-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (66.49 % copper) (0.040-in. stock).

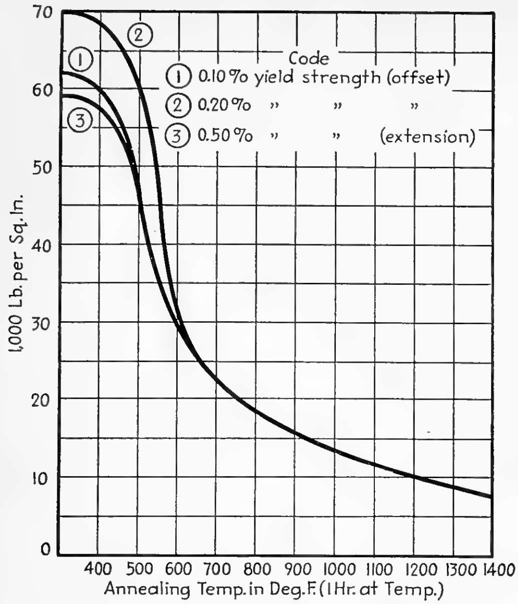


Chart 135.—The effect of annealing on the yield strength of common high-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.070 mm. (66.49 % copper) (0.040-in. stock).

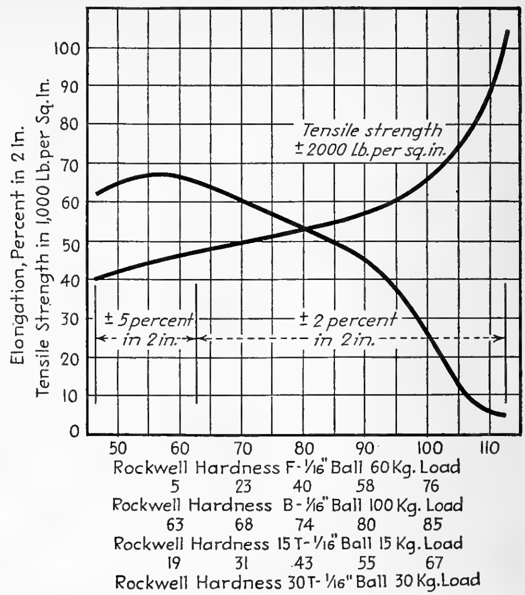


Chart 136.—This chart can be employed to determine the approximate tensile strength and percentage elongation of common high-brass strip (66.49 % copper) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

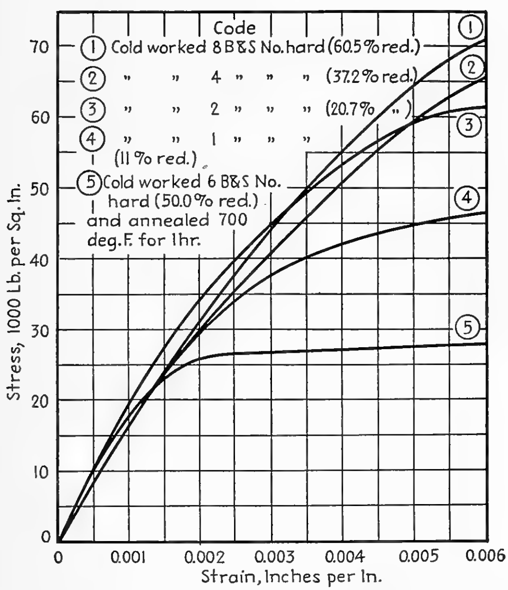


Chart 137.—The effect of cold rolling on the stress-strain characteristics of common high-brass strip (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm. (66.49 % copper); 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used.

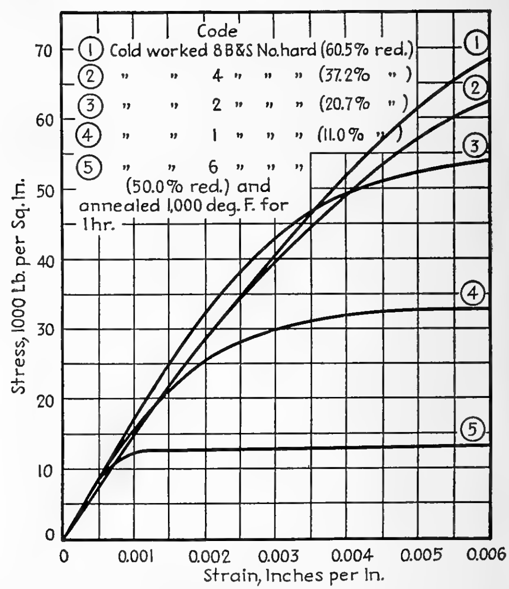


Chart 138.—The effect of cold rolling on the stress-strain characteristics of common high-brass strip (0.040 in. thick) having a ready-to-finish grain size of 0.070 mm. (66.49 % copper); 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used.

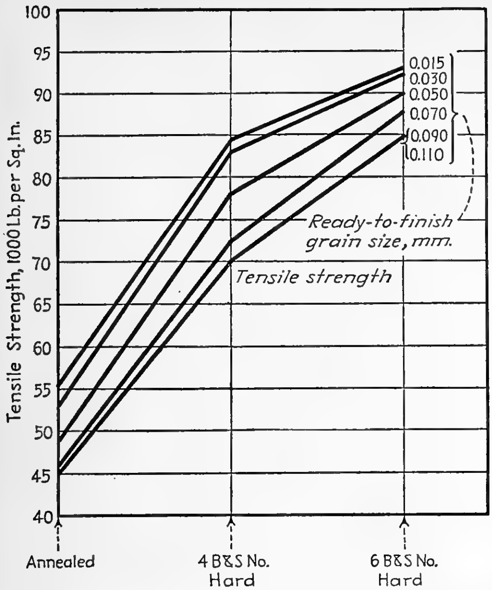


Chart 139.—The effect of ready-to-finish grain size on the tensile strength of cold-rolled common high-brass strip (65.10 % copper) (0.040-in. stock).

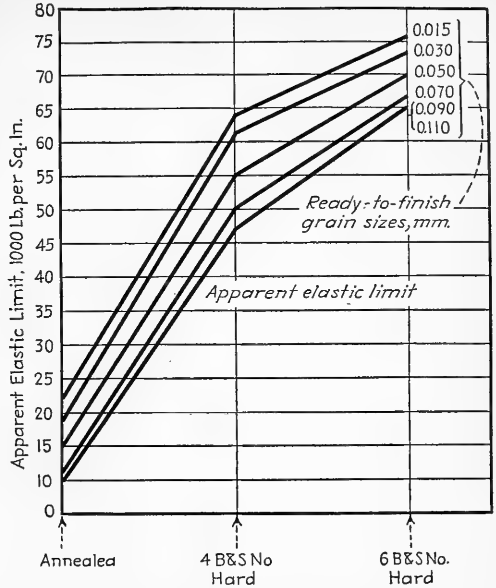


Chart 140.—The effect of ready-to-finish grain size on the apparent elastic limit of cold-rolled common high-brass strip (65.10 % copper) (0.040-in. stock).

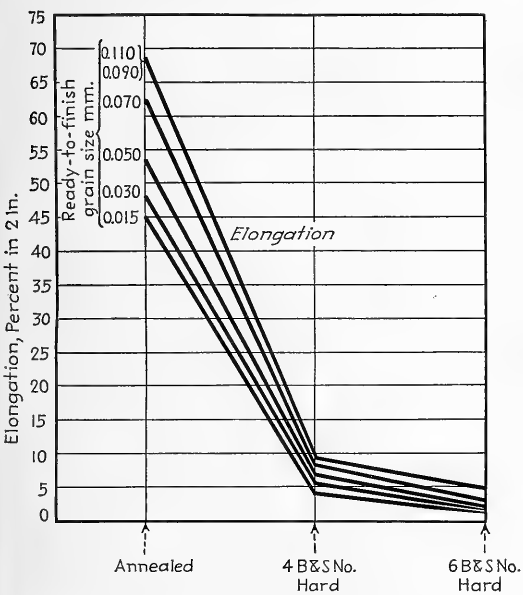


Chart 141.—The effect of ready-to-finish grain size on percentage elongation in 2 in. of cold-rolled common high-brass strip (65.10 % copper) (0.040-in. stock).

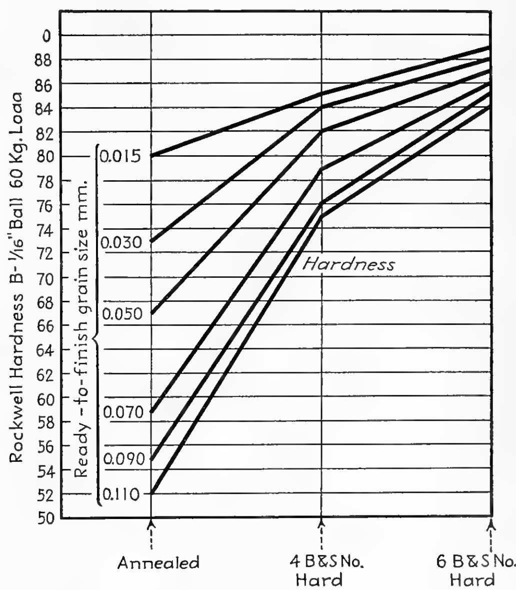


Chart 142.—The effect of ready-to-finish grain size on Rockwell hardness of cold-rolled common high-brass strip (65.10 % copper) (0.040-in. stock).

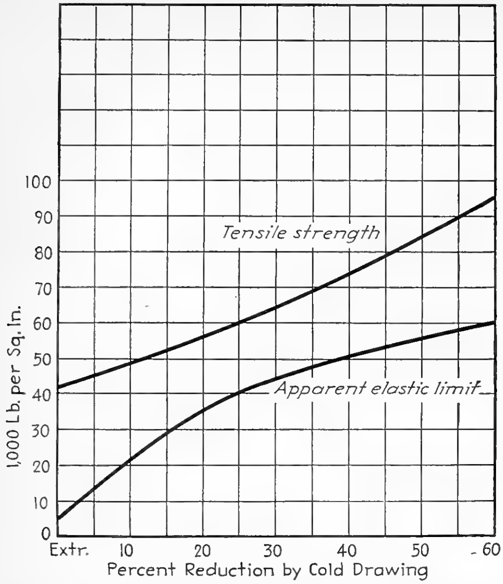


Chart 143.—The effect of cold drawing on the tensile strength and apparent elastic limit of common high-brass rod, previously annealed to a grain size of 0.040 mm. (64.87 % copper) (rod under 1 in. in diameter).

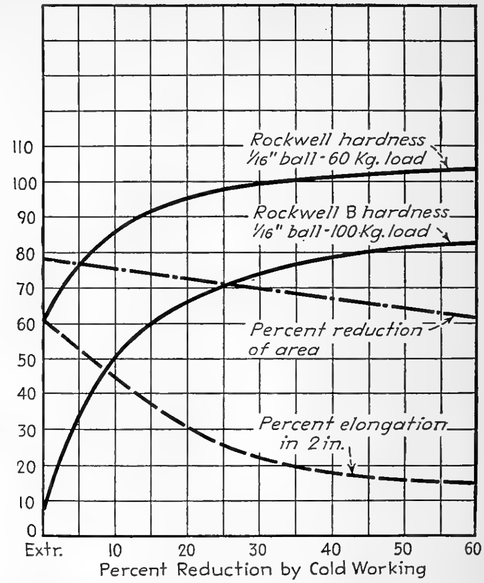


Chart 144.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in. and percentage reduction of area of common high-brass rod, previously annealed to a grain size of 0.040 mm. (64.87 % copper) (rod under 1 in. in diameter).

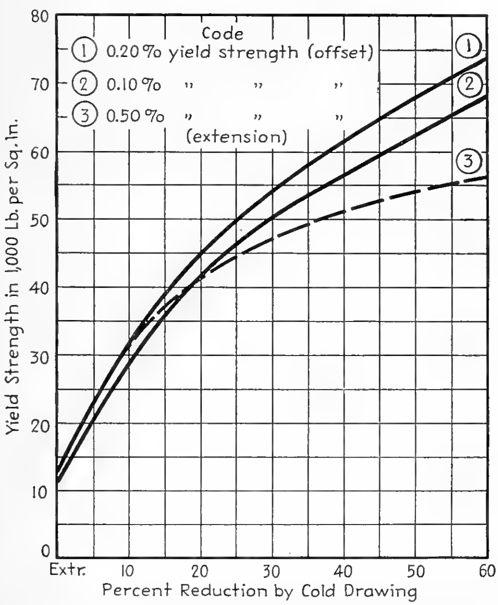


Chart 145.—The effect of cold drawing on the yield strength of common high-brass rod, previously annealed to a grain size of 0.040 mm. (64.87 % copper) (rod under 1 in. in diameter).

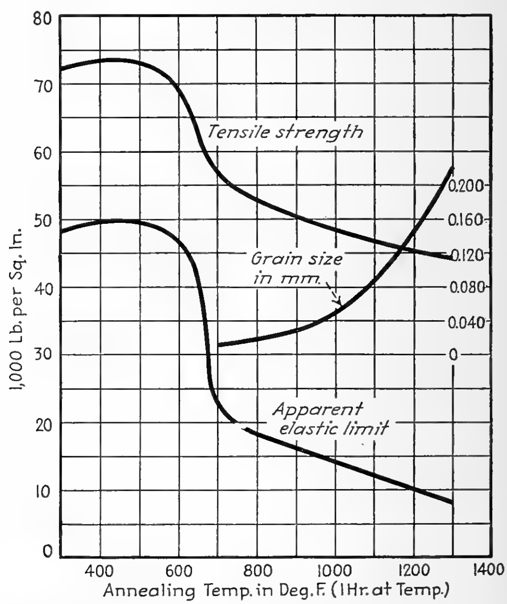


Chart 146.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of common high-brass rod, previously cold-drawn 40 per cent (reduction of area) from material having a grain size of 0.040 mm. (64.87 % copper) (rod under 1 in. in diameter).

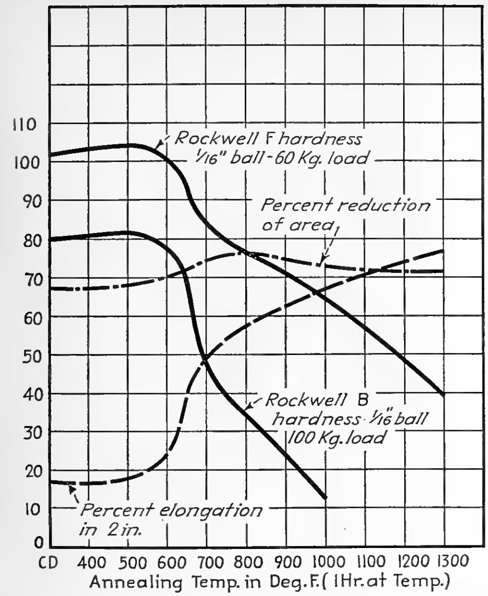


CHART 147.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of common high-brass rod, previously cold-drawn 40 per cent (reduction of area) from material having a grain size of 0.040 mm. (64.87 % copper) (rod under 1 in. in diameter).

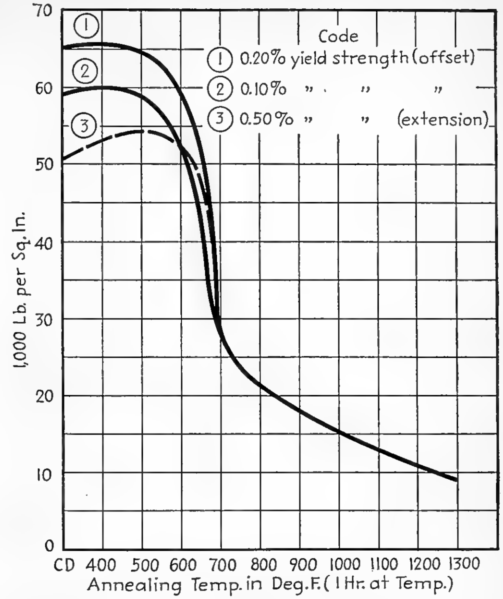


CHART 148.—The effect of annealing on the yield strength of common high-brass rod, previously cold-drawn 40 per cent (reduction of area) from material having a grain size of 0.040 mm. (64.87 % copper) (rod under 1 in. in diameter).

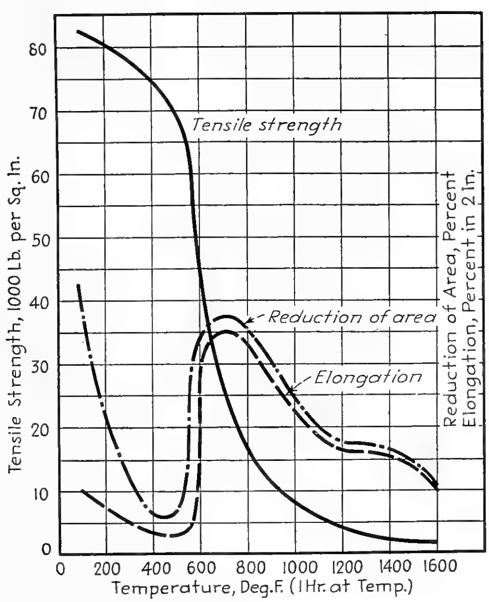


CHART 149.—The effect of elevated temperature on the tensile strength, percentage reduction of area, and percentage elongation in 2 in. of common high-brass rod, previously cold-worked 50 per cent (reduction of area) according to W. B. Price[7] (67.61 % copper).

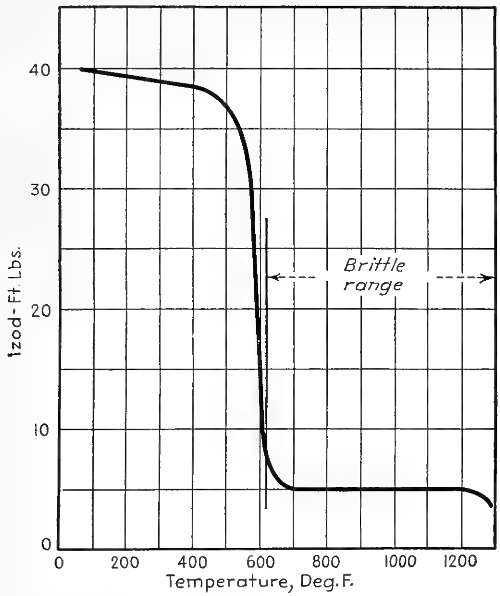


CHART 150.—The effect of elevated temperatures on the Izod-impact strength of previously annealed common high brass (66.00 % copper) according to D. Bunting.(5)

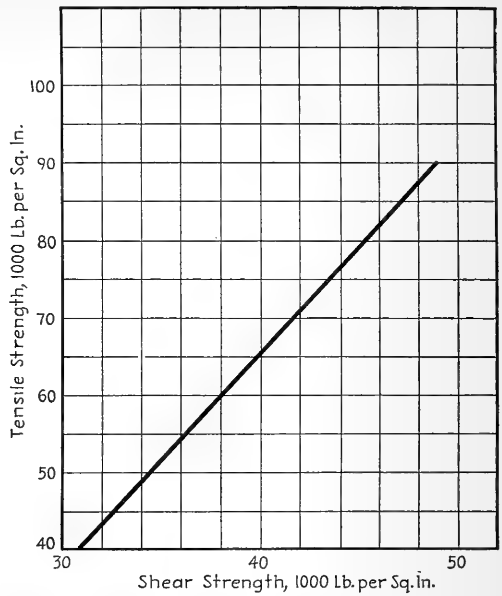


CHART 151.—Conversion chart for determination of shear strength of high brass (65.00 % copper, balance zinc) when tensile strength is known. Accurate to ±5 %.(86)

TABLE 9
COMMON BRASS ROD
Copper, 62.65 %; lead, 0.03 %; iron, trace; zinc, balance

Property	Rod		Forgings	
	Hard[a]	Soft[b]	Cold[c]	Cold[d]
Tensile strength, p.s.i. (000 omitted)	88	47	51–80	83
Apparent elastic limit, p.s.i. (000 omitted)	60	12	25–53	56
Yield strength, 0.5 % extension, p.s.i. (000 omitted)	57	16	31–52	56
Yield strength, 0.2 % offset, p.s.i. (000 omitted)	74	16	30–65	70
Yield strength, 0.1 % offset, p.s.i. (000 omitted)	65	15	27–57	61
Elongation, % in 2 in.	15	60	50–18	16
Reduction of area, %	60	75	73–63	62
Endurance limit, p.s.i. (000 omitted)	22	17		
Rockwell hardness F, 1/16-in. ball, 60-kg. load	104	77	87–100	103
Rockwell hardness B, 1/16-in. ball, 100-kg. load	86	35	50–82	84
Brinell hardness, 10-mm. ball, 500-kg. load	145	71	83–135	140
Modulus of elasticity, p.s.i.	15,000,000			
Melting point, °F.	1680			
Coefficient of expansion, per °C. from 25–300°C.	0.0000205			
Electrical conductivity, % I.A.C.S., 68°F.	27.6			
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	71			
Density, lb. per cu. in.	0.304			

[a] Refers to rod cold-drawn 50 % and for rod under 1 in. in diameter with a ready-to-finish grain size, 0.045 mm.
[b] Refers to a 1300°F. anneal (1 hr.).
[c] Material cold-forged from soft rod (5–40 % reduction of area).
[d] Material cold-forged from cold-worked condition (40 %).

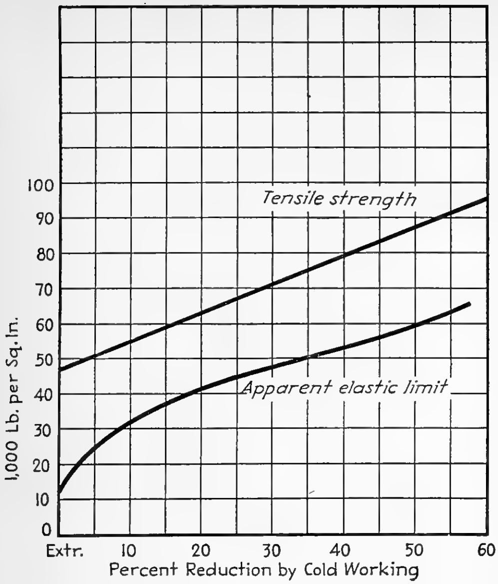


CHART 152.—The effect of cold drawing on the tensile strength and apparent elastic limit of common brass rod, previously annealed to a grain size of 0.045 mm. (62.65 % copper) (rod under 1 in. in diameter).

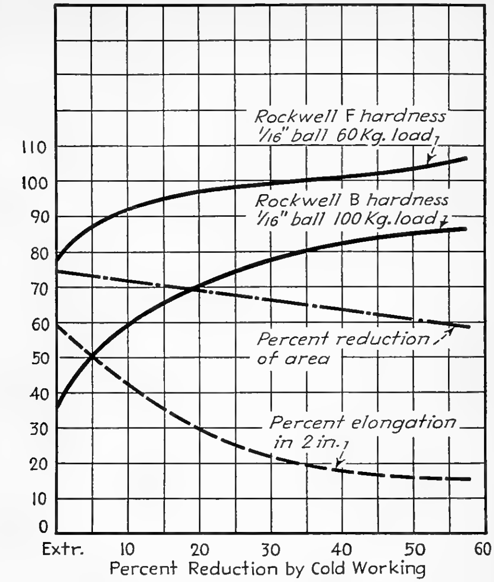


CHART 153.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of common brass rod, previously annealed to a grain size of 0.045 mm. (62.65 % copper) (rod under 1 in. in diameter).

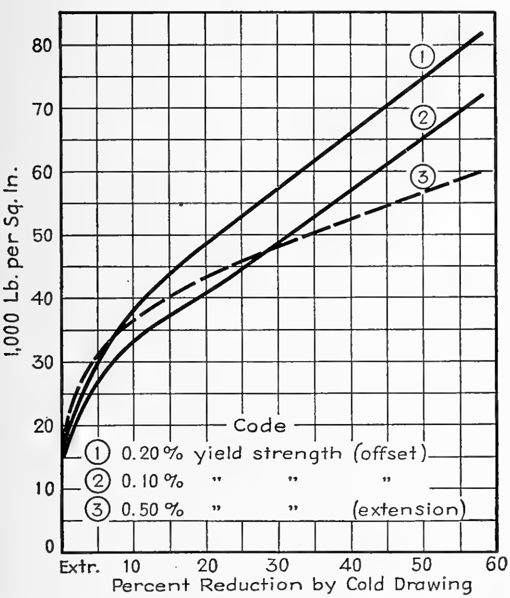


CHART 154.—The effect of cold drawing on the yield strength of common brass rod, previously annealed to a grain size of 0.045 mm. (62.65 % copper) (rod under 1 in. in diameter).

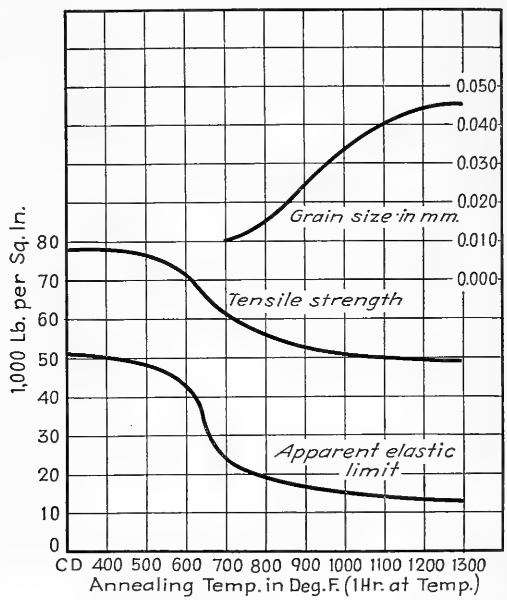


CHART 155.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of common brass rod, previously cold-drawn 38 per cent (reduction of area) from material having a grain size of 0.045 mm. (62.65 % copper) (rod under 1 in. in diameter).

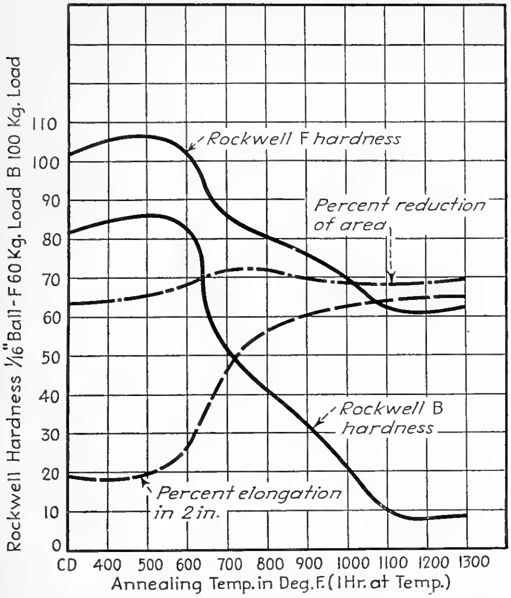


CHART 156.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., percentage reduction of area of common brass rod, previously cold-drawn 38 per cent (reduction of area) from material having a grain size of 0.045 mm. (62.45 % copper) (rod under 1 in. in diameter).

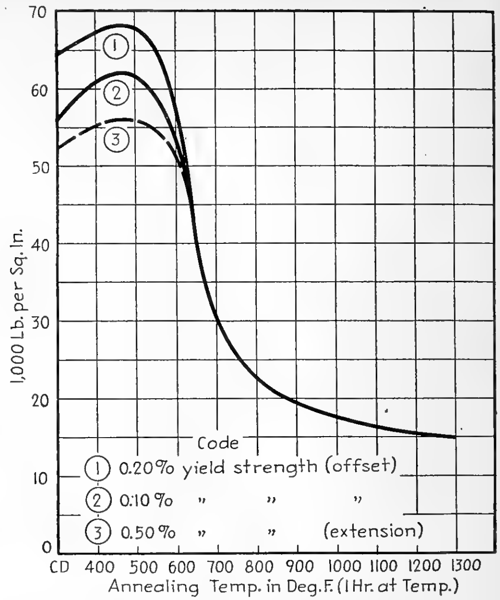


CHART 157.—The effect of annealing on the yield strength of common brass rod, previously cold-drawn 38 per cent (reduction of area) from material having a grain size of 0.045 mm. (62.65 % copper) (rod under 1 in. in diameter).

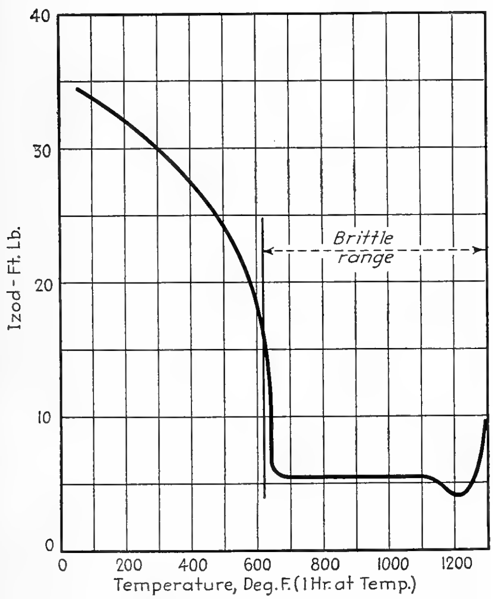


CHART 158.—The effect of elevated temperature on the Izod-impact strength of previously annealed common brass (64.00 % copper) according to D. Bunting.[5]

FOOTNOTES TO TABLE 10

[a] Refers to rod cold-drawn 30 %; rod under 1 in. in diameter with ready-to-finish grain size, 0.010 mm.
[b] Refers to a 900°F. anneal (1 hr.).
[c] Material cold-struck from forged condition.
[d] All tests conducted on 0.040-in. stock.
[e] 6 B. & S. Nos., hard, 0.045–0.015 mm. grain size at ready-to-finish.
[f] Refers to 1300°F. anneal (1 hr. at temperature).
[g] Cold-drawn to 3/4 by 0.049 in.
[h] 1200°F. anneal (1 hr.).

TABLE 10
MUNTZ METAL
GENERAL DATA—ROD
Copper, 60.73%; lead, 0.07%; iron, 0.02%, zinc, balance

Property	Rod		Forgings	
	Hard[a]	Soft[b]	Hot	Cold[c]
Tensile strength, p.s.i. (000 omitted)	80	52	56–60	56–62
Apparent elastic limit, p.s.i. (000 omitted)	50	17	12–19	25–30
Yield strength, 0.5% extension, p.s.i. (000 omitted)	57	22	17–22	30–35
Yield strength, 0.2% offset, p.s.i. (000 omitted)	66	22	16–22	25–35
Yield strength, 0.1% offset, p.s.i. (000 omitted)	57	22	15–20	25–35
Elongation, % in 2 in.	20	48	55–45	45–40
Reduction of area, %	58	70	70–60	65–60
Endurance limit, p.s.i. (000 omitted)	25	21		
Rockwell hardness F, 1/16-in. ball, 60-kg. load	104	84	75–78	90–95
Rockwell hardness B, 1/16-in. ball, 100-kg. load	88	49	33–45	57–67
Brinell hardness, 10-mm. ball, 500-kg. load	151	82	69–79	91–106
Modulus of elasticity, p.s.i	15,000,000			
Forging range	1250–1450			
Forging quality	Excellent			
Type structure	Two-phase structure, alpha-beta			

GENERAL DATA—STRIP[d]

Property	Hard[e]	Soft[f]
Tensile strength, p.s.i. (000 omitted)	91–93	56–58
Apparent elastic limit, p.s.i. (000 omitted)	61	13
Yield strength, 0.5% extension, p.s.i. (000 omitted)	65–66	15.5–18
Yield strength, 0.2% offset, p.s.i. (000 omitted)	77–81	15.5–17.5
Yield strength, 0.1% offset, p.s.i. (000 omitted)	68–72	15–17
Elongation, % in 2 in.	5	45–52
Rockwell hardness F, 1/16-in. ball, 60-kg. load	108	74
Rockwell hardness B, 1/16-in. ball, 100-kg. load	90	33
Rockwell hardness G, 1/16-in. ball, 150-kg. load	66	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	90	72
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	77	37
Endurance limit, p.s.i.	25,000	21,000
Young's modulus of elasticity, p.s.i.	15,000,000	

GENERAL DATA—TUBE
Copper, 60.80%; lead, 0.01%; iron, trace; zinc, balance

Property	Hard[g]	Soft[h]
Tensile strength, p.s.i. (000 omitted)	88	59
Elongation, % in 2 in.	12	49
Apparent elastic limit, p.s.i. (000 omitted)	82	15
Rockwell hardness F, 1/16-in. ball, 60-kg. load	109	73
Young's modulus of elasticity, lb. per sq. in.	15,000,000	

PHYSICAL DATA

Melting point, °F.	1660
Coefficient of expansion, per °C. from 25–300°C.	0.0000208
Electrical conductivity,[87] % I.A.C.S., 68°F.	28.8
Thermal conductivity,[87] B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	73
Density, lb. per cu. in.	0.303

AVAILABLE CREEP DATA[3]
Previous history: hot-rolled to 0.750-in.-diameter rod; grain size alpha constituent 0.020 mm.

Temperature °F.	No measurable flow	Stress, p.s.i., required, to produce designated rate of creep per 1,000 hr.		
		0.01%	0.10%	1.00%
300	7,500	9,000	12,000	17,000
400	Approaches zero	2,000	4,750	11,500

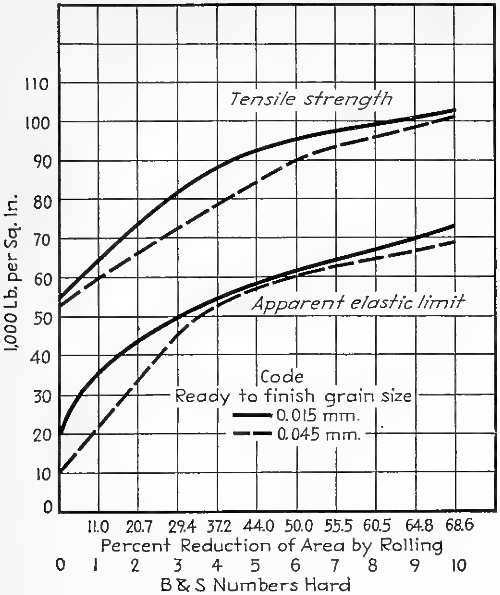


CHART 159.—The effect of cold rolling on the tensile strength and apparent elastic limit of Muntz metal strip, previously annealed to two different sizes, 0.015 and 0.045 mm. (60.50 % copper) (0.040-in. stock).

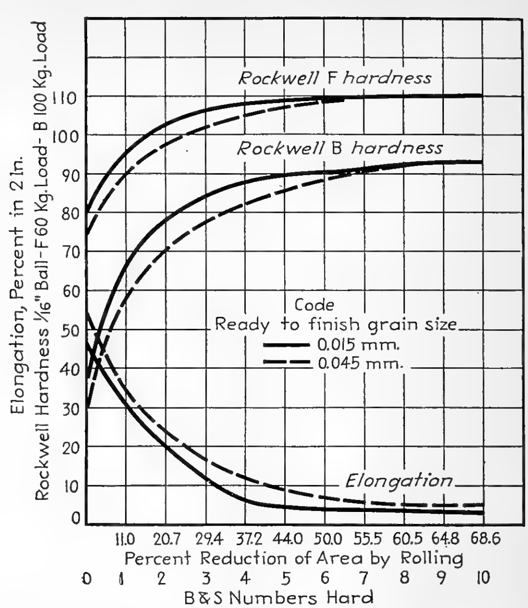


CHART 160.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of Muntz metal strip, previously annealed to two different grain sizes, 0.015 and 0.045 mm. (60.50 % copper) (0.040-in. stock).

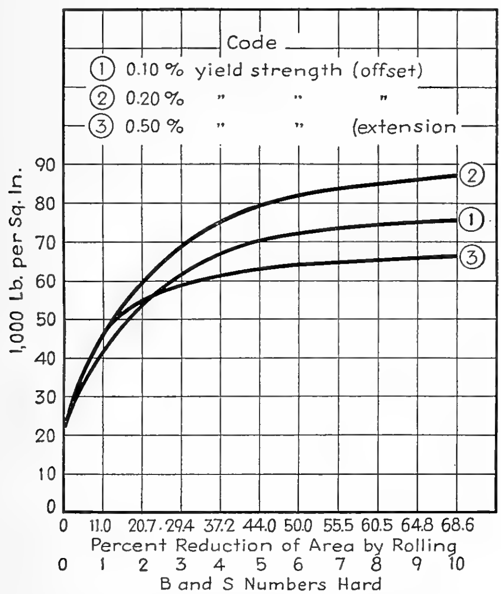


CHART 161.—The effect of cold rolling on the yield strengths of Muntz metal strip, previously annealed to a grain size of 0.015 mm. (60.50 % copper) (0.040-in. stock).

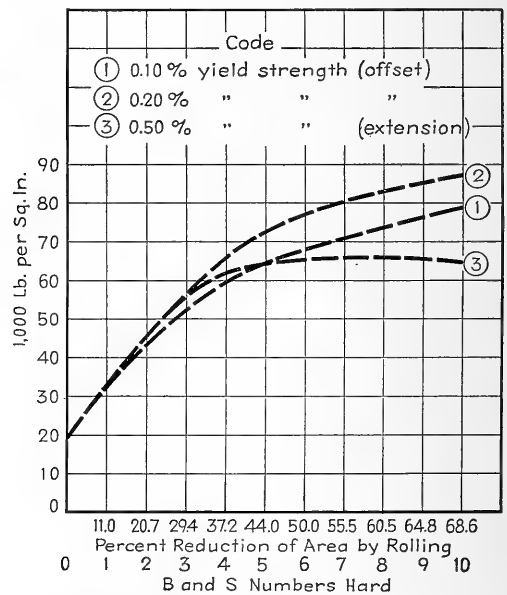


CHART 162.—The effect of cold rolling on the yield strengths of Muntz metal strip, previously annealed to a grain size of 0.045 mm. (60.50 % copper) (0.040-in. stock).

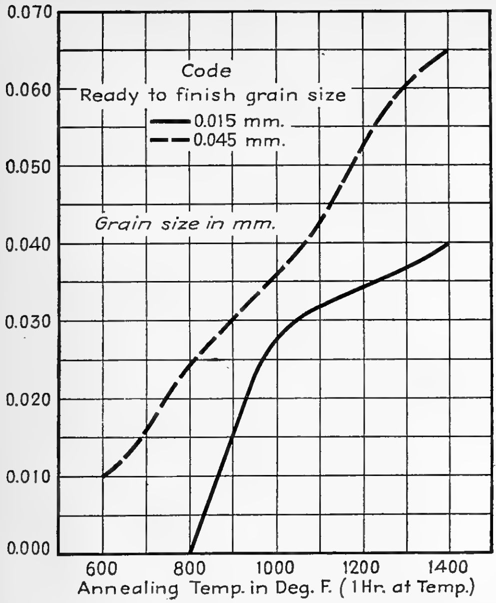


CHART 163.—The effect of annealing on the grain-growing characteristics of Muntz metal strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.045 mm. (60.50 % copper) (0.040-in. stock).

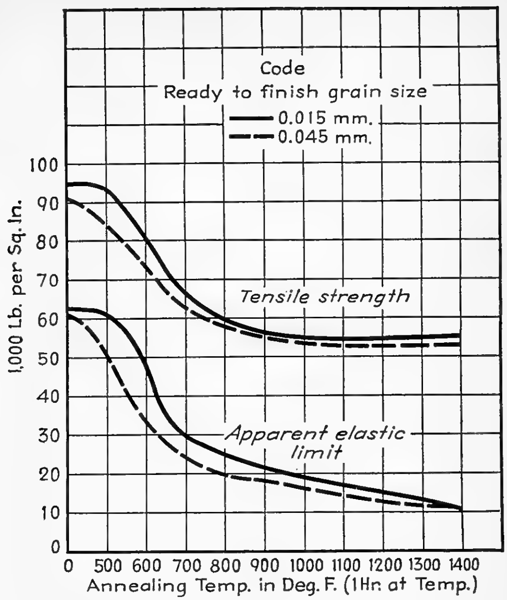


CHART 164.—The effect of annealing on the tensile strength and apparent elastic limit of Muntz metal strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.045 mm. (60.50 % copper) (0.040-in. stock).

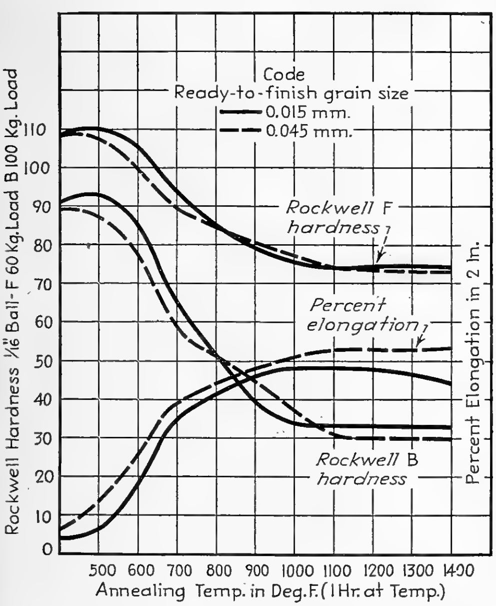


CHART 165.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of Muntz metal strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.045 mm. (60.50 % copper) (0.040-in. stock).

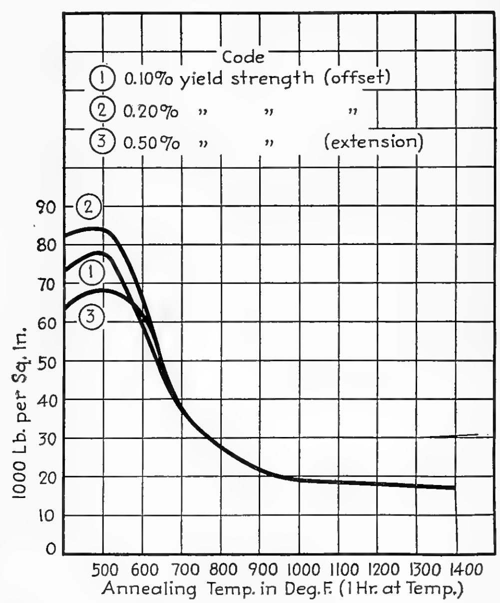


CHART 166.—The effect of annealing on the yield strength of Muntz metal strip, previously cold-rolled 6. B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (60.50 % copper) (0.040-in. stock).

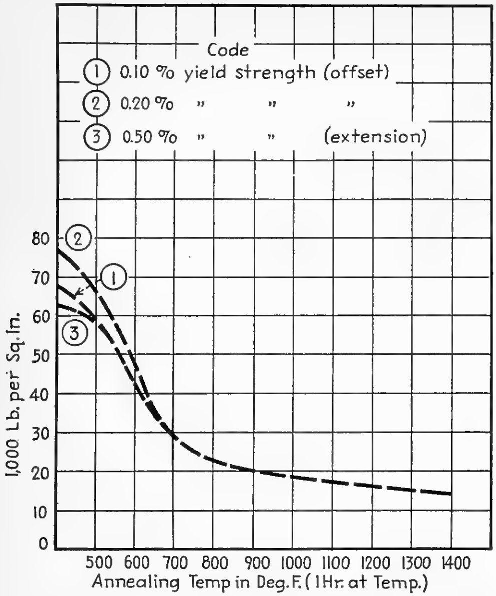


CHART 167.—The effect of annealing on the yield strength of Muntz metal strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.045 mm. (60.50 % copper) (0.040-in. stock).

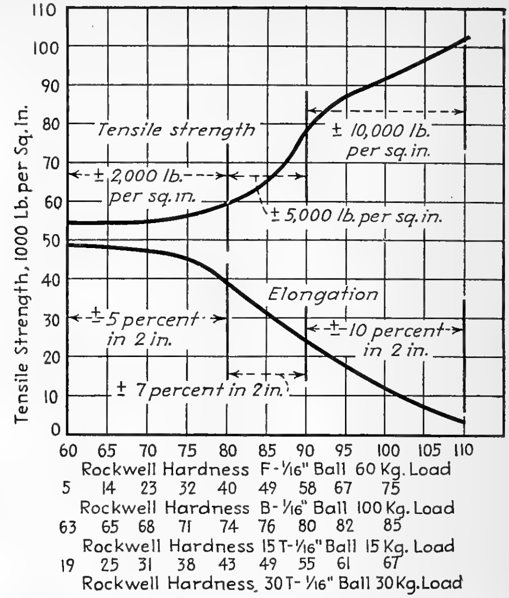


CHART 168.—This chart can be employed to determine the approximate tensile strength and percentage elongation of Muntz metal strip (60.50 % copper) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

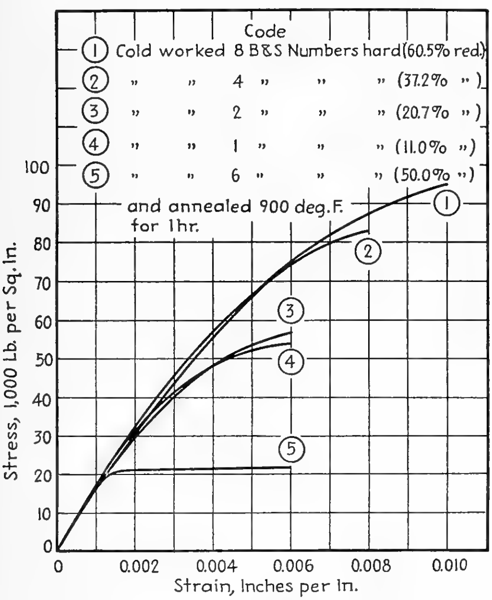


CHART 169.—The effect of cold rolling on the stress-strain characteristics of Muntz metal strip (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm. (60.50 % copper); 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used.

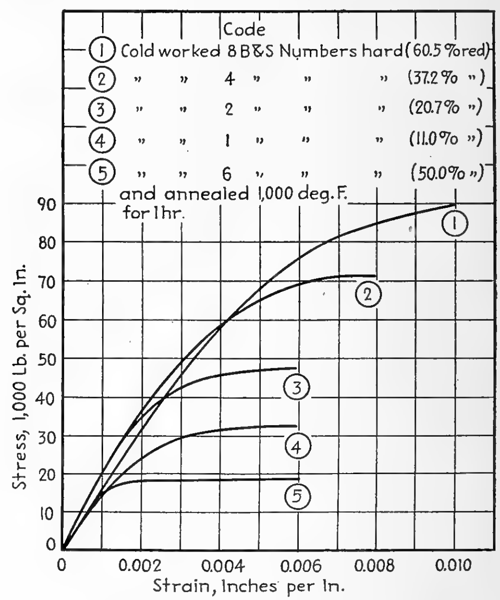


CHART 170.—The effect of cold rolling on the stress-strain characteristics of Muntz metal strip (0.040 in. thick) having a ready-to-finish grain size of 0.045 mm. (60.50 % copper); 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used.

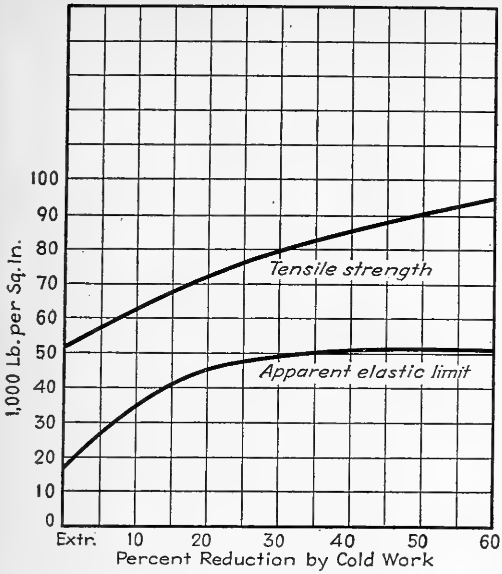


CHART 171.—The effect of cold drawing on the tensile strength and apparent elastic limit of Muntz metal rod, previously extruded to a grain size of 0.010 mm. (60.73 % copper) (rod under 1 in. in diameter).

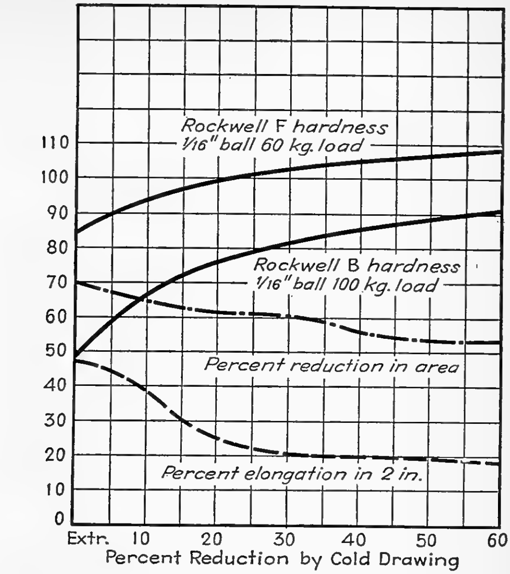


CHART 172.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of Muntz metal rod, previously extruded to a grain size of 0.010 mm. (60.73 % copper) (rod under 1 in. in diameter).

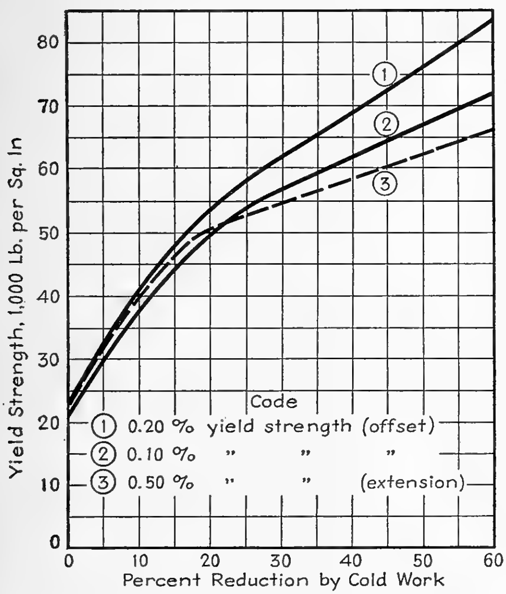


CHART 173.—The effect of cold drawing on the yield strength of Muntz metal rod, previously extruded to a grain size of 0.010 mm. (60.73 % copper) (rod under 1 in. in diameter).

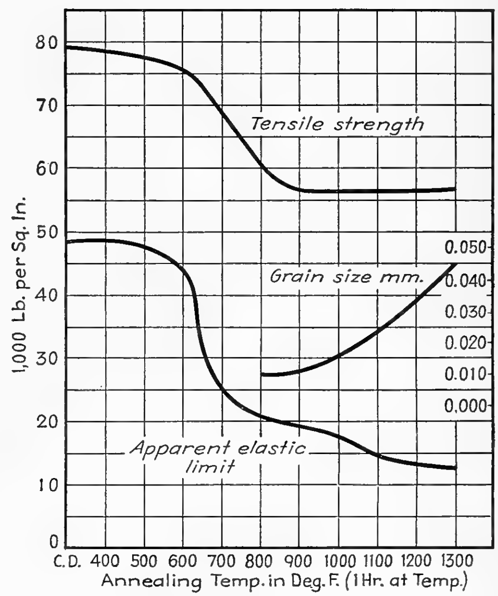


CHART 174.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of Muntz metal rod, previously cold-drawn 30 per cent (reduction of area) from extruded material having a grain size of 0.010 mm. (60.73 % copper) (rod under 1 in. in diameter).

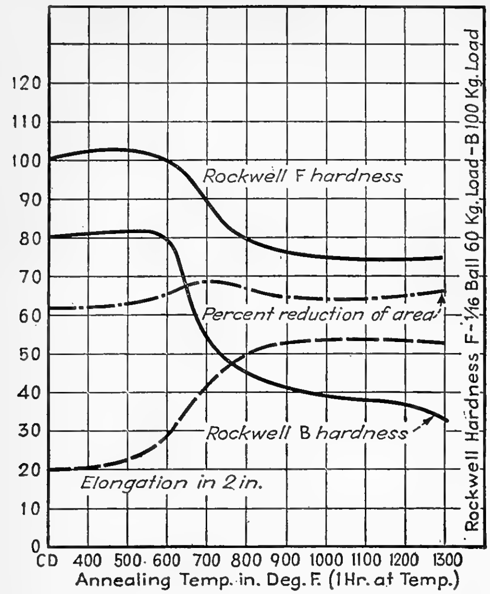


Chart 175.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of Muntz metal rod, previously cold-drawn 30 per cent (reduction of area) from extruded material having a grain size of 0.010 mm. (60.73 % copper) (rod under 1 in. in diameter).

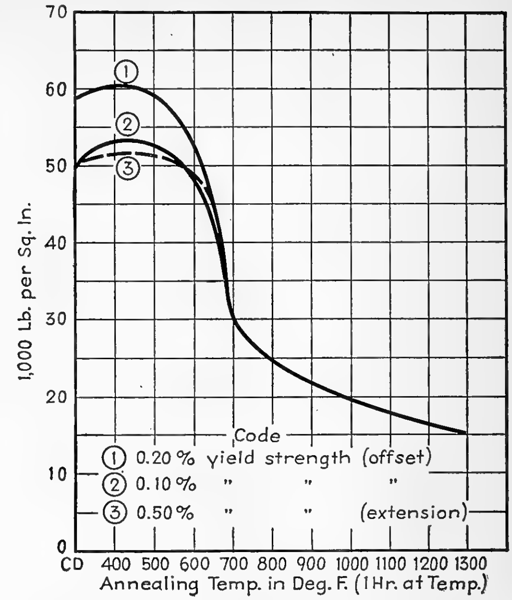


Chart 176.—The effect of annealing on the yield strength of Muntz metal rod, previously cold-drawn 30 per cent (reduction of area) from extruded material having a grain size of 0.010 mm. (60.73 % copper) (rod under 1 in. in diameter)

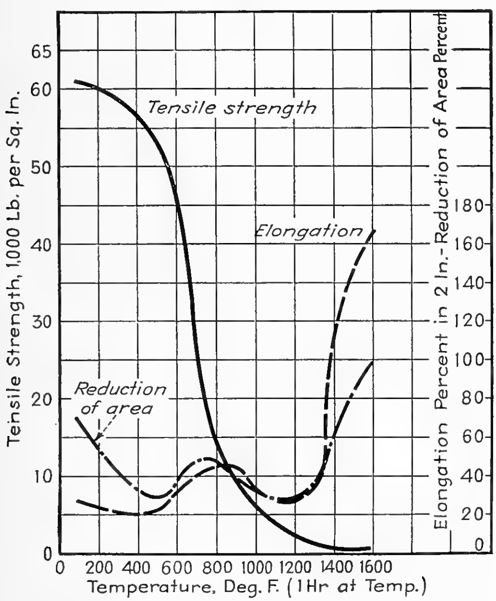


Chart 177.—The effect of elevated temperatures on the tensile strength, percentage reduction of area, and percentage elongation in 2 in. of Muntz metal rod (62.40 % copper), previously cold-drawn 20 per cent (rod under 1 in. in diameter).

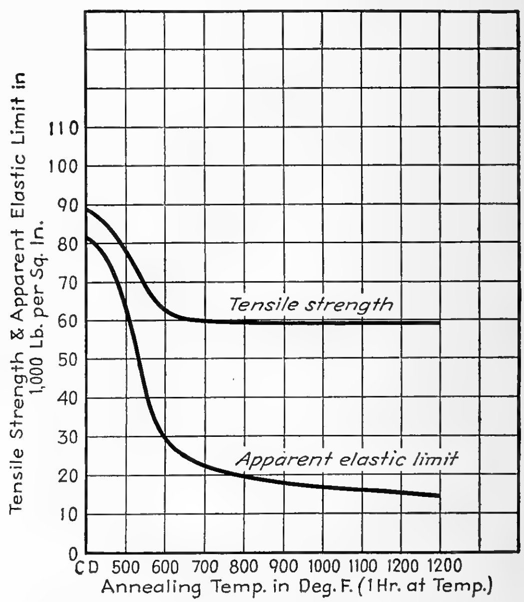


Chart 178.—The effect of annealing on the tensile strength and apparent elastic limit of Muntz metal (60.80 % copper) tube, previously cold-drawn 50 per cent (reduction of area) from a grain size of 0.020 mm.

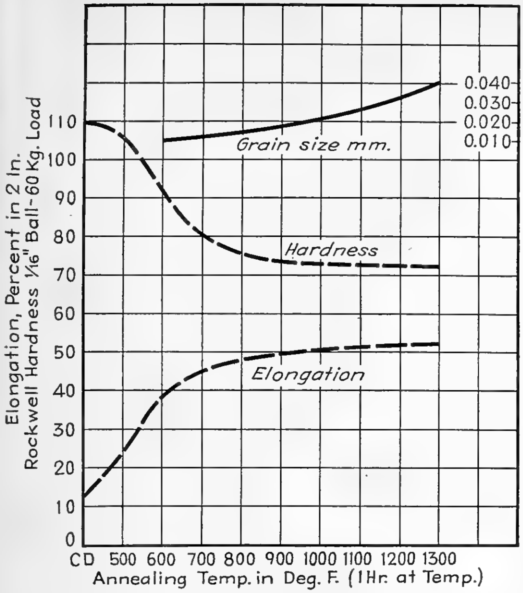


CHART 179.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and grain size of Muntz metal (60.80 % copper) tube, previously cold-drawn 50 per cent (reduction of area) from a grain size of 0.020 mm.

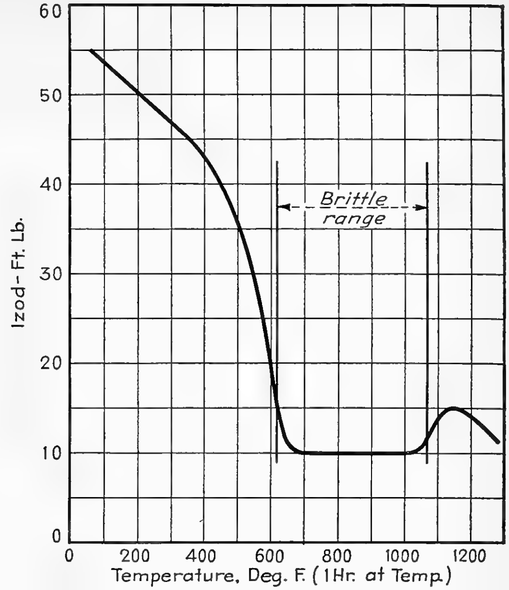


CHART 180.—The effect of elevated temperature on the Izod-impact strength of previously annealed Muntz metal (61.00 % copper) according to D. Bunting.[5]

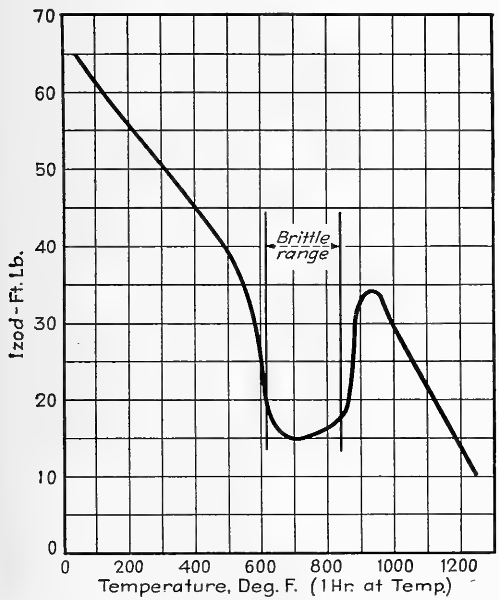


CHART 181.—The effect of elevated temperature on the Izod-impact strength of a previously annealed 58 % copper-zinc alloy according to D. Bunting.[5]

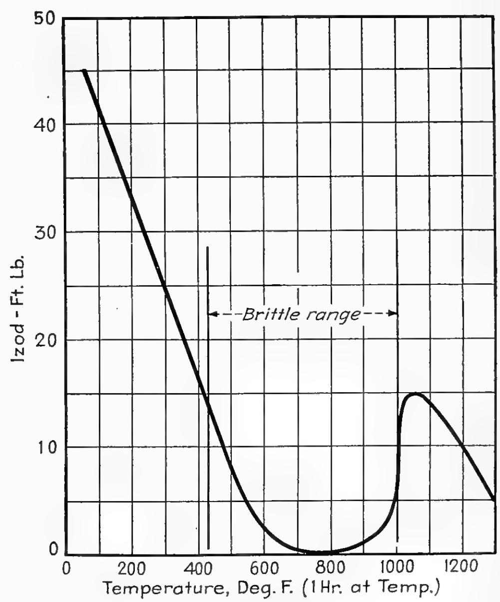


CHART 182.—The effect of elevated temperature on the Izod-impact strength of a previously annealed 52 % copper-zinc alloy according to D. Bunting.[5]

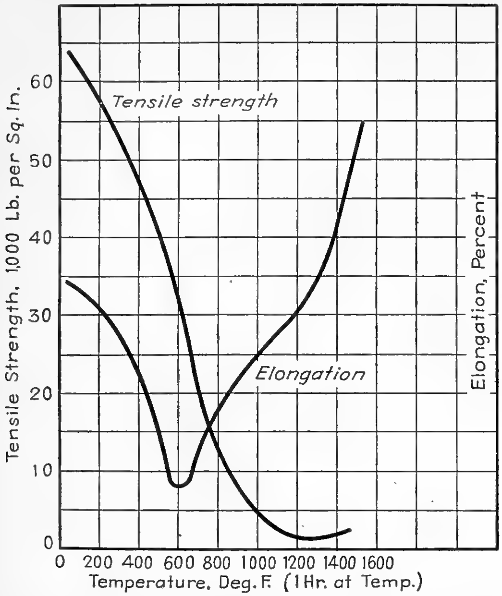


Chart 183.—The effect of elevated temperature on the tensile strength and percentage elongation in 2 in. of rolled Muntz metal (60.52 % copper, 0.40 % lead) according to Bengough.(11,9)

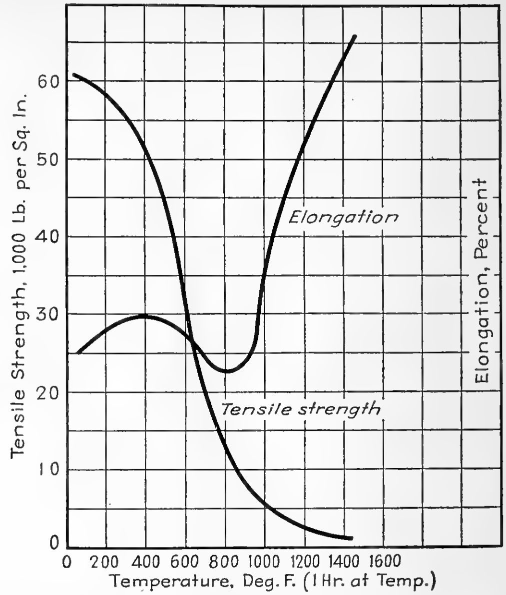


Chart 184.—The effect of elevated temperature on the tensile strength and percentage elongation in 2 in. of rolled Muntz metal (59.52 % copper, 0.74 % lead, 0.39 % nickel) according to Bengough.(11,9)

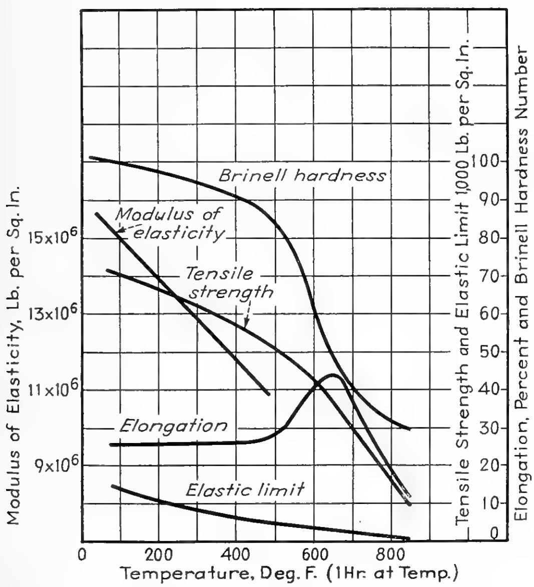


Chart 185.—The effect of elevated temperature on the tensile strength, elastic limit, modulus of elasticity, Brinell hardness, and percentage elongation in 2 in. of a modified Muntz metal (58.96 % copper, 0.56 % tin, 0.67 % lead) according to Lea.(12,13,9)

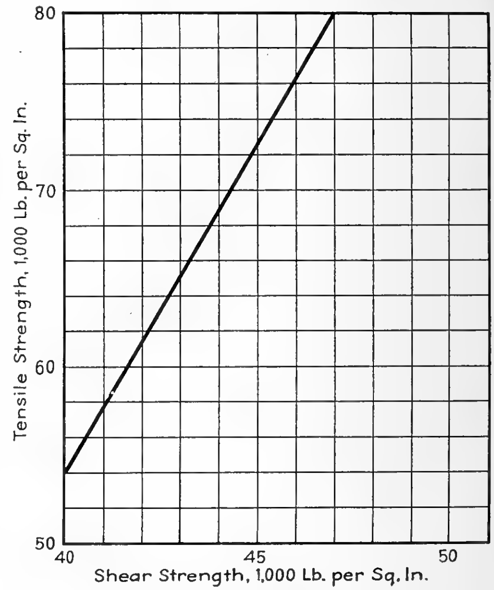


Chart 186.—Conversion chart for determination of shear strength of Muntz metal (60.00 % copper, balance zinc) when tensile strength is known. Accurate to ±5 %.(86)

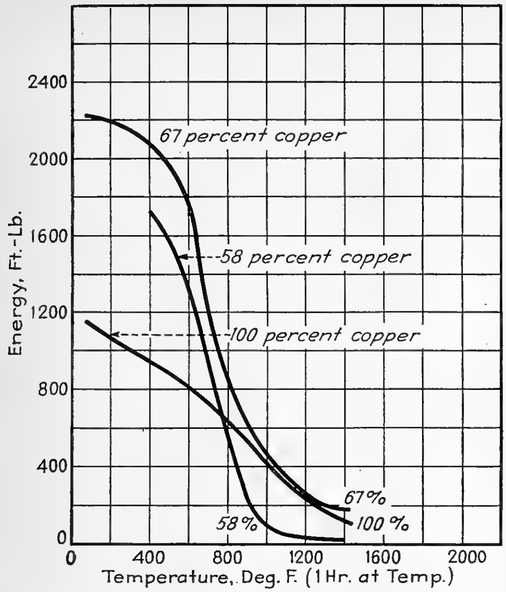


CHART 187.—The effect of elevated temperature on the resistance to compression of copper-zinc alloys according to Doernickel and Trockkels.(14,9)

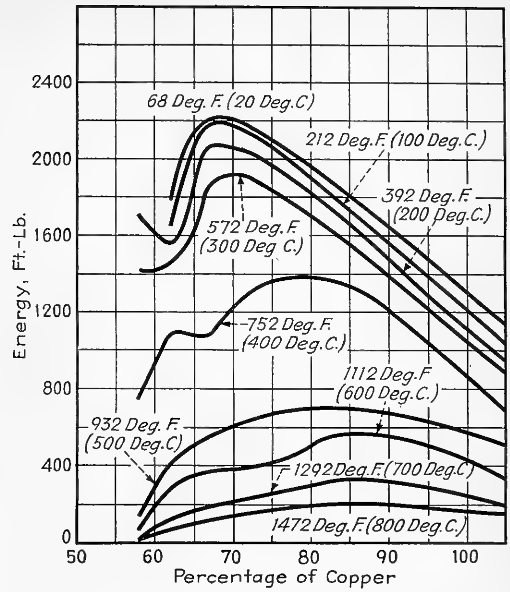


CHART 188.—The effect of chemical composition on the resistance to compression of copper-zinc alloys at various temperatures according to Doernickel and Trockkels.(14,9)

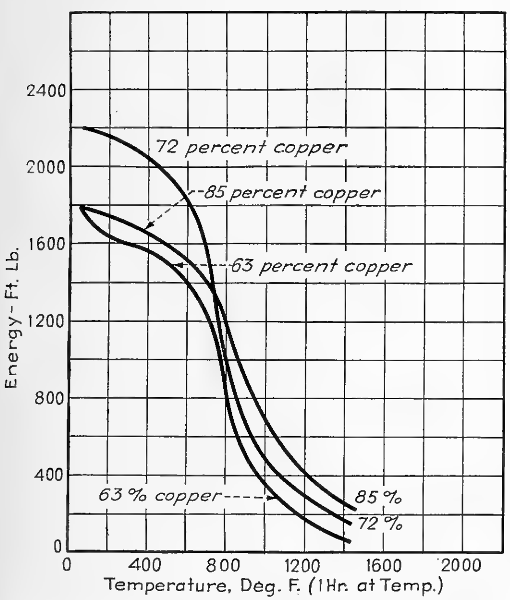


CHART 189.—The effect of elevated temperature on the resistance to compression of copper-zinc alloys according to Doernickel and Trockkels.(14,9)

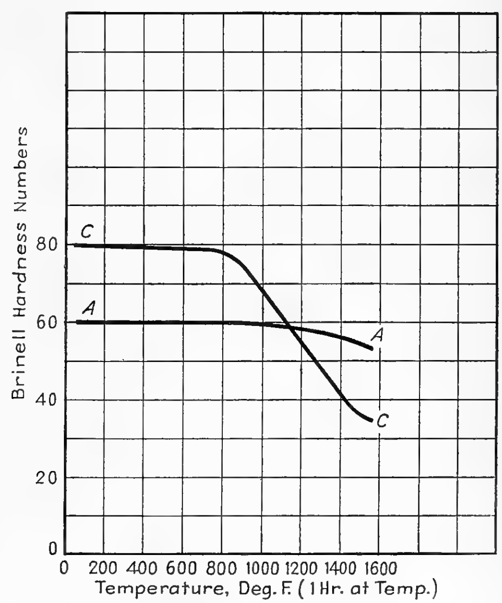


CHART 190.—The effect of elevated temperature on the Brinell hardness of two copper-zinc alloys according to Edwards and Herbert.(15,9) (A—70.63 % copper; C—60.88 % copper.)

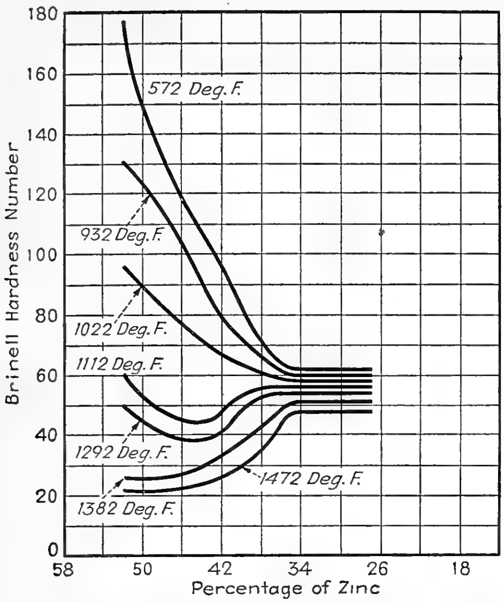


CHART 191.—The effect of chemical composition on Brinell hardness of copper-zinc alloys at various temperatures according to Edwards and Herbert.(15,9)

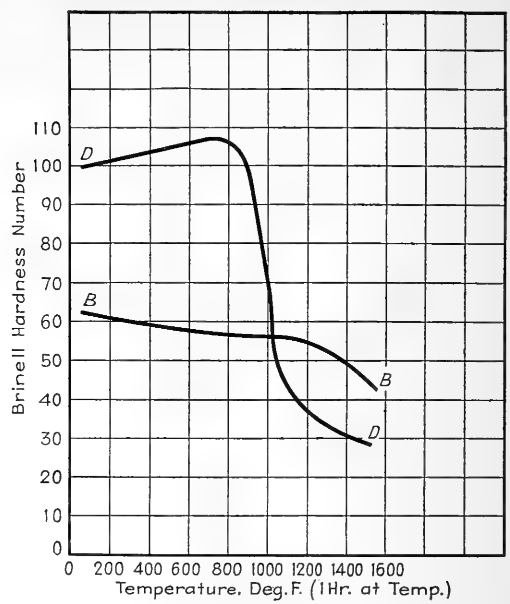


CHART 192.—The effect of elevated temperature on the Brinell hardness of two copper-zinc alloys according to Edwards and Herbert.(15,9) (B—65.10 % copper; D—56.84 % copper.)

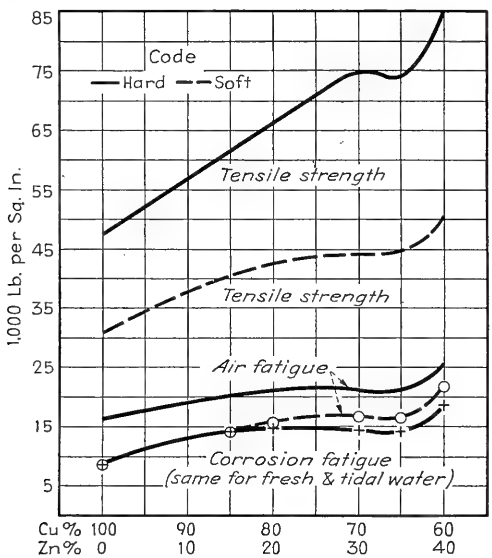


CHART 193.—The tensile strength, fatigue, and corrosion fatigue strength of alloys of copper and zinc according to H. J. Gough.(8)

CHAPTER III

THE LEADED BRASSES

Lead is virtually insoluble in alloys of copper and zinc and, when present, occurs as finely divided and distributed metallic particles. Its presence in brass does not appreciably influence the mechanical strength or corrosion resistance of the parent alloy but it does drastically reduce the ease of flaring, upsetting, cold-heading, and bending operations, all of which can be performed without difficulty on most of the unleaded copper-zinc alloys. The one reason why lead is added to brass is to improve its machinability. Copper-zinc alloys, because of their ductility, machine rather poorly. The chips are long and tough, tool wear is high, and lubrication problems are difficult. Lead uniformly distributed in a brass alloy causes the chips to break off and, since the chips of leaded brass are practically undistorted and are only in momentary contact with the tool face, very little heat is transmitted to the cutting edge of the tool during machining.

With leaded brasses, friction between the chip and the tool is reduced to a minimum. Experiments conducted on leaded brass indicate that, at any feed with cutting speeds up to 500 feet per minute, the principal factor determining the cutting life of the tool is the linear distance traveled by the cutting edge in contact with the work.[(16)]

In selecting leaded brass for a particular application, however, thought must be given not only to the matter of machinability, but to the question of the influence of lead on future operations or on the service life or performance of the fabricated part.

Brass that is to be cold-headed should contain little if any lead. Careful control of lead is required in brass that is to be brazed, welded, or silver-soldered. Where spinning, heavy knurling, or heavy roll-threading operations are to be performed, a high lead content should be avoided. There are available brass rods either lead-free or semi-leaded that are satisfactory for operations of this type.

Lead in brasses definitely improves shearing, blanking, and piercing operations.

Lead in the alpha brasses renders them hot short and unsuitable for fabricating by hot-working methods.

The alpha-beta brasses containing between 55 and 60 per cent of copper can be hot-rolled if the lead does not exceed 1 per cent and can be successfully hot-forged with up to 2 per cent of lead. If greater amounts of lead than this are present, cracking in forging may occur. As the copper content increases beyond 60 per cent, smaller amounts of lead can be tolerated. When the limit of the beta phase is reached, between 63 and 64 per cent of copper, lead must be kept to a trace if hot-working properties are to be retained.

In the annealing of leaded brasses care must be taken to avoid sudden exposure of cold-worked parts or material to high temperature as the presence of lead makes brass more sensitive to "fire cracking" (see Brasses).

There are available today a wide range of compositions in leaded brass to cover a multiplicity of requirements. The most common commercial leaded brasses are as follows:

Most common name	Copper, %	Lead, %	Zinc, %
Hardware "bronze"	87–90	1–2	Balance
Lancashire brass	73	2.50	Balance
Leaded high brass	65	0.90	Balance
Brass rod (leaded)	64	1.25	Balance
Heavy-leaded sheet	64	2.50	Balance
Engraver's brass	63.50	1.50	Balance
Leaded brass	62	1.50	Balance
Riveting and turning rod	62	1.60	Balance
Free-cutting brass rod	61.50	3.00	Balance
Low-leaded rod	63	0.50	Balance
Deep-drilling rod	61.50	3.75	Balance
Forging rod	60	2.00	Balance
Extruded shapes	59	2.00	Balance
Architectural "bronze"	56.50	2.20	Al, 0.3%; Zn, balance
Red brass	55	1.50	Balance

Hardware bronze, so-called because it is used in the manufacture of hardware, is most commonly fabricated in rod form. This material has excellent cutting properties and has a color closely approximating that of the more expensive tin bronzes. In addition, it has corrosion- and tarnish-resistance properties approximating that of copper. The most important physical and general mechanical properties are given in Table 1 on page 91. Detailed data on the effect of cold working and annealing on the mechanical properties are given on Charts 1 to 7 on pages 91 to 93.

Lancashire brass is widely used in the fabrication of clock parts. The presence of the lead in this alloy causes it to shear and punch with clean, smooth edges. It is most commonly fabricated in strip form only. Physical properties and general mechanical properties are given in Table 2. More detailed data are given in Charts 8 to 20 on pages 94 to 97.

Superior figures in parentheses refer to the numbered items in the Bibliography, pages 331–332.

Leaded high brass has the same copper content as common high brass, which is one of the most popular of all the brasses and which is used extensively for deep drawing, stamping, or any cold operation requiring unusual ductility. Lead is present in this mixture to improve piercing, punching, and shearing operations. Because of the high copper and reasonably low lead content, this alloy is well suited for those applications requiring good machinability, shearing, and punching properties in combination with reasonably good bending and forming properties. It is extensively used for the manufacture of plumbing parts and is most commonly fabricated in strip form. Its physical properties and general mechanical properties are given in Table 3. More detailed data are given in Charts 21 to 32 on pages 98 to 100.

Leaded-brass rod, because of its copper and low lead content, has the same desirable properties as leaded high brass and it is suited for applications requiring these properties. This alloy is seldom supplied except in rod form. It is used in the manufacture of spark-plug terminals, battery terminals, and similar machined parts that are required to be knurled. Its physical and general mechanical properties are shown in Table 4 on page 101. More detailed mechanical data are given in Charts 33 to 40 on pages 101 to 103.

Heavy-leaded brass containing 2.50 per cent of lead and engraver's brass containing 1.50 per cent of lead are used extensively for applications involving good free-cutting properties. The more severe the engraving and/or tooling, the higher the lead content will be. Both of these alloys have poor bending or forming properties and are usually fabricated in strip form only. Their physical and general mechanical properties are given in Tables 5 and 6 on pages 103 and 107. Greater detailed mechanical properties are shown in Charts 41 to 63 on pages 104 to 110.

Free-cutting brass rod is the most important of all the leaded brasses. Each year millions of pounds are consumed in the manufacture of screws, nuts, bolts, door hinges, and general hardware of all kinds. This product has excellent plasticity within a temperature range of 1200 to 1450° F. and can be extruded into intricate shapes. It cannot be hot-rolled or forged because of its high lead content. It is usually fabricated by hot extruding and cold drawing to size. Commercially free-cutting brass rod is furnished in the hard condition for best machining properties. If very light upsetting operations are necessary in the manufacture of a specific part, it is best practice to use an annealed or soft rod, thereby sacrificing somewhat machining or free-cutting properties in order to obtain the ductility required. Physical and general mechanical properties are shown in Table 9 on page 115. More detailed data are given in Charts 80 to 87 on pages 116 and 117.

Deep-drilling rod, as the name implies, is used for parts requiring deep and accurate drilling. Because of the very high lead content of this alloy, tool and drill wear is reduced to a minimum. This alloy is most commonly supplied in the form of rod. Physical and general mechanical properties are given in Table 11 on page 120. Charts 94 to 100 on pages 120 to 122 give in greater detail the effect of cold working and annealing on the mechanical properties.

Riveting and turning rod represents a compromise between good machining and forming properties. This alloy has good free-cutting properties and in addition can be lightly cold-worked by such operations as riveting, flanging, upsetting, knurling, and roll threading. Its physical and general mechanical properties are given in Table 7, and Charts 64 to 69 on pages 111 and 112 show the effect of cold drawing and annealing on the mechanical properties.

Low-leaded rod is used extensively in the manufacture of screws, bolts, and like parts, which require for their manufacture good cold-upsetting properties in combination with fair machinability. Although this alloy is considerably more difficult to machine than free-cutting brass, the presence of 0.50 per cent of lead drastically increases the machinability over that of a non-leaded brass in this composition range at not too great a sacrifice of ductility. For example, an addition of 0.60 per cent of lead to an alloy of this type reduces the power required by machining 46 per cent; a 3.5 per cent lead addition will reduce it by only 15 per cent more. Physical and general mechanical properties are given in Table 10. Charts 88 to 93 on pages 118 and 119 show the influence of cold working and annealing treatment.

Forging rod is used almost exclusively for the production of hot pressings and hammer forgings. It contains the maximum of lead that will not cause difficulty in its copper range in hot forging. This alloy is extremely plastic within a temperature range of 1200 to 1450°F. and can be shaped hot into a multiplicity of shapes. It is used for the fabrication of all kinds of brass hardware, ammunition parts, transformer caps, valve stems, plumbing fixtures, and similar parts. Lead is present as an aid to machinability and also to improve piercing, punching, and shearing operations. The physical and general mechanical properties of brass forging rod are given in Table 12. For greater detail see Charts 101 to 107 on pages 123 and 124.

Architectural bronze and *extruded-shape brass,* because of their lower copper content and consequently greater amount of beta phase, are considerably more plastic than forging rod and consequently can be extruded with less power and greater ease into more intricate shapes. These leaded alloys may contain a small amount of aluminum added primarily for its effect on color. Copper-zinc alloys in this range of copper have a color approximating the "bronzes" and for this reason are known commercially as "architectural bronze." As the name implies, they are used for architectural trim in such applications as door frames, jambs, thresholds, cornices, and window sash. Physical and general mechanical properties are shown in Tables 13 and 14 on pages 125 and 127. Charts 108 to 120 on pages 125 to 129 give in greater detail the effect of cold working and annealing on the mechanical properties of this alloy.

Red brass (forging) is used for the hot forging or stamping of plumbing fixtures. Its color closely approximates the higher copper content copper-zinc alloy containing 85 per cent of copper and for that reason it is known as "red" brass. Its physical and general mechanical properties are given in Table 15 on page 129. More detailed mechanical data are given in Charts 121 to 126 on pages 130 and 131.

TABLE 1
HARDWARE BRONZE
GENERAL DATA—ROD
Copper, 88.78%; lead, 1.61%; zinc, balance

Property	Hard[a]	Soft[b]
Tensile strength, p.s.i. (000 omitted)	62	37
Apparent elastic limit, p.s.i. (000 omitted)	50	6
Yield strength, 0.5% extension, p.s.i. (000 omitted)	59	10
Yield strength, 0.2% offset, p.s.i. (000 omitted)	61	9
Yield strength, 0.1% offset, p.s.i. (000 omitted)	55	8
Elongation, % in 2 in.	15	50
Reduction of area, %	60	70
Endurance limit, p.s.i. (000 omitted)	18	12
Rockwell hardness F, $\frac{1}{16}$-in. ball, 60-kg. load	96	50
Rockwell hardness B, $\frac{1}{16}$ ball, 100-kg. load	64	
Modulus of elasticity, p.s.i.	15,000,000	
Melting point, °F.	1913	
Density, lb. per cu. in.	0.318	
Coefficient of expansion, per °C. from 25–300°C.	0.0000182	
Electrical conductivity,[87] % I.A.C.S, 68°F.	42.3	
Thermal conductivity,[87] B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	104	

[a] Refers to rod cold-drawn 37%; rod under 1 in. in diameter, ready-to-finish grain size, 0.050 mm.
[b] Refers to rod cold-drawn 37% and annealed at 1300°F. for 1 hr. at temperature.

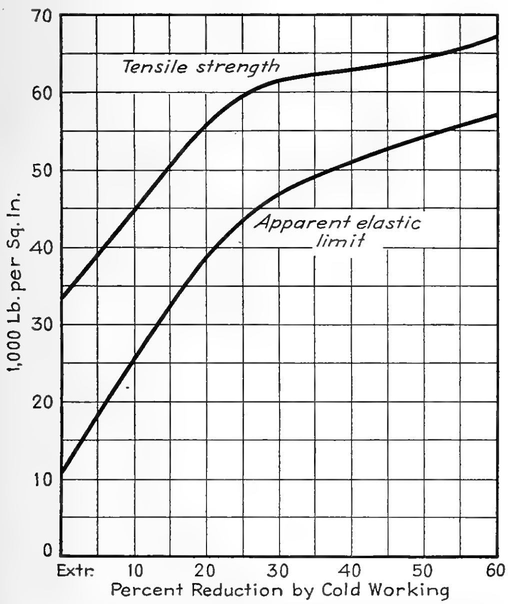


CHART 1.—The effect of cold drawing on the tensile strength and apparent elastic limit of hardware-bronze rod, previously annealed to a grain size of 0.050 mm. (88.78% copper, 1.61% lead, balance zinc) (rod under 1 in. in diameter).

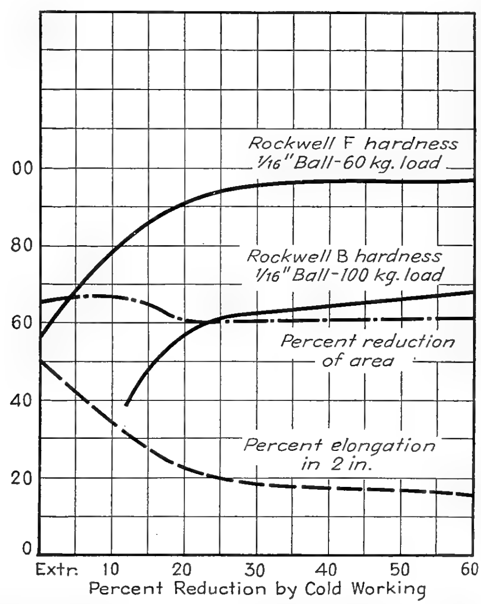


CHART 2.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of hardware-bronze rod, previously annealed to a grain size of 0.050 mm. (88.78% copper, 1.61% lead, balance zinc) (rod under 1 in. in diameter).

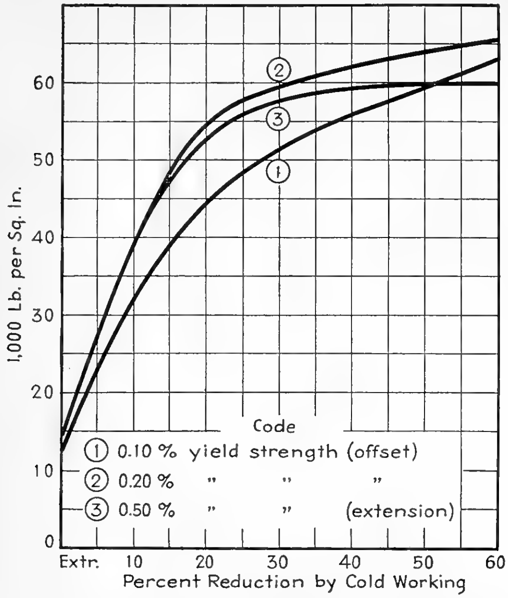


CHART 3.—The effect of cold drawing on the yield strength of hardware-bronze rod, previously annealed to a grain size of 0.050 mm. (88.78 % copper, 1.61 % lead, balance zinc) (rod under 1 in. in diameter).

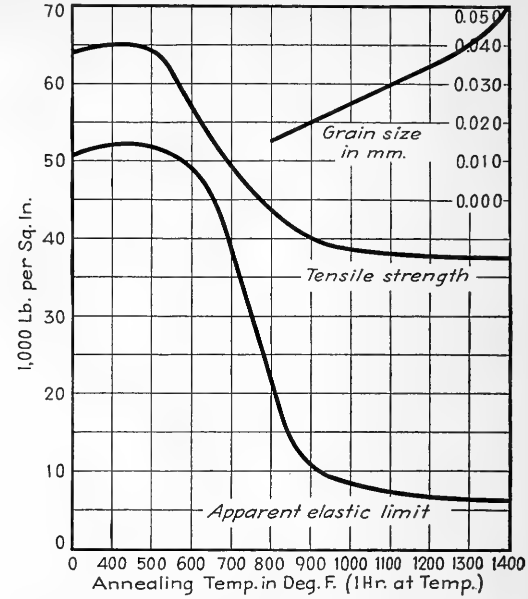


CHART 4.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of hardware-bronze rod, previously cold-drawn 37 per cent (reduction of area) from material having a grain size of 0.050 mm. (88.78 % copper, 1.61 % lead, balance zinc) (rod under 1 in. in diameter).

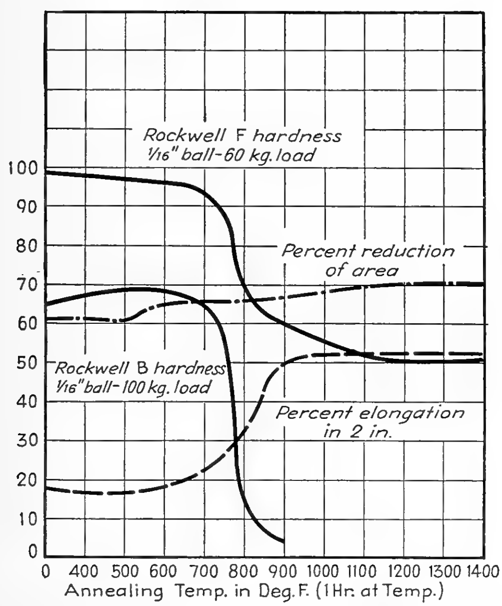


CHART 5.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of hardware-bronze rod, previously cold drawn 37 per cent (reduction of area) from material having a grain size of 0.050 mm. (88.78 % copper, 1.61 % lead, balance zinc) (rod under 1 in. in diameter).

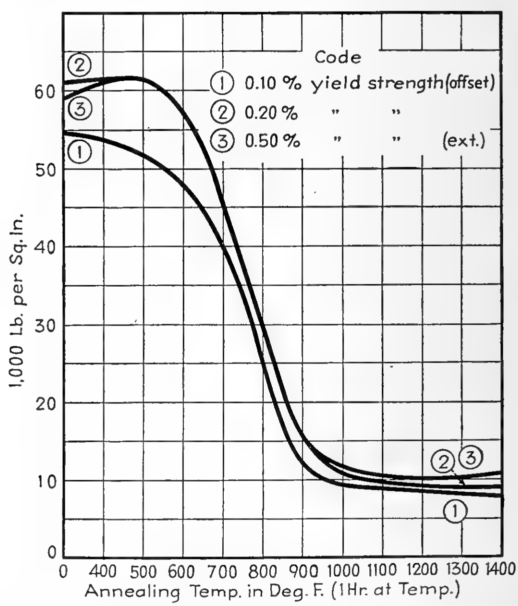


CHART 6.—The effect of annealing on the yield strength of hardware-bronze rod, previously cold-drawn 37 per cent (reduction of area) from material having a grain size of 0.050 mm. (88.78 % copper, 1.61 % lead, balance zinc) (rod under 1 in. in diameter).

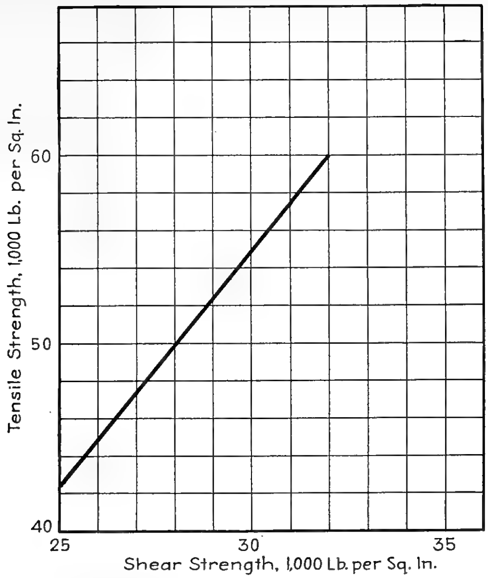


CHART 7.—Conversion chart for determination of shear strength of hardware bronze (87.00 to 90.00 % copper, 1.00 to 2.00 % lead, balance zinc) when tensile strength is known. Accurate to ±5 %.(86)

TABLE 2
LANCASHIRE BRASS
GENERAL DATA—STRIP[a]
Copper, 73.53%; lead, 2.24%; zinc, balance

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	83–95	45–48
Apparent elastic limit, p.s.i. (000 omitted)	56–63	12
Yield strength, 0.5% extension, p.s.i. (000 omitted)	73–86	13–14
Yield strength, 0.2% offset, p.s.i. (000 omitted)	70–81	13–14
Yield strength, 0.1% offset, p.s.i. (000 omitted)	65–70	13–14
Elongation, % in 2 in.	5	59–54
Rockwell hardness F, 1/16-in. ball, 60-kg. load	106–108	64
Rockwell hardness B, 1/16-in. ball, 100-kg. load	85–89	13
Rockwell hardness G, 1/16-in. ball, 150-kg. load	56–65	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	90–90	65
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	74–78	23
Endurance limit, p.s.i. (000 omitted)	23	17
Young's modulus of elasticity, p.s.i.	15,000,000	
Melting point, °F.	1769	
Density, lb. per cu. in.	0.309	
Coefficient of expansion, per °C. from 25–300°C.	0.0000198	
Electrical conductivity, % I.A.C.S., 68°F.	28.6	
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	71	

[a] All tests conducted on 0.040-in. stock.
[b] 6 B. & S. Nos., hard, 0.070–0.015 mm. grain size at ready-to-finish.
[c] Refers to 1200°F. anneal (1 hr. at temperature).

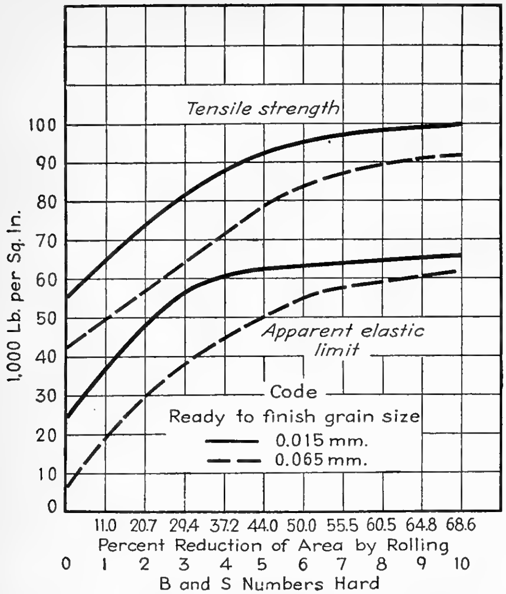


CHART 8.—The effect of cold rolling on the tensile strength and apparent elastic limit of Lancashire brass strip, previously annealed to two different grain sizes, 0.015 and 0.065 mm. (73.53 % copper, 2.24 % lead, balance zinc) (0.040-in. stock).

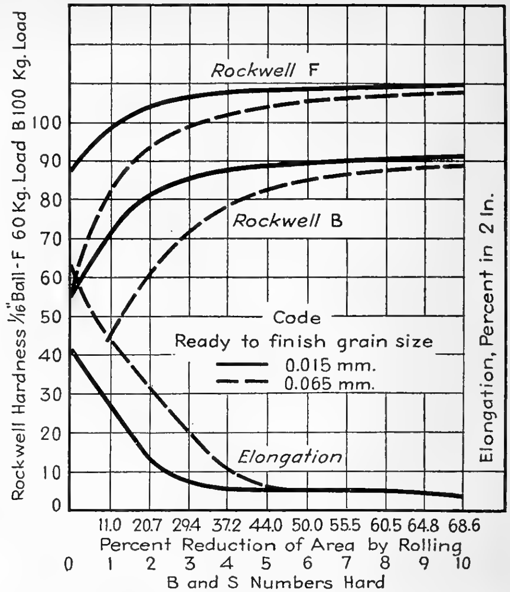


CHART 9.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of Lancashire brass strip, previously annealed to two different grain sizes, 0.015 and 0.065 mm. (73.53 % copper, 2.24 % lead, balance zinc) (0.040-in. stock).

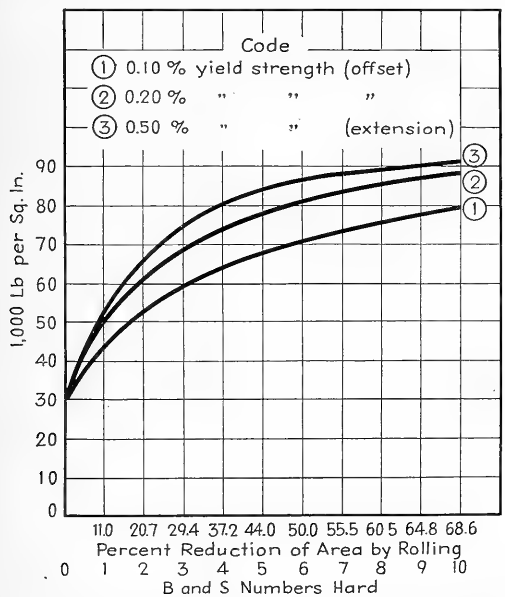


CHART 10.—The effect of cold rolling on the yield strengths of Lancashire brass strip, previously annealed to a grain size of 0.015 mm. (73.53 % copper, 2.24 % lead, balance zinc) (0.040-in. stock).

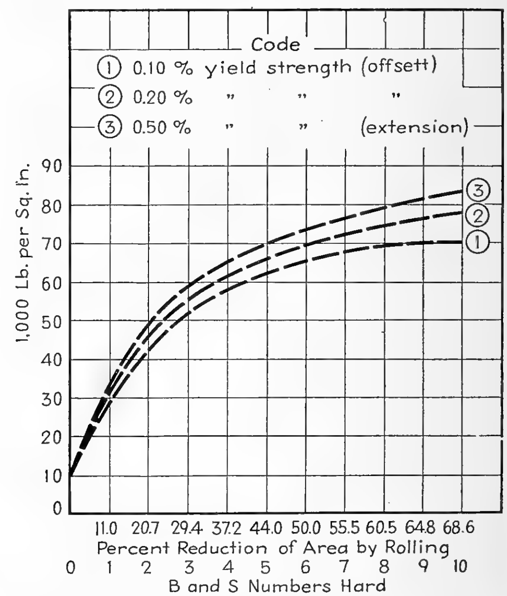


CHART 11.—The effect of cold rolling on the yield strengths of Lancashire brass strip, previously annealed to a grain size of 0.065 mm. (73.53 % copper, 2.24 % lead, balance zinc) (0.040-in. stock).

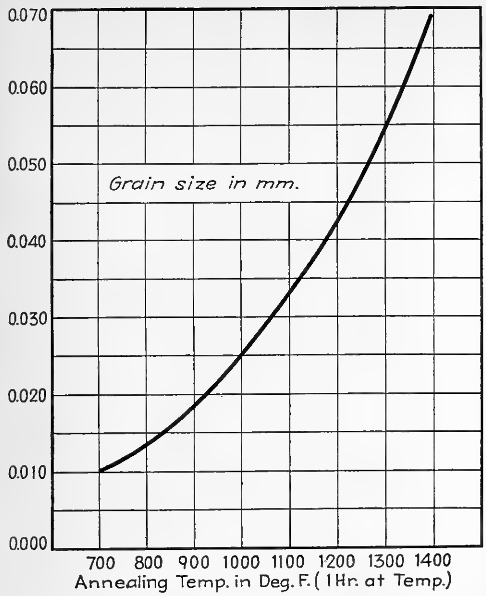


CHART 12.—The effect of annealing on the grain-growing characteristics of Lancashire brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.065 mm. (73.53 % copper, 2.24 % lead, balance zinc) (0.040-in. stock).

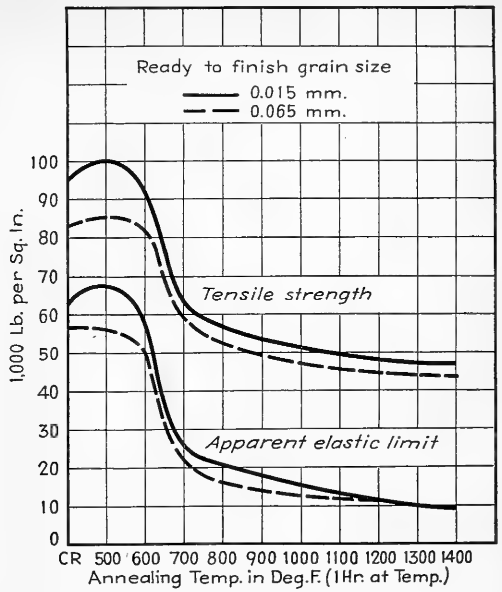


CHART 13.—The effect of annealing on the tensile strength and apparent elastic limit of Lancashire brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.065 mm. (73.53 % copper, 2.24 % lead, balance zinc) (0.040-in. stock).

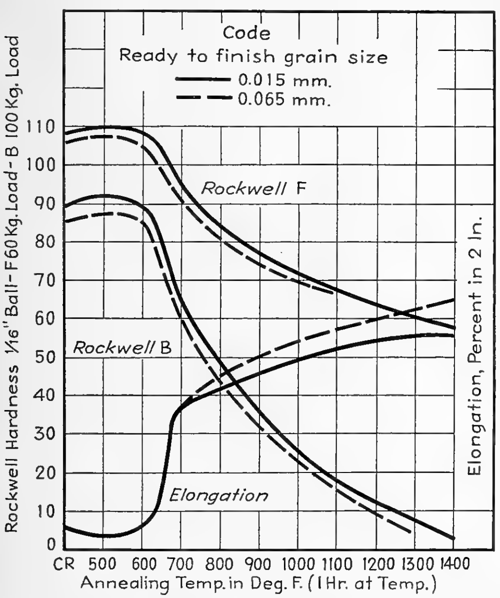


CHART 14.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of Lancashire brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.065 mm. (73.53 % copper, 2.24 % lead, balance zinc) (0.040-in. stock).

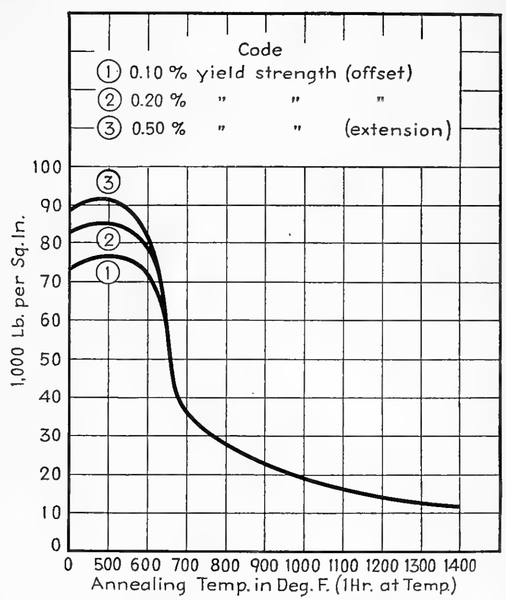


CHART 15.—The effect of annealing on the yield strength of Lancashire brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (73.53 % copper, 2.24 % lead, balance zinc) (0.040-in. stock).

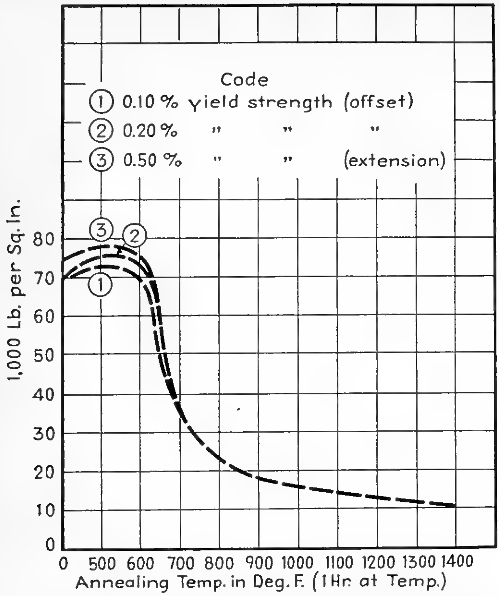


CHART 16.—The effect of annealing on the yield strength of Lancashire brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.065 mm. (73.53 % copper, 2.24 % lead, balance zinc) (0.040-in. stock).

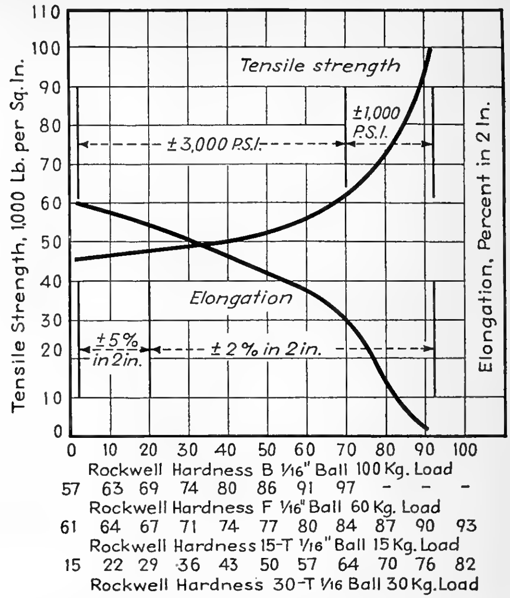


CHART 17.—This chart can be employed to determine the approximate tensile strength and percentage elongation of Lancashire brass strip (73.53 % copper, 2.24 % lead, balance zinc) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 inches within the given limits.

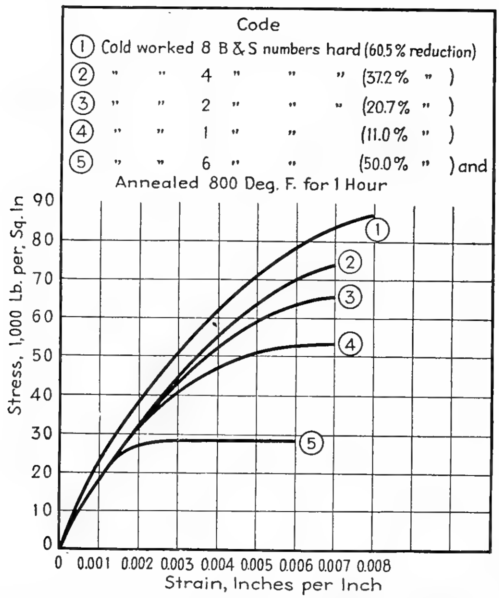


CHART 18.—The effect of cold rolling on the stress-strain characteristics of Lancashire brass strip (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (73.53 % copper, 2.24 % lead, balance zinc.)

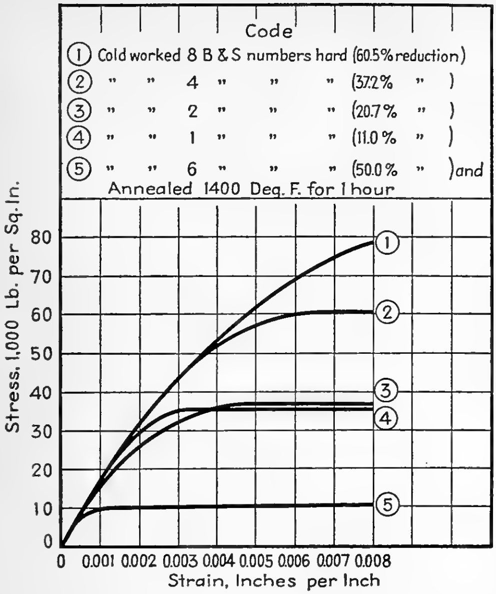


CHART 19.—The effect of cold rolling on the stress-strain characteristics of Lancashire brass strip (0.040 in. thick) having a ready-to-finish grain size of 0.065 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (73.53 % copper, 2.24 % lead, balance zinc.)

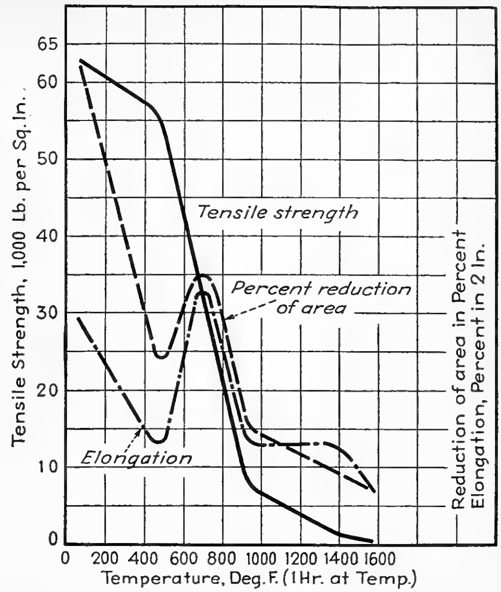


CHART 20.—The effect of elevated temperature on the tensile strength, percentage reduction of area, and percentage elongation of a leaded brass (70.95 % copper, 1.10 % lead, balance zinc) according to W. B. Price.[7]

TABLE 3
LEADED HIGH BRASS

GENERAL DATA—STRIP[a]

Copper, 65.19%; lead, 1.09%; iron, 0.04%; zinc, balance

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	82–98	45–49
Elongation, % in 2 in.	4–6	55–64
Apparent elastic limit, p.s.i. (000 omitted)	61–68	9
Yield strength, 0.5% extension, p.s.i. (000 omitted)	66–67	12–13
Yield strength, 0.2% offset, p.s.i. (000 omitted)	76–83	12–13
Yield strength, 0.1% offset, p.s.i. (000 omitted)	66–73	12–13
Rockwell hardness F, 1/16-in. ball, 60-kg. load	106–110	58–62
Rockwell hardness B, 1/16-in. ball, 100-kg. load	84–91	3–8
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	88–90	62–64
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	73–77	17–21
Young's modulus of elasticity, p.s.i.	15,000,000	
Melting point, °F.	1700	
Density, lb. per cu. in.	0.306	
Coefficient of expansion, per °C. from 25–300°C.	0.0000202	
Electrical conductivity, % I.A.C.S., 68°F.	26	
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F.	67	

[a] All tests conducted on 0.040-in. stock.

[b] 6 B. & S. Nos., hard, 0.080–0.015 mm., grain size at ready-to-finish.

[c] 1200°F. anneal (1 hr. at temperature) of material described in footnote *a*.

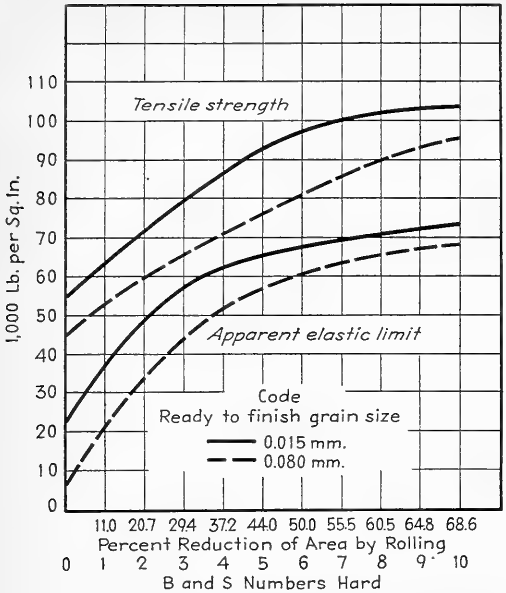


Chart 21.—The effect of cold rolling on the tensile strength and apparent elastic limit of leaded high-brass strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (65.19 % copper, 1.09 % lead, balance zinc) (0.040-in. stock).

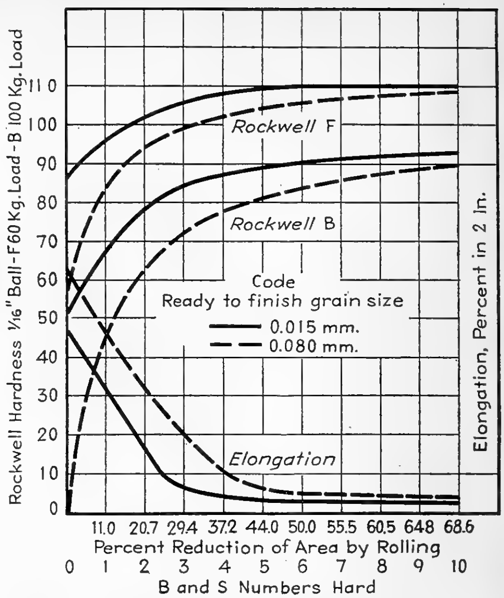


Chart 22.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of leaded high-brass strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (65.19 % copper, 1.09 % lead, balance zinc) (0.040-in. stock).

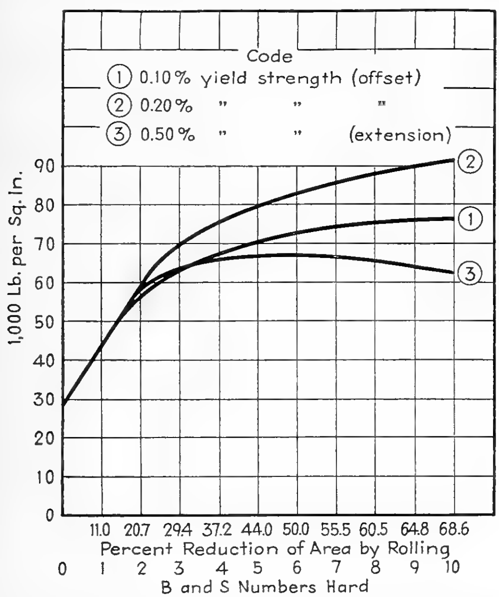


Chart 23.—The effect of cold rolling on the yield strengths of leaded high-brass strip, previously annealed to a grain size of 0.015 mm. (65.19 % copper, 1.09 % lead, balance zinc) (0.040-in. stock).

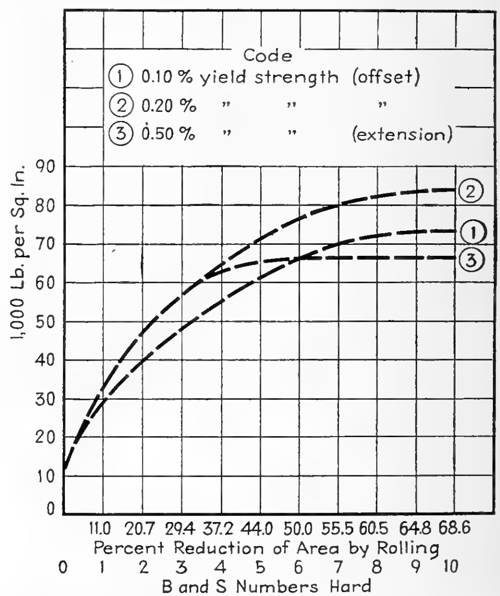


Chart 24.—The effect of cold rolling on the yield strengths of leaded high-brass strip, previously annealed to a grain size of 0.080 mm. (65.19 % copper, 1.09 % lead, balance zinc) (0.040-in. stock).

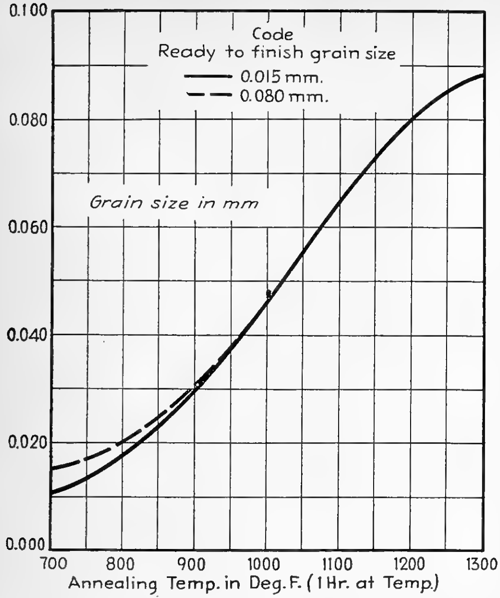


CHART 25.—The effect of annealing on the grain-growing characteristics of leaded high-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (65.19 % copper, 1.09 % lead, balance zinc) (0.040-in. stock).

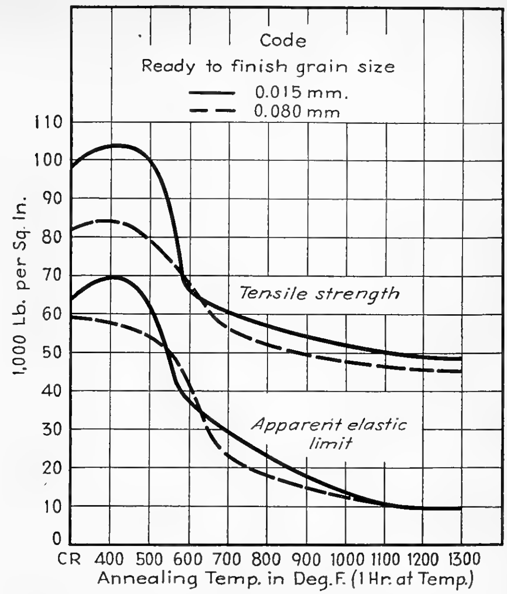


CHART 26.—The effect of annealing on the tensile strength and apparent elastic limit of leaded high-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (65.19 % copper, 1.09 % lead, balance zinc) (0.040-in. stock).

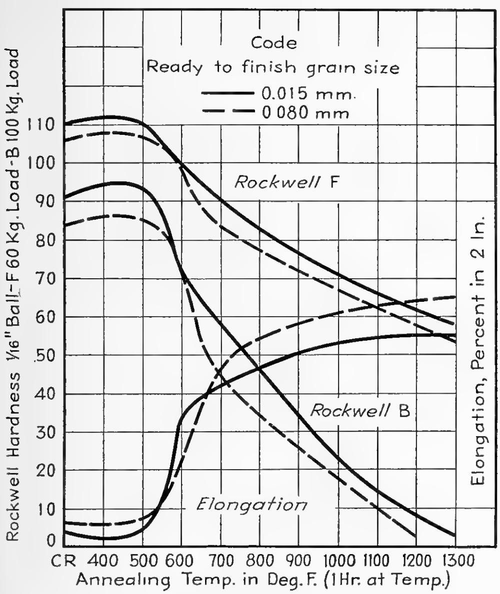


CHART 27.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of leaded high-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (65.19 % copper, 1.09 % lead, balance zinc) (0.040-in. stock).

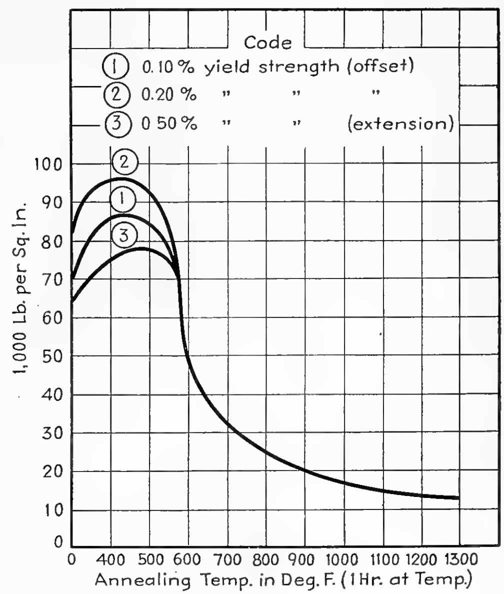


CHART 28.—The effect of annealing on the yield strength of leaded high-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (65.19 % copper, 1.09 % lead, balance zinc) (0.040-in. stock).

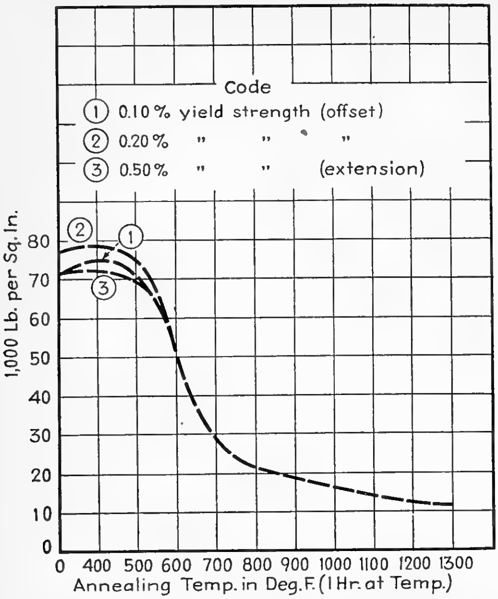


CHART 29.—The effect of annealing on the yield strength of leaded high-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.080 mm. (65.19 % copper, 1.09 % lead, balance zinc) (0.040-in. stock).

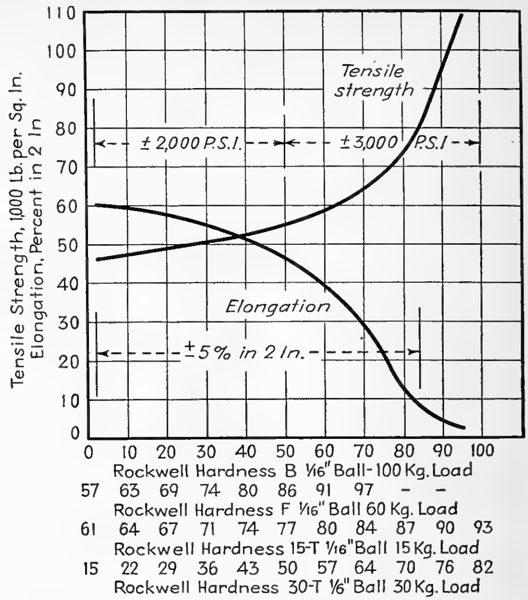


CHART 30.—This chart can be employed to determine the approximate tensile strength and percentage elongation of leaded high-brass strip (65.19 % copper, 1.09 % lead, balance zinc) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

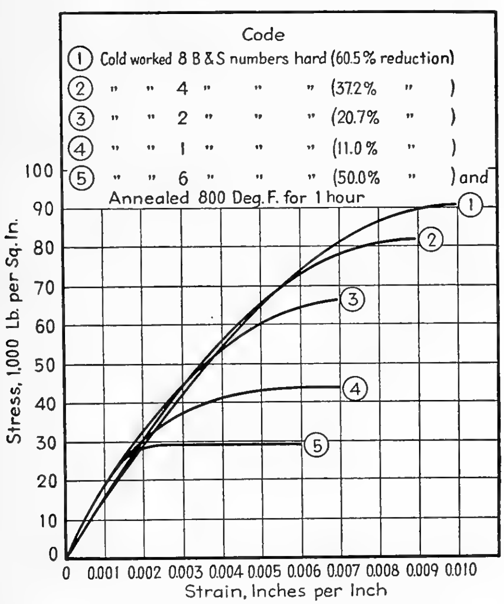


CHART 31.—The effect of cold rolling on the stress-strain characteristics of leaded high-brass strip (65.19 % copper, 1.09 % lead, balance zinc) having a ready-to-finish grain size of 0.015 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used (0.040-in. stock).

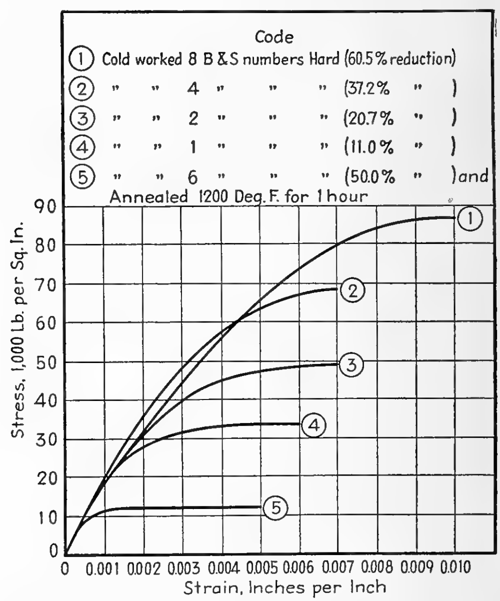


CHART 32.—The effect of cold rolling on the stress-strain characteristics of leaded high-brass strip (65.19 % copper, 1.09 % lead, balance zinc) having a ready-to-finish grain size of 0.080 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used (0.040-in. stock).

TABLE 4
LEADED-BRASS ROD
Copper, 63.89%; lead, 1.38%; iron, 0.10%; zinc, balance

Property	Rod		Forgings
	Hard[a]	Soft[b]	Cold[c]
Tensile strength, p.s.i. (000 omitted)	71	42	45–60
Apparent elastic limit, p.s.i. (000 omitted)	49	13	20–40
Yield strength, 0.5% extension, p.s.i. (000 omitted)	45	15	25–42
Yield strength, 0.2% offset, p.s.i. (000 omitted)	56	15	24–50
Yield strength, 0.1% offset, p.s.i. (000 omitted)	47	15	22–42
Elongation, % in 2 in.	15	60	50–20
Reduction of area, %	50	65	62–58
Rockwell hardness F, 1/16-in. ball, 60-kg. load	100	68	76–96
Rockwell hardness B, 1/16-in. ball, 100-kg. load	76	18	36–68
Brinell hardness, 10-mm. ball, 500-kg. load	122	60	71–107
Modulus of elasticity, p.s.i.	15,000,000		
Melting point, °F.	1680		
Coefficient of expansion, per °C. from 25–300°C.	0.0000202		
Electrical conductivity, % I.A.C.S.	26.8		
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	69		
Density, lb. per cu. in.	0.307		
Type structure	Single phase, alpha		

[a] Refers to rod cold-worked 38%; rod under 1 in. in diameter, ready-to-finish grain size, 0.035–0.045 mm.
[b] Refers to 1100°F. anneal (1 hr.).
[c] Material cold-forged from soft rod (5–20% reduction of area).

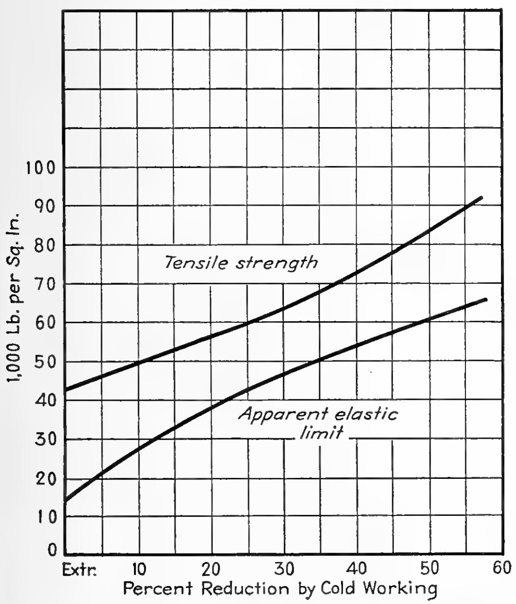


CHART 33.—The effect of cold drawing on the tensile strength and apparent elastic limit of leaded high-brass rod, previously extruded to a grain size of 0.045 mm. (63.89% copper, 1.38% lead, balance zinc) (rod under 1 in. in diameter).

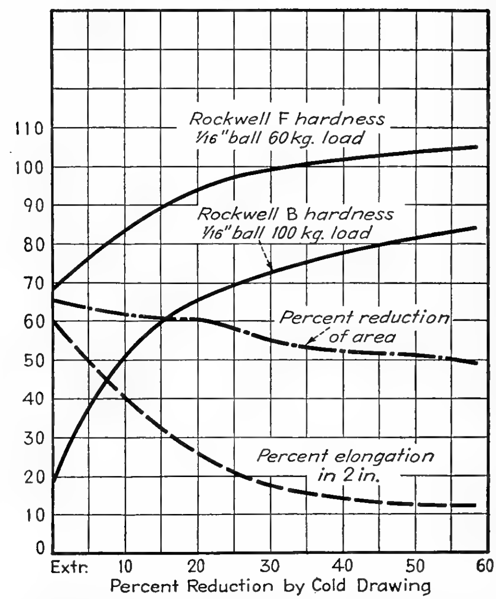


CHART 34.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of leaded high-brass rod, previously extruded to a grain size of 0.045 mm. (63.89% copper, 1.38% lead, balance zinc) (rod under 1 in. in diameter).

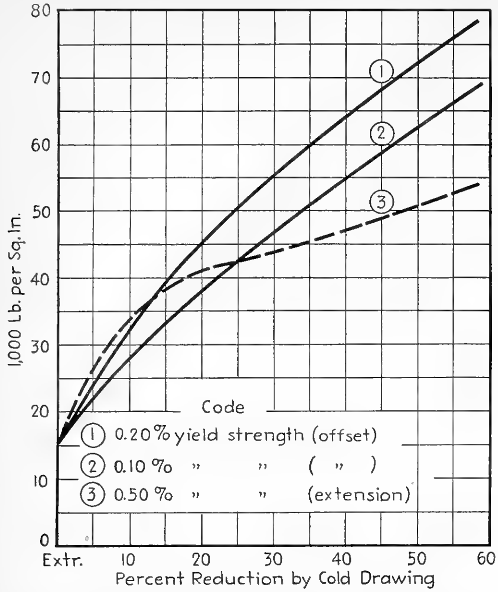


Chart 35.—The effect of cold drawing on the yield strength of leaded high-brass rod, previously extruded to a grain size of 0.045 mm. (63.89 % copper, 1.38 % lead, balance zinc) (rod under 1 in. in diameter).

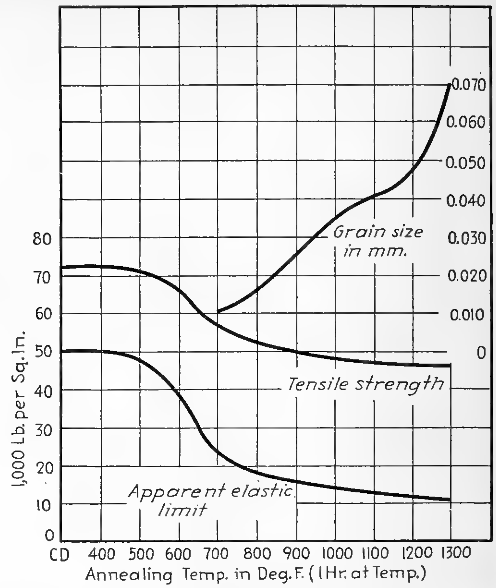


Chart 36.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of leaded high-brass rod, previously cold-drawn 38 per cent (reduction of area) from extruded material having a grain size of 0.045 mm. (63.89 % copper, 1.38 % lead, balance zinc) (rod under 1 in. in diameter).

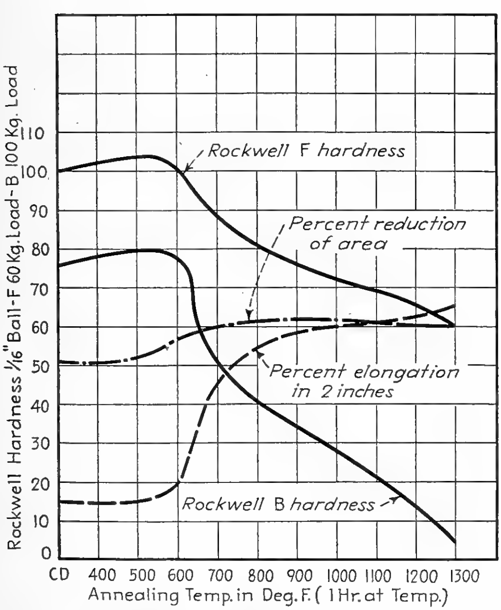


Chart 37.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of leaded high-brass rod, previously cold-drawn 38 per cent (reduction of area) from extruded material having a grain size of 0.045 mm. (63.89 % copper, 1.38 % lead, balance zinc) (rod under 1 in. in diameter).

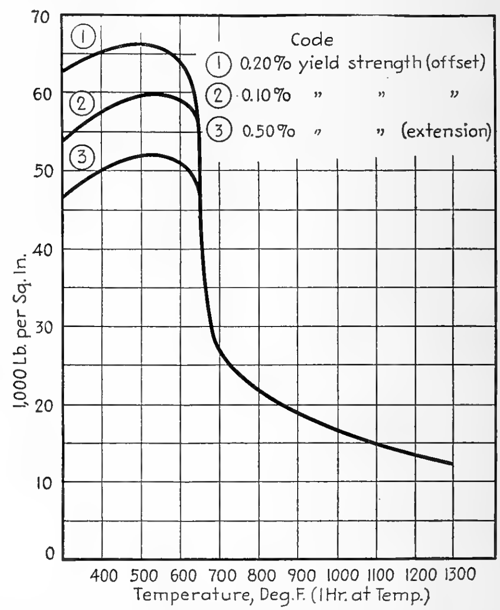


Chart 38.—The effect of annealing on the yield strength of leaded high-brass rod, previously cold-drawn 38 per cent (reduction of area) from extruded material having a grain size of 0.045 mm. (63.89 % copper, 1.38 % lead, balance zinc) (rod under 1 in. in diameter).

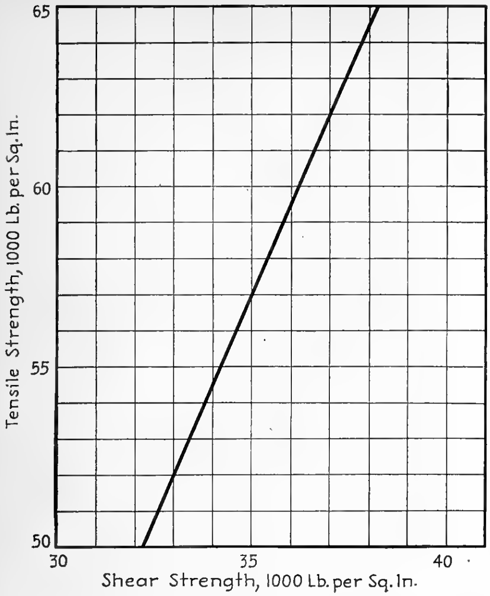


CHART 39.—Conversion chart for determination of shear strength of leaded high brass (65.00 % copper, 0.90 % lead, balance zinc) when tensile strength is known. Accurate to ±5 %.[86]

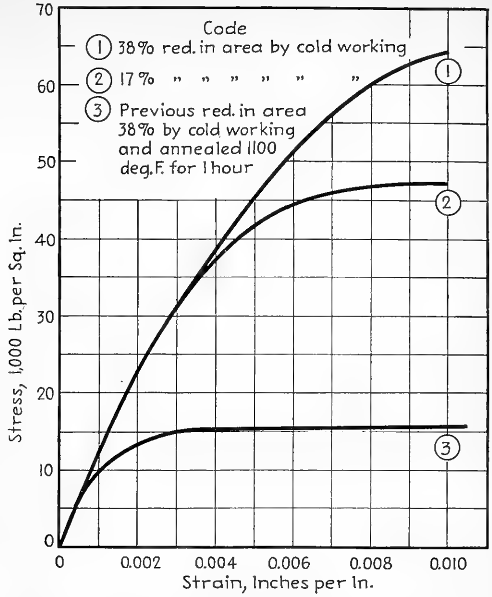


CHART 40.—The effect of cold rolling on the stress-strain characteristics of leaded high-brass rod (under 1 in. in diameter) previously extruded to a grain size of 0.045 mm.; 100,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (63.89 % copper, 1.38 % lead, balance zinc.)

TABLE 5
HEAVY-LEADED BRASS
GENERAL DATA—STRIP[a]
Copper, 63.35%; lead, 2.79%; iron, 0.08%; zinc, balance

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	82–93	44–46
Elongation, % in 2 in.	3–5	58–65
Apparent elastic limit, p.s.i. (000 omitted)	59–62	8–11
Yield strength, 0.5% extension, p.s.i. (000 omitted)	64–66	11–13
Yield strength, 0.2% offset, p.s.i. (000 omitted)	75–79	11–13
Yield strength, 0.1% offset, p.s.i. (000 omitted)	65–70	11–13
Rockwell hardness F, 1/16-in. ball, 60-kg. load	105–108	56
Rockwell hardness B, 1/16-in. ball, 100-kg. load	83–89	
Rockwell hardness G, 1/16-in. ball, 150-kg. load	54–64	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	88–90	
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	72–76	
Charpy impact value, ft.-lb	8	
Young's modulus of elasticity, lb. per sq. in.	15,000,000	
Melting point, °F	1680	
Density, lb. per cu. in.	0.307	
Coefficient of expansion, per °C. from 25–300°C	0.0000204	
Electrical conductivity, % I.A.C.S., 68°F	27	
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F	69	

[a] All tests conducted on 0.040-in. stock.
[b] 6 B. & S. Nos., hard, 0.080–0.015 mm. grain size at ready-to-finish.
[c] 1400°F. anneal (1 hr. at temperature) of material described in footnote *a*.

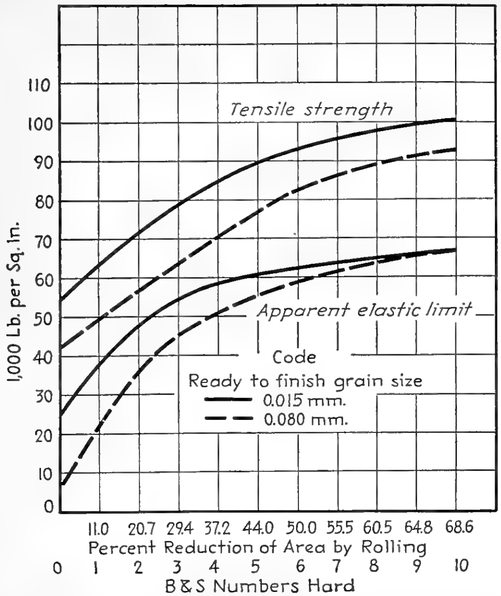


CHART 41.—The effect of cold rolling on the tensile strength and apparent elastic limit of leaded-brass strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (63.35 % copper, 2.79 % lead, balance zinc) (0.040-in. stock).

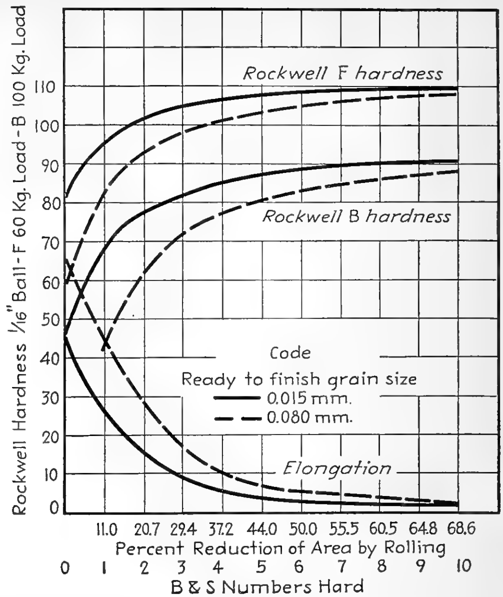


CHART 42.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of leaded-brass strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (63.35 % copper, 2.79 % lead, balance zinc) (0.040-in. stock).

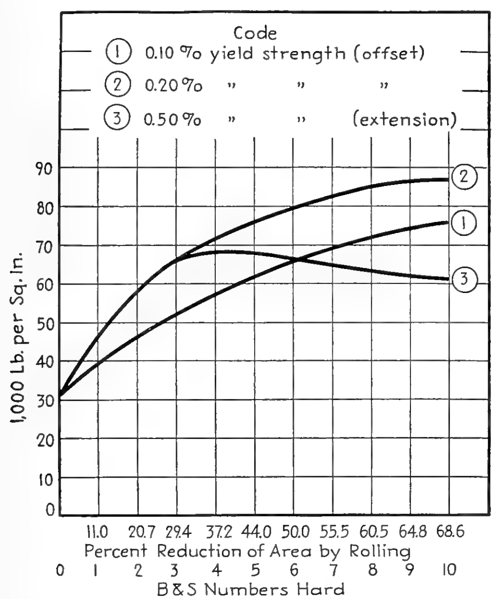


CHART 43.—The effect of cold rolling on the yield strengths of leaded-brass strip, previously annealed to a grain size of 0.015 mm. (63.35 % copper, 2.79 % lead, balance zinc) (0.040-in. stock).

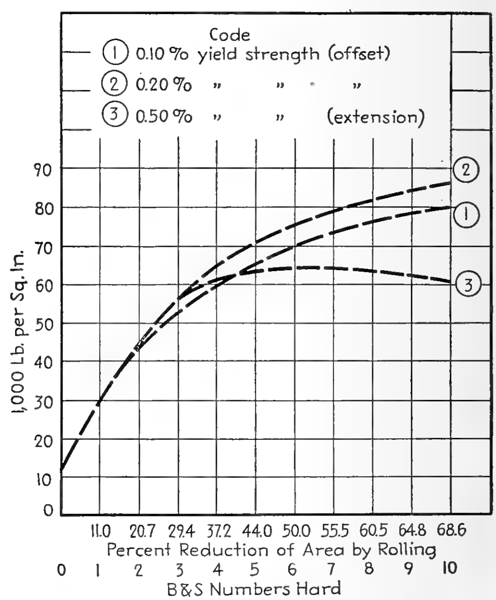


CHART 44.—The effect of cold rolling on the yield strengths of leaded-brass strip, previously annealed to a grain size of 0.080 mm. (63.35 % copper, 2.79 % lead, balance zinc) (0.040-in. stock).

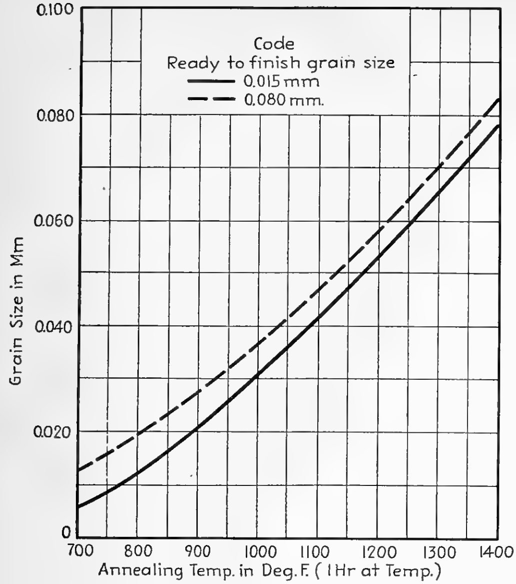


CHART 45.—The effect of annealing on the grain-growing characteristics of leaded-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (63.35 % copper, 2.79 % lead, balance zinc) (0.040-in. stock).

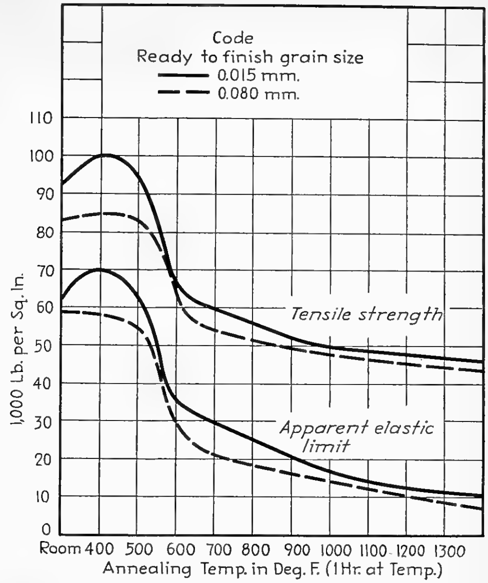


CHART 46.—The effect of annealing on the tensile strength and apparent elastic limit of leaded-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (63.35 % copper, 2.79 % lead, balance zinc) (0.040-in. stock).

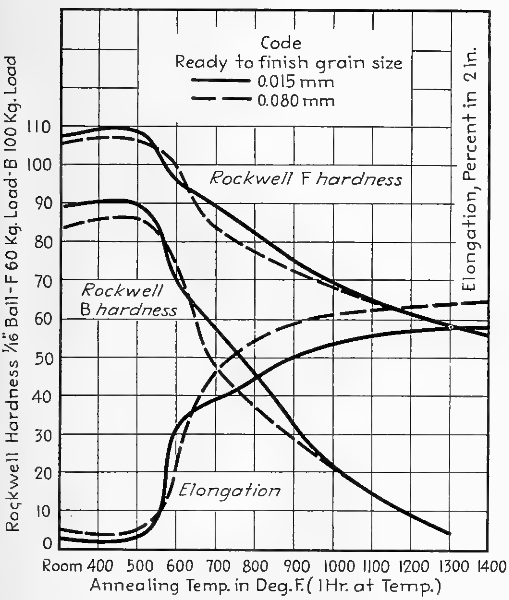


CHART 47.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of leaded-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (63.35 % lead, balance zinc) (0.040-in. stock).

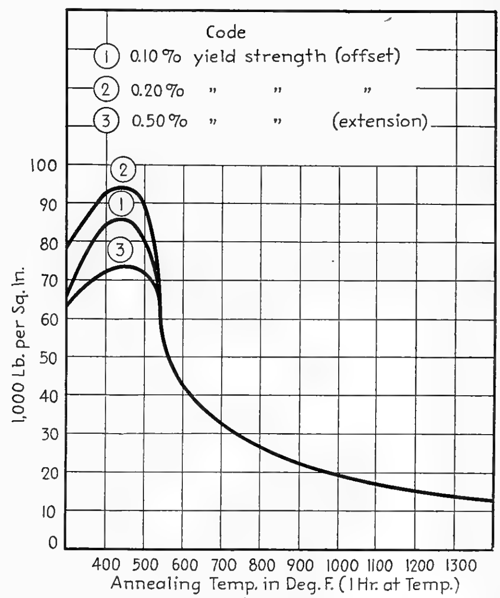


CHART 48.—The effect of annealing on the yield strength of leaded-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (63.35 % copper, 2.79 % lead, balance zinc) (0.040-in. stock).

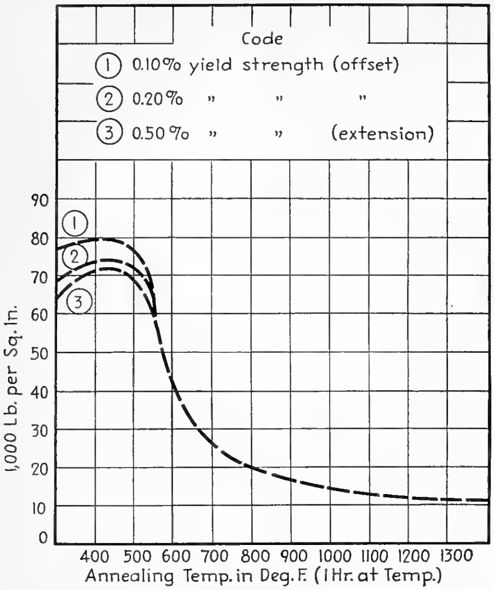


CHART 49.—The effect of annealing on the yield strength of leaded-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.080 mm. (63.35 % copper, 2.79 % lead, balance zinc) (0.040-in. stock).

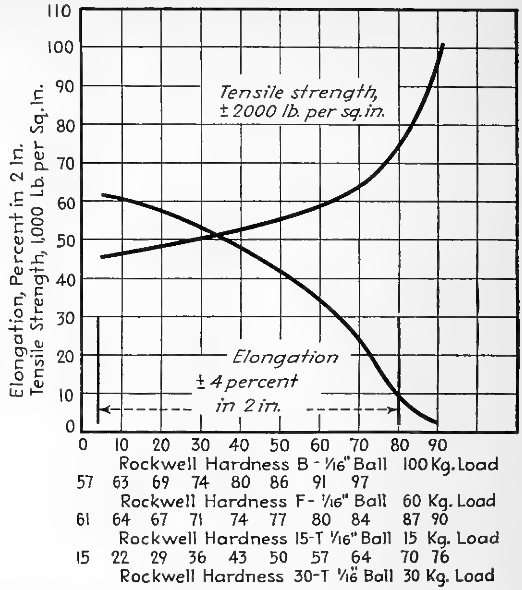


CHART 50.—This chart can be employed to determine the approximate tensile strength and percentage elongation of leaded-brass strip (63.35 % copper, 2.79 % lead, balance zinc) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

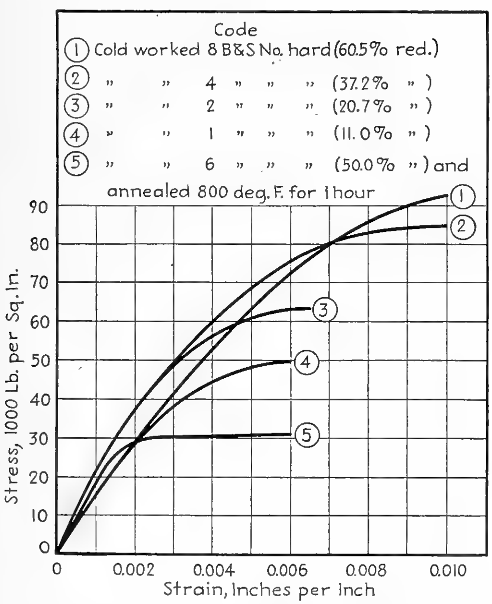


CHART 51.—The effect of cold rolling on the stress-strain characteristics of heavy leaded-brass strip (0.040 in. thick) (63.35 % copper, 2.79 % lead, balance zinc) having a ready-to-finish grain size of 0.015 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used.

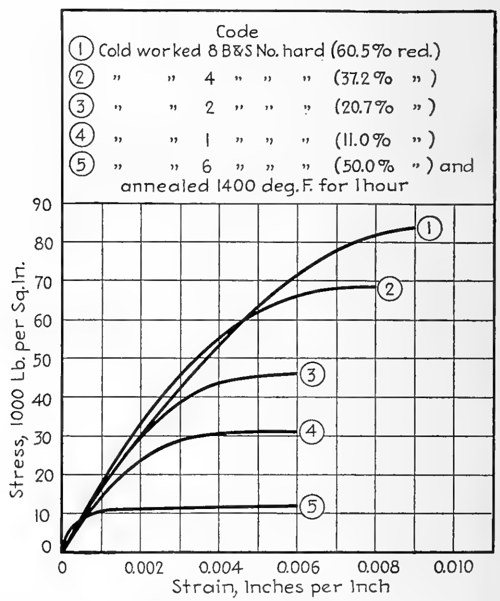


CHART 52.—The effect of cold rolling on the stress-strain characteristics of heavy leaded-brass strip (0.040 in. thick) (63.35 % copper, 2.79 % lead, balance zinc) having a ready-to-finish grain size of 0.080 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used.

TABLE 6
ENGRAVER'S BRASS
GENERAL DATA—STRIP[a]
Copper, 63.37%; lead, 1.53%; iron, 0.08%; zinc, balance

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	82–94	45–47
Elongation, % in 2 in.	4–6	55–65
Apparent elastic limit, p.s.i. (000 omitted)	57–66	8–10
Yield strength, 0.5% extension, p.s.i. (000 omitted)	66–67	12–13
Yield strength, 0.2% offset, p.s.i. (000 omitted)	74–74	12–13
Yield strength, 0.1% offset, p.s.i. (000 omitted)	67–74	12–13
Rockwell hardness F, 1/16-in. ball, 60-kg. load	105–109	58–62
Rockwell hardness B, 1/16-in. ball, 100-kg. load	85–90	5–8
Rockwell hardness G, 1/16-in. ball, 150-kg. load	58–66	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	88–90	63–64
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	74–76	19–22
Young's modulus of elasticity, p.s.i.	15,000,000	
Melting point, °F	1680	
Density, lb. per cu. in.	0.306	
Coefficient of expansion, per °C. from 25–300°C	0.0000202	
Electrical conductivity,[87] % I.A.C.S., 68°F	26.8	
Thermal conductivity,[87] B.t.u. per sq. ft. per ft. per hr. per °F., 68°F	69	

[a] All tests conducted on 0.040-in. stock.
[b] 6 B. & S. Nos., hard, 0.080–0.015 mm. grain size at ready-to-finish.
[c] 1200°F. anneal (1 hr. at temperature) of material described in footnote *b*.

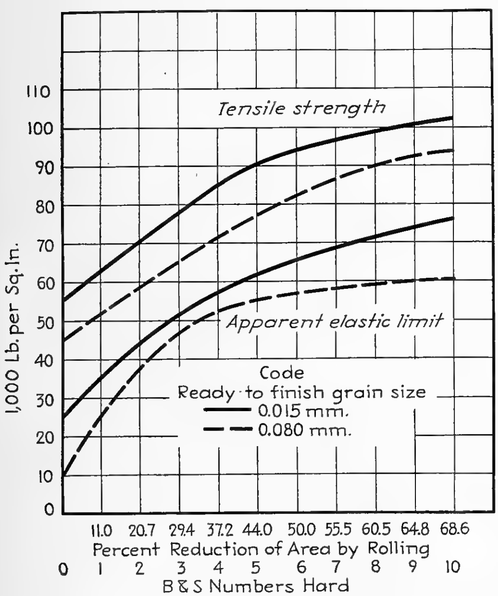


CHART 53.—The effect of cold rolling on the tensile strength and apparent elastic limit of engraver's brass strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (63.37% copper, 1.53% lead, balance zinc) (0.040-in. stock).

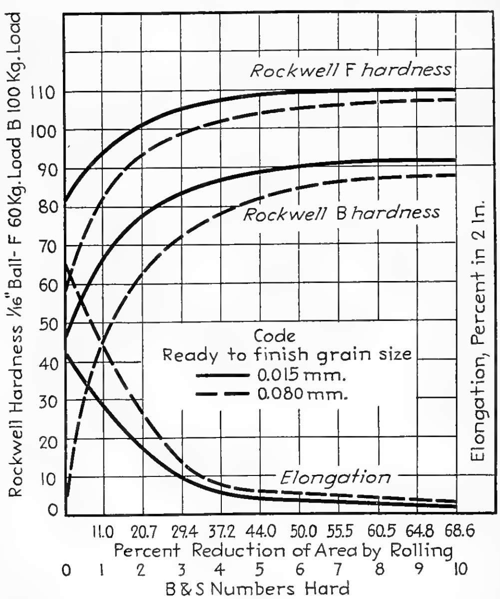


CHART 54.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of engraver's brass strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (63.37% copper, 1.53% lead, balance zinc) (0.040-in. stock).

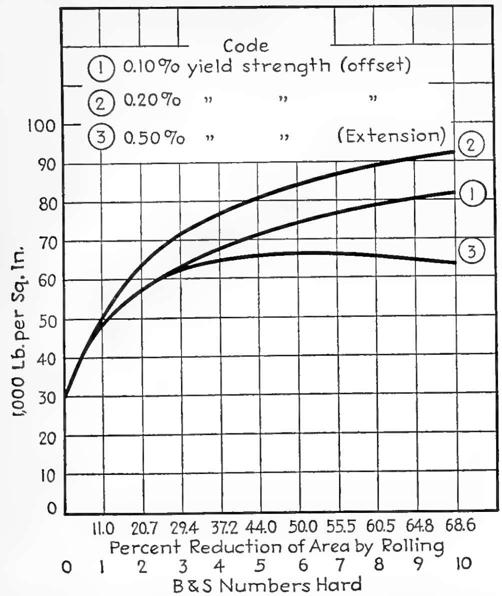


CHART 55.—The effect of cold rolling on the yield strengths of engraver's brass strip, previously annealed to a grain size of 0.015 mm. (63.37 % copper, 1.53 % lead, balance zinc) (0.040-in. stock).

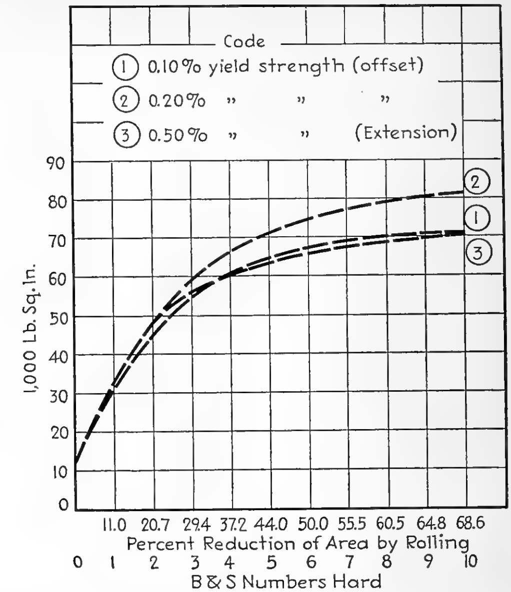


CHART 56.—The effect of cold rolling on the yield strengths of engraver's brass strip, previously annealed to a grain size of 0.080 mm. (63.37 % copper, 1.53 % lead, balance zinc) (0.040-in. stock).

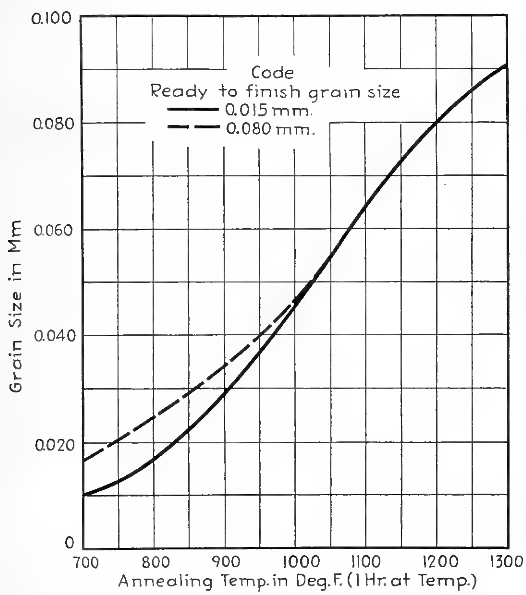


CHART 57.—The effect of annealing on the grain-growing characteristics of engraver's brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (63.37 % copper, 1.53 % lead, balance zinc) (0.040-in. stock).

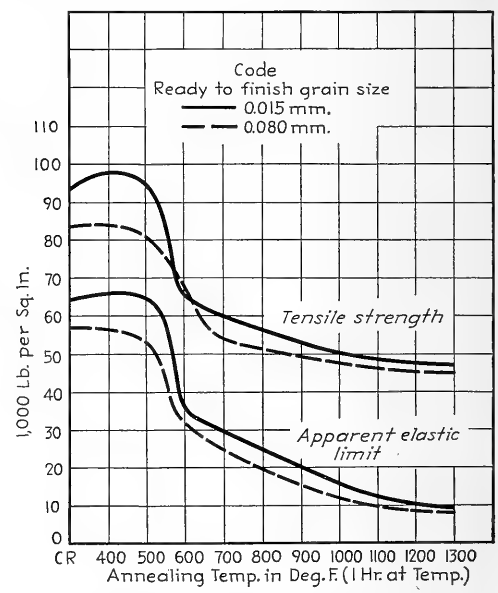


CHART 58.—The effect of annealing on the tensile strength and apparent elastic limit of engraver's brass strip (63.37 % copper, 1.53 % lead, balance zinc), previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (0.040-in. stock).

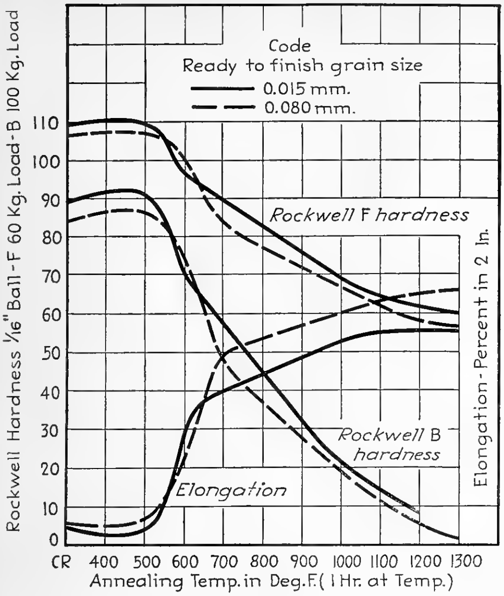


CHART 59.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of engraver's brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (63.37 % copper, 1.53 % lead, balance zinc) (0.040-in. stock).

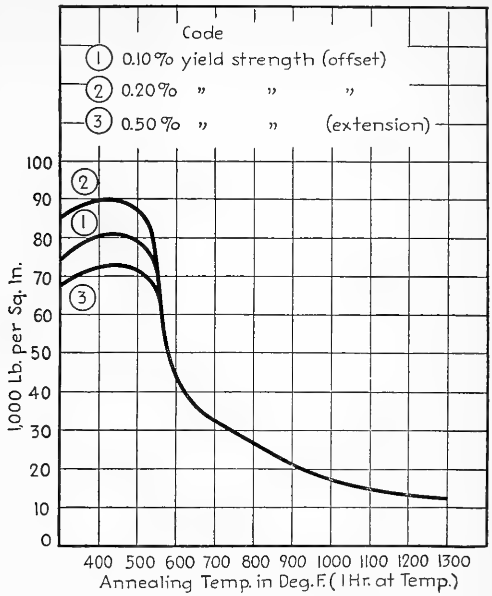


CHART 60.—The effect of annealing on the yield strength of engraver's brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (63.37 % copper, 1.53 % lead, balance zinc) (0.040-in. stock).

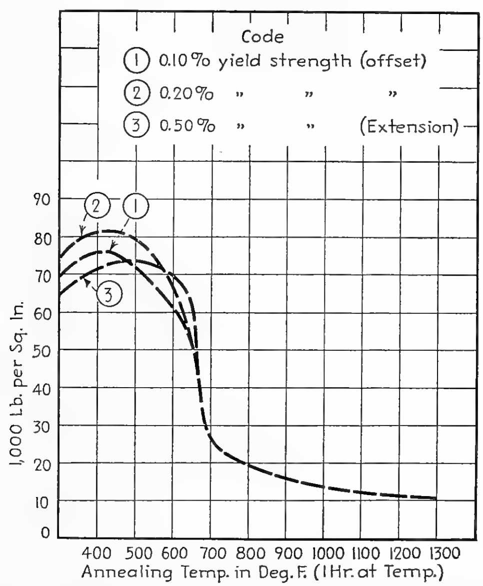


CHART 61.—The effect of annealing on the yield strength of engraver's brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.080 mm. (63.37 % copper, 1.53 % lead, balance zinc) (0.040-in. stock).

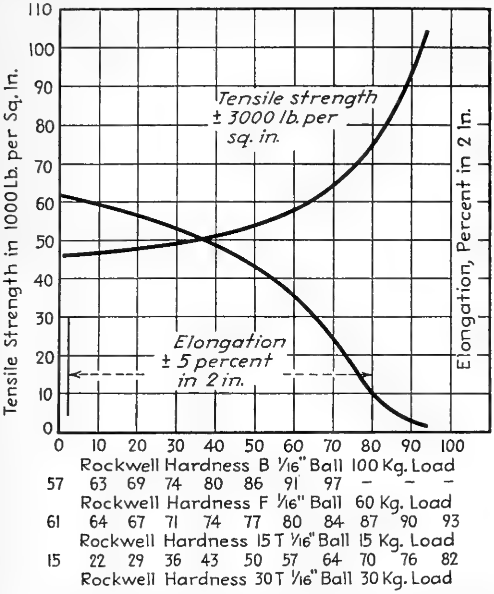


CHART 62.—This chart can be employed to determine the approximate tensile strength and percentage elongation of engraver's brass strip (63.37 % copper, 1.53 % lead, balance zinc), when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

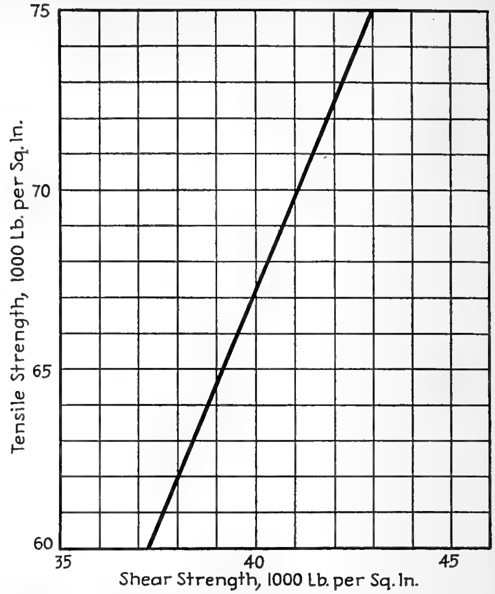


CHART 63.—Conversion chart for determination of shear strength of engraver's brass (63.50 % copper, 1.50 % lead, balance zinc) when tensile strength is known. Accurate to ±5 %.[86]

TABLE 7
RIVETING-TURNING ROD[a]
Copper, 61.98%; lead, 1.42%; iron, 0.12%; zinc, balance

Property	Rod		Forgings
	Hard[b]	Soft[c]	Cold[d]
Tensile strength, p.s.i. (000 omitted)	80	50	51–55
Apparent elastic limit, p.s.i. (000 omitted)	58	13	22–28
Yield strength, 0.5% extension, p.s.i. (000 omitted)	53	17	27–35
Yield strength, 0.2% offset, p.s.i. (000 omitted)	64	17	27–35
Yield strength, 0.1% offset, p.s.i. (000 omitted)	53	15	22–28
Elongation, % in 2 in.	15	49	42–38
Reduction of area, %	50	63	62–57
Rockwell hardness F, 1/16-in. ball, 60-kg. load	105	78	85–90
Rockwell hardness B, 1/16-in. ball, 100-kg. load	84	33	46–56
Brinell hardness, 10-mm. ball, 500-kg. load	140	70	80–101
Modulus of elasticity, p.s.i.	15,000,000		
Melting point, °F	1650		
Coefficient of expansion, per °C. from 25–300°C	0.0000204		
Electrical conductivity,[87] % I.A.C.S., 68°F	28		
Thermal conductivity,[87] B.t.u. per sq. ft. per ft. per hr. per °F., 68°F	73		
Density, lb. per cu. in.	0.306		
Type structure	Two phase, alpha-beta		

[a] This alloy combines excellent machinability with fair cold-forging properties.
[b] Refers to rod cold-worked 40%; rod under 1 in. in diameter, ready-to-finish grain size, 0.040 mm.
[c] Refers to 1100°F. anneal (1 hr.).
[d] Material cold-forged from soft rod (5–10% reduction of area).

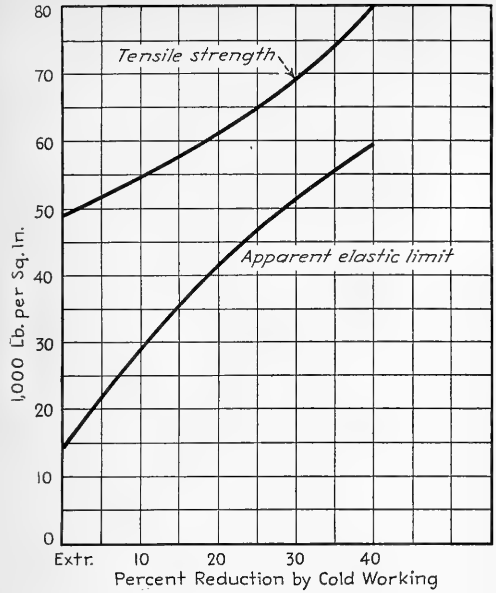


CHART 64.—The effect of cold drawing on the tensile strength and apparent elastic limit of riveting-and-turning rod, previously extruded to a grain size of 0.040 mm. (61.98 % copper, 1.42 % lead, balance zinc) (rod under 1 in. in diameter).

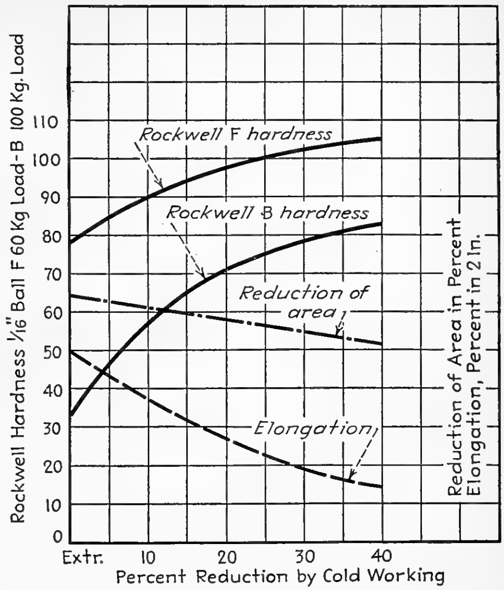


CHART 65.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of riveting-and-turning rod, previously extruded to a grain size of 0.040 mm. (61.98 % copper, 1.42 % lead, balance zinc) (rod under 1 in. in diameter).

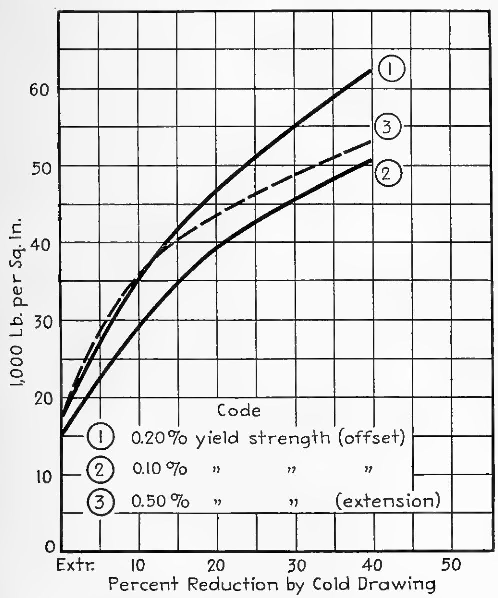


CHART 66.—The effect of cold drawing on the yield strength of riveting-and-turning rod, previously extruded to a grain size of 0.040 mm. (61.98 % copper, 1.42 % lead, balance zinc) (rod under 1 in. in diameter).

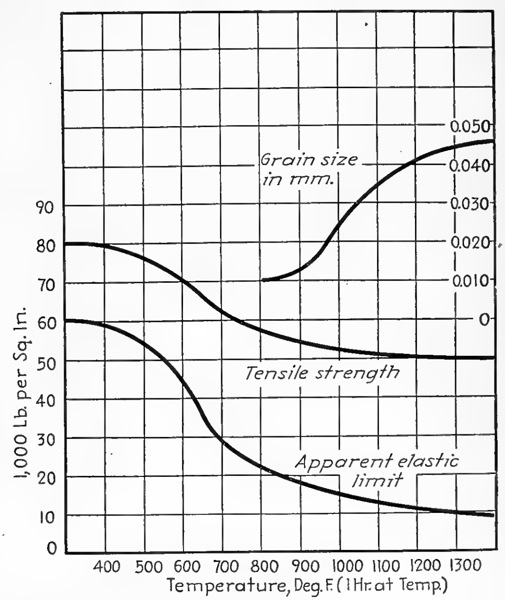


CHART 67.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of riveting-and-turning rod, previously cold-drawn 40 per cent (reduction of area) from extruded material having a grain size of 0.040 mm. (61.98 % copper, 1.42 % lead, balance zinc) (rod under 1 in. in diameter).

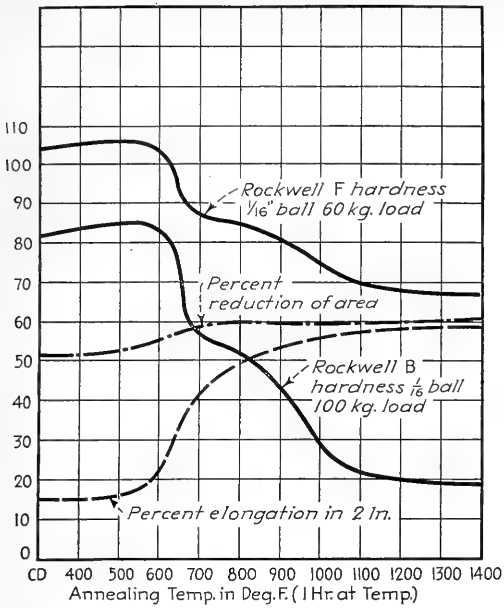


CHART 68.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., percentage reduction of area of riveting-and-turning rod, previously cold-drawn 40 per cent (reduction of area) from extruded material having a grain size of 0.040 mm. (61.98 % copper, 1.42 % lead, balance zinc) (rod under 1 in. in diameter).

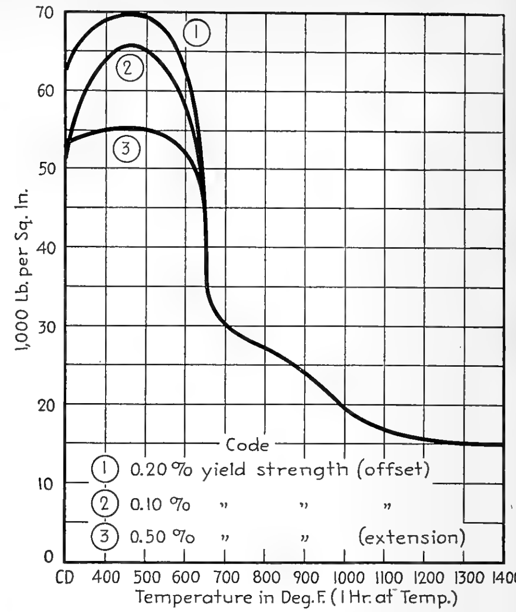


CHART 69.—The effect of annealing on the yield strength of riveting-and-turning rod, previously cold-drawn 40 per cent (reduction of area) from extruded material having a grain size of 0.040 mm. (61.98 % copper, 1.42 % lead, balance zinc) (rod under 1 in. in diameter).

TABLE 8
LEADED BRASS
GENERAL DATA—STRIP

Copper, 60.96%; lead, 1.53%; iron, 0.04%; zinc, balance

Property	Hard[a]	Soft[b]
Tensile strength, p.s.i. (000 omitted)	88–96	50–51
Apparent elastic limit, p.s.i. (000 omitted)	56–63	13.5–16.5
Yield strength, 0.5% extension, p.s.i. (000 omitted)	65–65	17.5–18
Yield strength, 0.2% offset, p.s.i. (000 omitted)	79–82	17.5–18
Yield strength, 0.1% offset, p.s.i. (000 omitted)	72.5–73	17.5–18
Elongation, % in 2 in.	6–5	52–45.5
Rockwell hardness F, 1/16-in. ball, 60-kg. load	108.5–109.5	71–72
Rockwell hardness B, 1/16-in. ball, 100-kg. load	88.5–90	27–29
Rockwell hardness G, 1/16-in. ball, 150-kg. load	61–66	
Rockwell superficial 15-T, 1/16-in. ball, 15-kg. load	90–91	68–72
Rockwell superficial 30-T, 1/16-in. ball, 30-kg. load	77	32–36
Young's modulus of elasticity, p.s.i.	15,000,000	
Melting point, °F.	1645	
Density, lb. per cu. in.	0.306	
Coefficient of expansion[c]	0.0000208	
Electrical conductivity,(87) % I.A.C.S. at 68°F.	28.6	
Thermal conductivity,(87) B.t.u. per sq. ft. per ft. per hr. per °F., 68°F	73	
Specific gravity	8.49	

[a] 6 B. & S. Nos., hard, 0.035–0.015 mm. grain size at ready-to-finish (0.040-in. stock).
[b] Refers to a 1100°F. anneal (1 hr. at temperature).
[c] Average linear coefficient per °C., 25–300°C.

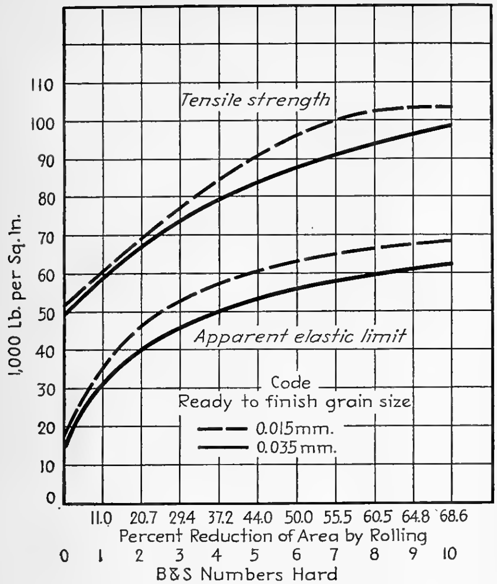


CHART 70.—The effect of cold rolling on the tensile strength and apparent elastic limit of leaded-brass strip, previously annealed to two different grain sizes, 0.015 and 0.035 mm. (60.96 % copper, 1.53 % lead, balance zinc) (0.040-in. stock).

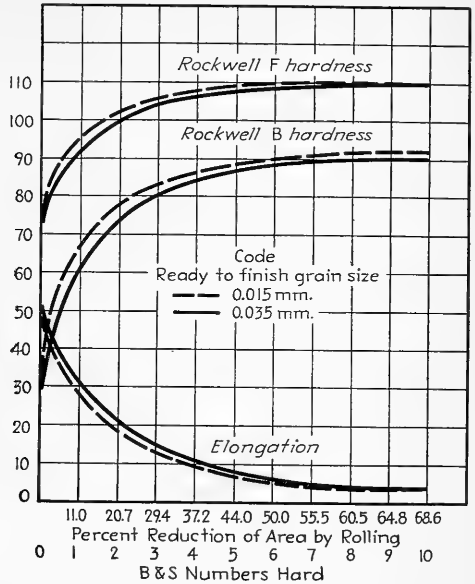


CHART 71.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of leaded-brass strip, previously annealed to two different grain sizes, 0.015 and 0.035 mm. (60.96 % copper, 1.53 % lead, balance zinc) (0.040-in. stock).

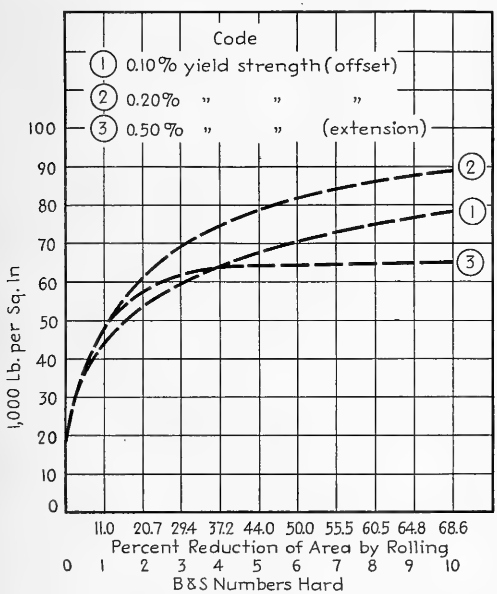


CHART 72.—The effect of cold rolling on the yield strengths of leaded-brass strip, previously annealed to a grain size of 0.015 mm. (60.96 % copper, 1.53 % lead, balance zinc) (0.040-in. stock).

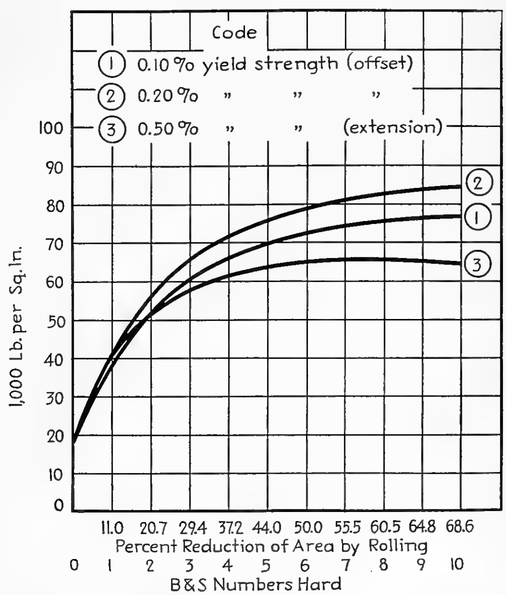


CHART 73.—The effect of cold rolling on the yield strengths of leaded-brass strip, previously annealed to a grain size of 0.035 mm. (60.96 % copper, 1.53 % lead, balance zinc) (0.040-in. stock).

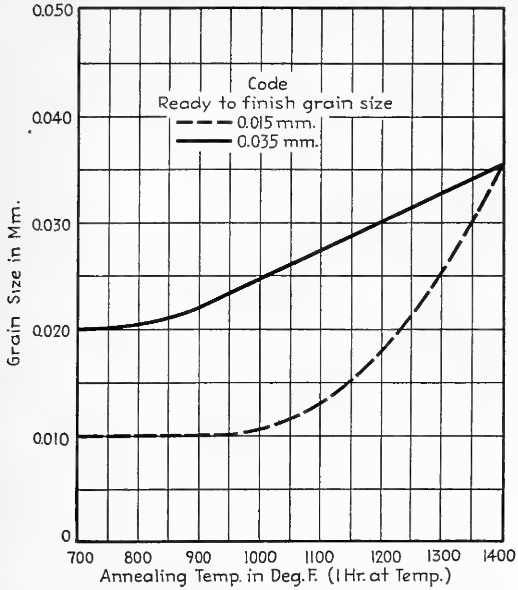


CHART 74.—The effect of annealing on the grain-growing characteristics of leaded-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.035 mm. (60.96 % copper, 1.53 % lead, balance zinc) (0.040-in. stock).

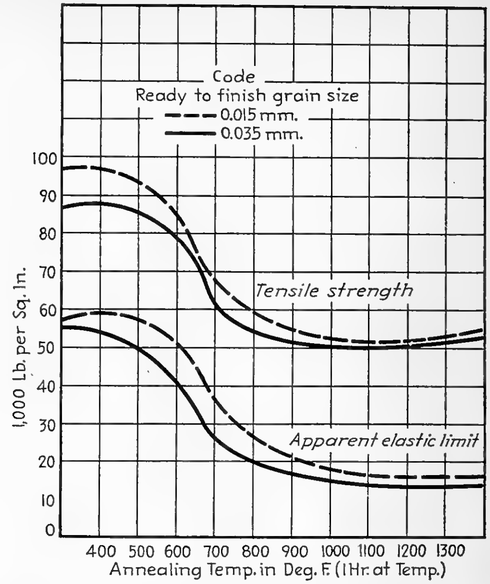


CHART 75.—The effect of annealing on the tensile strength and apparent elastic limit of leaded-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.035 mm. (60.96 % copper, 1.53 % lead, balance zinc) (0.040-in. stock).

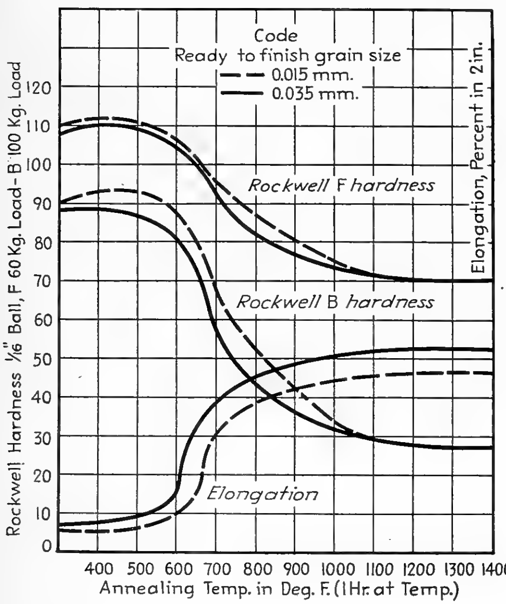


CHART 76.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of leaded-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.035 mm. (60.96 % copper, 1.53 % lead, balance zinc) (0.040-in. stock).

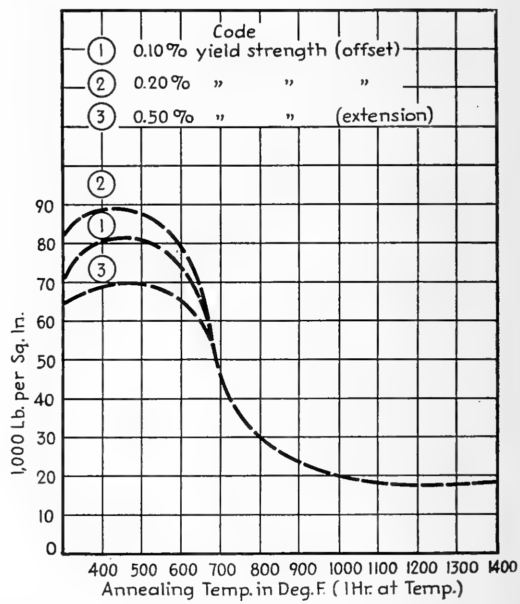


CHART 77.—The effect of annealing on the yield strength of leaded-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (60.98 % copper, 1.53 % lead, balance zinc) (0.040-in. stock).

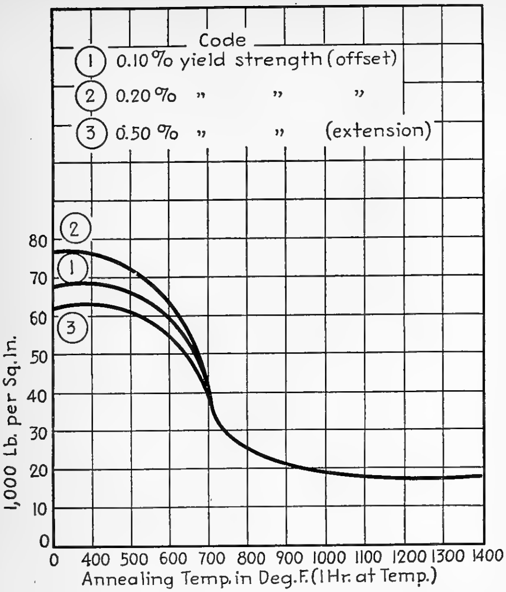


CHART 78.—The effect of annealing on the yield strength of leaded-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.035 mm. (60.98 % copper, 1.53 % lead, balance zinc) (0.040-in. stock).

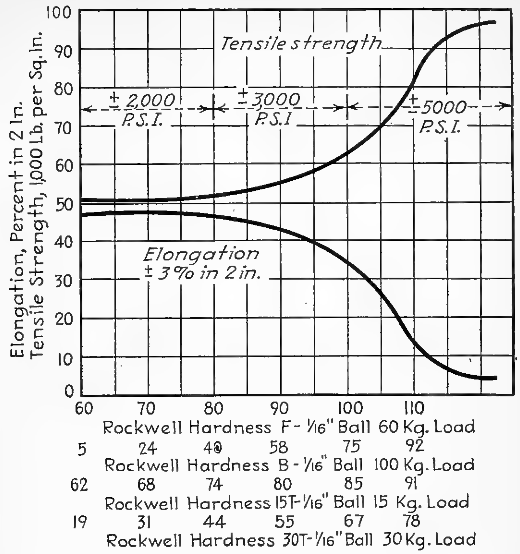


CHART 79.—This chart can be employed to determine the approximate tensile strength and percentage elongation of leaded-brass strip (60.98 % copper, 1.53 % lead, balance zinc) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

TABLE 9
FREE-CUTTING BRASS ROD
Copper, 60.99; lead, 3.13%; iron, 0.15%; zinc, balance

Property	Rod	
	Hard[a]	Soft[b]
Tensile strength, p.s.i. (000 omitted)	71	50
Apparent elastic limit, p.s.i. (000 omitted)	39	12
Yield strength, 0.5% extension, p.s.i. (000 omitted)	54	17
Yield strength, 0.2% offset, p.s.i. (000 omitted)	59	17
Yield strength, 0.1% offset, p.s.i. (000 omitted)	54	17
Elongation, % in 2 in.	50	10
Reduction of area, %	50	35
Rockwell hardness F, 1/16-in. ball, 50-kg. load	100	68
Rockwell hardness B, 1/16-in. ball, 100-kg. load	73	16
Brinell hardness, 10-mm. ball, 500-kg. load	116	60
Modulus of elasticity, p.s.i.	15,000,000	
Melting point, °F.	1645	
Coefficient of expansion, per °C. from 25–300°C.	0.0000204	
Electrical conductivity,(87) % I.A.C.S., 68°F.	28.6	
Thermal conductivity,(87) B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	73	
Density lb. per cu. in.	0.307	
Type structure	Two phase, alpha-beta	

[a] Refers to rod cold-worked 30%; rod under 1 in. in diameter, ready-to-finish grain size of 0.025 mm.
[b] Refers to a 1300°F. anneal (1 hr.).

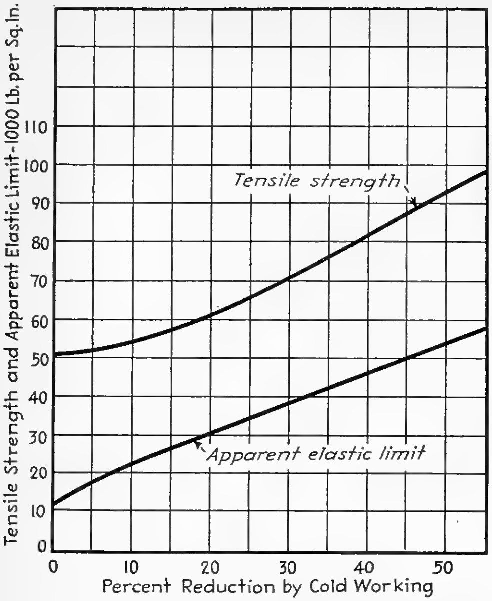


CHART 80.—The effect of cold drawing on the tensile strength and apparent elastic limit of free-cutting brass rod, previously extruded to a grain size of 0.030 mm. (60.99 % copper, 3.13 % lead, balance zinc) (rod under 1 in. in diameter).

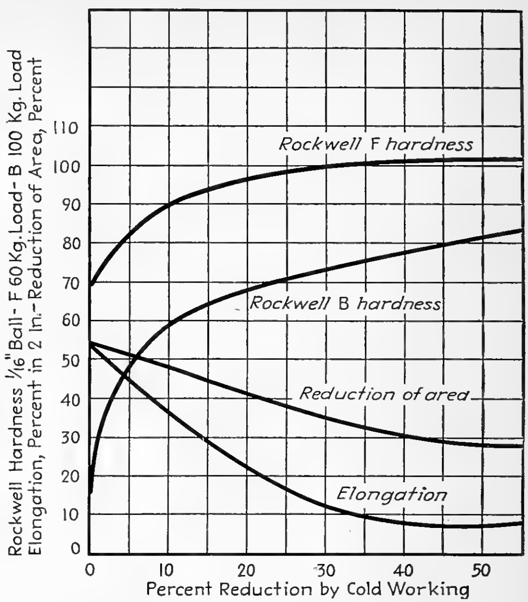


CHART 81.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of free-cutting brass rod, previously extruded to a grain size of 0.030 mm. (60.99 % copper, 3.13 % lead, balance zinc) (rod under 1 in. in diameter).

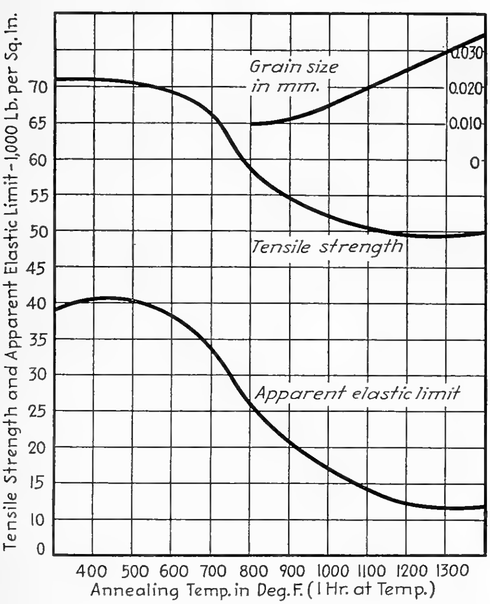


CHART 82.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of free-cutting brass rod, previously cold-drawn 30 per cent (reduction of area) from extruded material having a grain size of 0.030 mm. (60.99 % copper, 3.13 % lead, balance zinc) (rod under 1 in. in diameter).

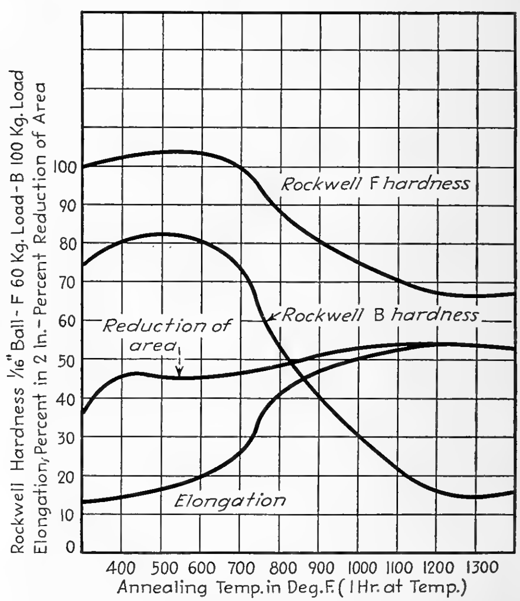


CHART 83.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of free-cutting brass rod, previously cold-drawn 30 per cent from extruded material having a grain size of 0.030 mm. (60.99 % copper, 3.13 % lead, balance zinc) (rod under 1 in. in diameter).

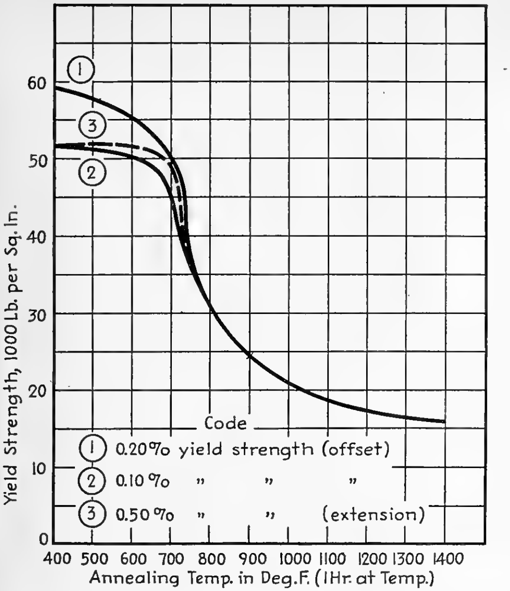


CHART 84.—The effect of annealing on the yield strength of free-cutting brass rod, previously cold-drawn 30 per cent (reduction of area) from extruded material having a grain size of 0.030 mm. (60.99 % copper, 3.13 % lead, balance zinc) (rod under 1 in. in diameter).

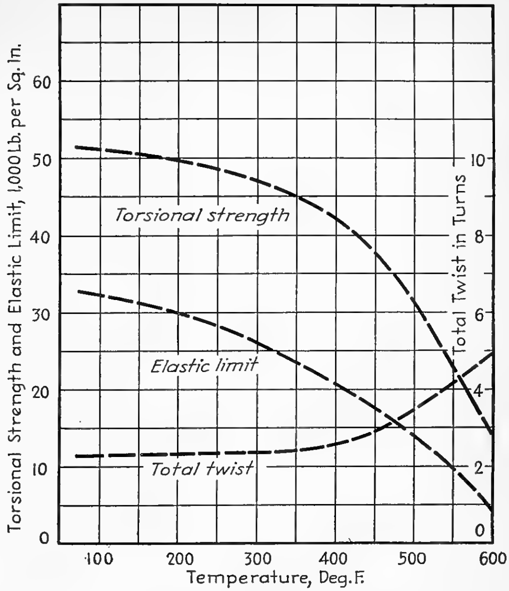


CHART 85.—Effect of temperature on torsional properties of rod brass (61.08 % copper, 2.34 % lead, 0.42 % iron; 0.18 % tin, balance zinc) according to Bregousky and Spring[22,9] (rod under 1 in. in diameter).

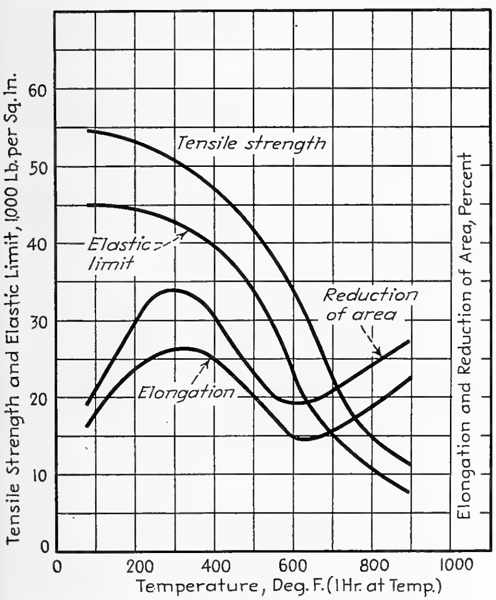


CHART 86.—Effect of temperature on tensile strength, elastic limit, percentage reduction of area, and percentage elongation in 2 in. of free-cutting brass (62.50 % copper, 2.50 % lead, balance zinc) according to Crane Company[17,9] (rod under 1 in. in diameter).

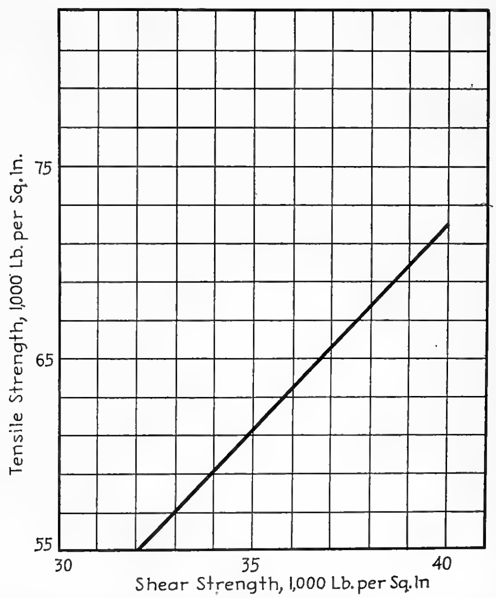


CHART 87.—Conversion chart for determination of shear strength of free-cutting brass (61.50 % copper, 3.00 % lead, balance zinc) when tensile strength is known. Accurate to ±5 %.[86]

TABLE 10
LOW-LEADED BRASS ROD[a]
Copper, 62.95%; lead, 0.60%; iron, 0.05%; zinc balance

Property	Rod		Forgings
	Hard[b]	Soft[c]	Cold[d]
Tensile strength, p.s.i. (000 omitted)	67	46	50–60
Apparent elastic limit, p.s.i. (000 omitted)	49	10	20–45
Yield strength, 0.5% extension, p.s.i. (000 omitted)	42	14	25–42
Yield strength, 0.2% offset, p.s.i. (000 omitted)	54	13	25–45
Yield strength, 0.1% offset, p.s.i. (000 omitted)	46	13	18–35
Elongation, % in 2 in.	19	55	45–25
Reduction of area, %	60	70	70–60
Rockwell hardness F, 1/16-in. ball, 60-kg. load	101	69	78–98
Rockwell hardness B, 1/16-in. ball, 100-kg. load	76	25	45–72
Brinell hardness, 10-mm. ball, 500-kg. load	122	64	79–114
Modulus of elasticity, p.s.i.	15,000,000		
Melting point, °F.	1660		
Coefficient of expansion, per °C. from 25–300°C.	0.0000204		
Electrical conductivity,(87) % I.A.C.S., 68°F.	26.8		
Thermal conductivity,(87) B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	69		
Density, lb. per cu. in.	0.306		

[a] This alloy is designed for operations involving intermediate cold working and free-cutting properties.
[b] Refers to rod cold-drawn 30%; rod under 1 in. in diameter, ready-to-finish grain size, 0.030 mm.
[c] Refers to 1300°F. anneal (1 hr.).
[d] Material cold-forged from soft rod (5–20% reduction of area).

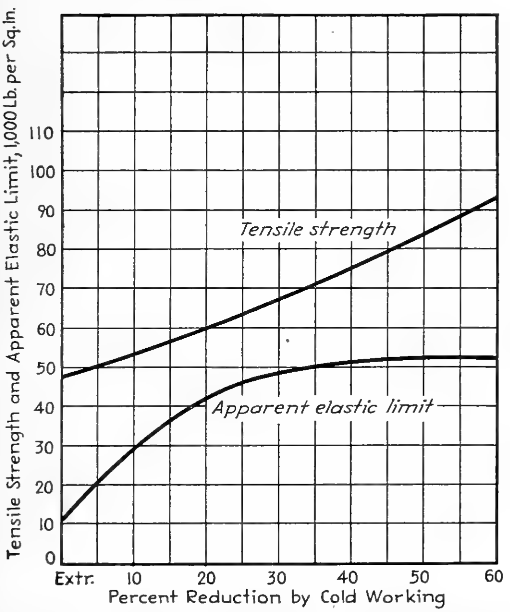


Chart 88.—The effect of cold drawing on the tensile strength and apparent elastic limit of low-leaded brass rod, previously extruded to a grain size of 0.030 mm.(62.95 % copper, 0.60 % lead, balance zinc) (rod under 1 in. in diameter).

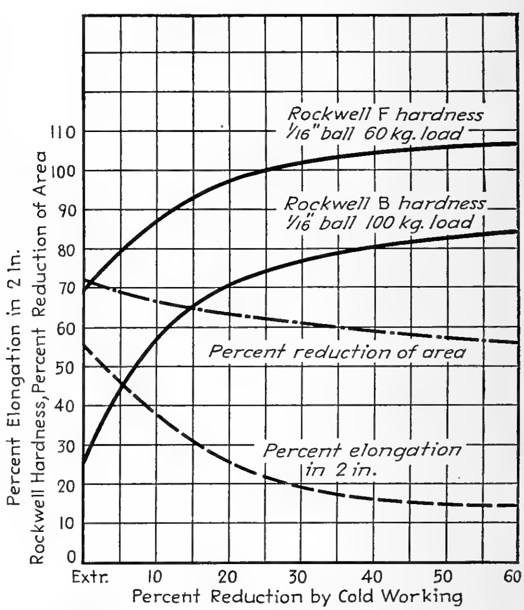


Chart 89.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of low-leaded brass rod, previously extruded to a grain size of 0.030 mm. (62.95 % copper, 0.60 % lead, balance zinc) (rod under 1 in. in diameter).

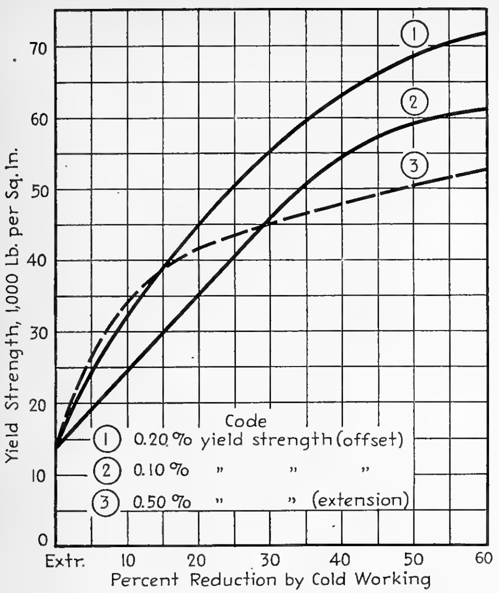


CHART 90.—The effect of cold drawing on the yield strength of low-leaded brass rod, previously extruded to a grain size of 0.030 mm. (62.95 % copper, 0.60 % lead, balance zinc) (rod under 1 in. in diameter).

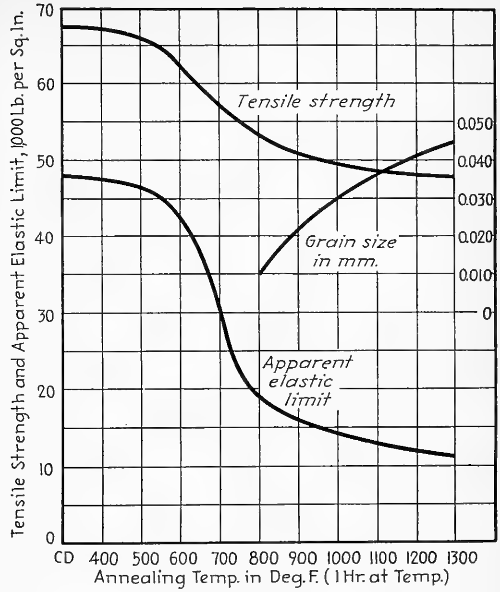


CHART 91.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of low-leaded brass rod, previously cold-drawn 30 per cent (reduction of area) from extruded material having a grain size of 0.030 mm. (62.95 % copper, 0.60 % lead, balance zinc) (rod under 1 in. in diameter).

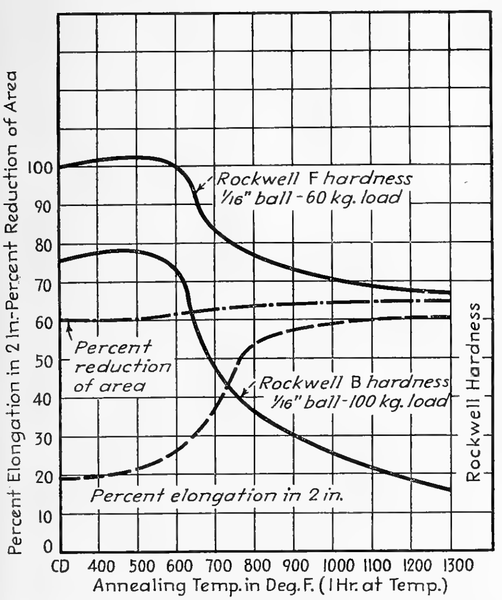


CHART 92.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of low-leaded brass rod, previously cold-drawn 30 per cent (reduction of area) from extruded material having a grain size of 0.030 mm. (62.95 % copper, 0.60 % lead, balance zinc) (rod under 1 in. in diameter).

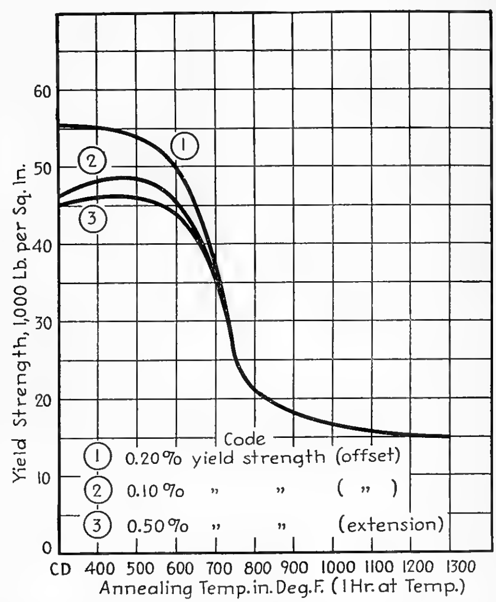


CHART 93.—The effect of annealing on the yield strength of low-leaded brass rod, previously cold-drawn 30 per cent (reduction of area) from extruded material having a grain size of 0.030 mm. (62.95 % copper, 0.60 % lead, balance zinc) (rod under 1 in. in diameter).

TABLE 11
DEEP-DRILLING ROD[a]
Copper, 62.11%; lead, 4.00%; iron, 0.05%; zinc, balance

Property	Rod	
	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	63	43
Apparent elastic limit, p.s.i. (000 omitted)	49	18
Yield strength, 0.5% extension, p.s.i. (000 omitted)	44	14
Yield strength, 0.2% offset, p.s.i. (000 omitted)	54	14
Yield strength, 0.1% offset, p.s.i. (000 omitted)	45	13
Elongation, % in 2 in.	13	52
Reduction of area, %	35	47
Rockwell hardness F, 1/16-in. ball, 60-kg. load	98	68
Rockwell hardness B, 1/16-in. ball, 100-kg. load	69	11
Brinell hardness, 10-mm. ball, 500-kg. load	109	57
Modulus of elasticity, p.s.i.	15,000,000	
Melting point, °F	1655	
Coefficient of expansion, per °C. from 25–300°C	0.0000204	
Electrical conductivity,(87) % I.A.C.S., 68°F	28	
Thermal conductivity,(87) B.t.u. per sq. ft. per ft. per hr. per° F., 68°F	73	
Density, lb. per cu. in.	0.308	

[a] This alloy has excellent machining properties.
[b] Refers to rod cold-drawn 30%; rod under 1 in. in diameter, ready-to-finish grain size, 0.050 mm.
[c] Refers to 1200°F. anneal (1 hr.).

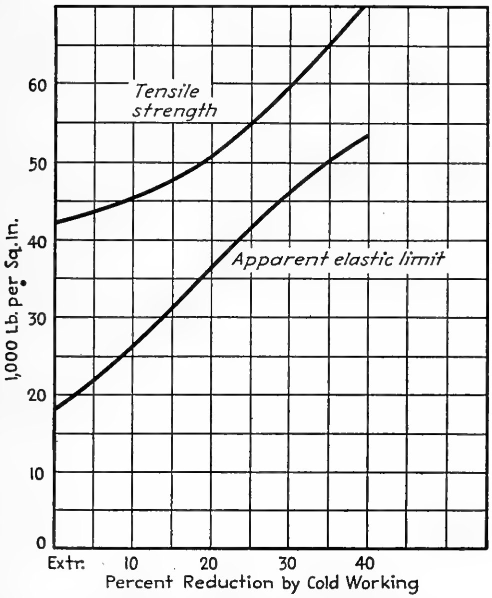


CHART 94.—The effect of cold drawing on the tensile strength and apparent elastic limit of deep-drilling rod, previously extruded to a grain size of 0.050 mm. (62.11% copper, 4.00% lead, balance zinc) (rod under 1 in. in diameter).

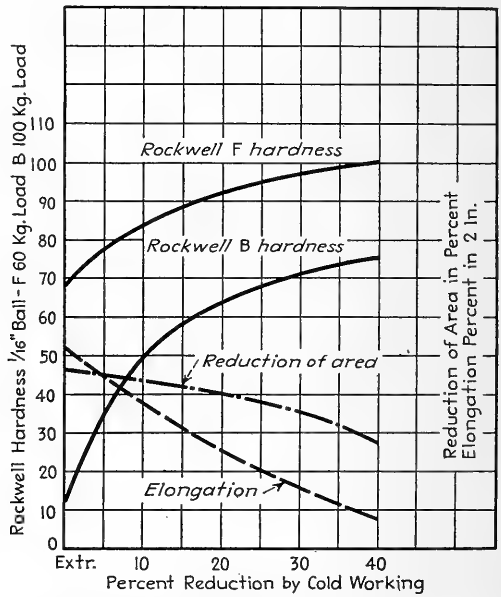


CHART 95.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of deep-drilling rod, previously extruded to a grain size of 0.050 mm. (62.11% copper, 4.00% lead, balance zinc) (rod under 1 in. in diameter).

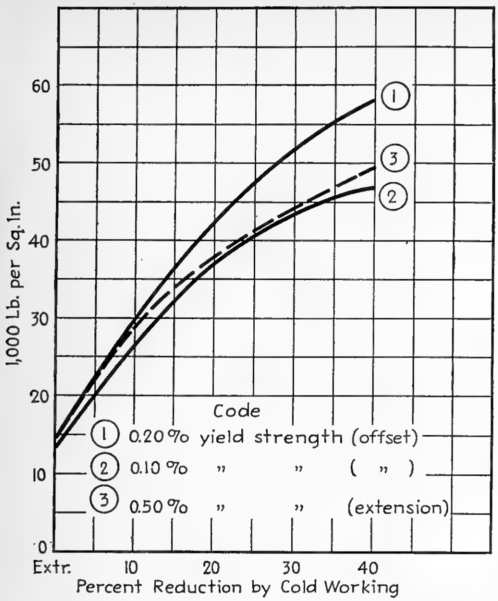


Chart 96.—The effect of cold drawing on the yield strength of deep-drilling rod, previously extruded to a grain size of 0.050 mm. (62.11 % copper, 4.00 % lead, balance zinc) (rod under 1 in. in diameter).

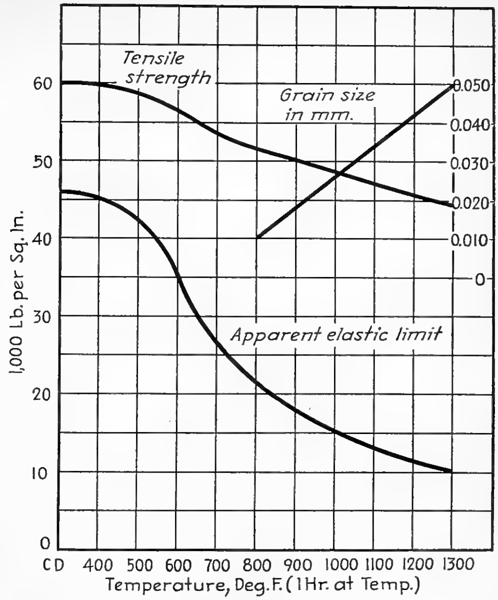


Chart 97.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of deep-drilling rod, previously cold-drawn 30 per cent (reduction of area) from extruded material having a grain size of 0.050 mm. (62.11 % copper, 4.00 % lead, balance zinc) (rod under 1 in. in diameter).

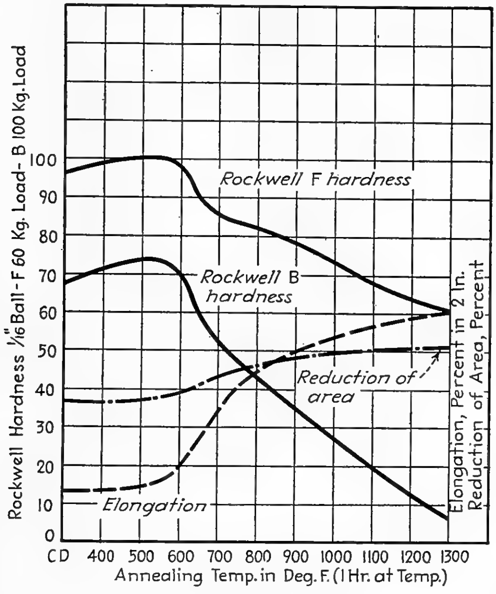


Chart 98.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of deep-drilling rod, previously cold-drawn 30 per cent (reduction of area) from extruded material having a grain size of 0.050 mm. (62.11 % copper, 4.00 % lead, balance zinc) (rod under 1 in. in diameter).

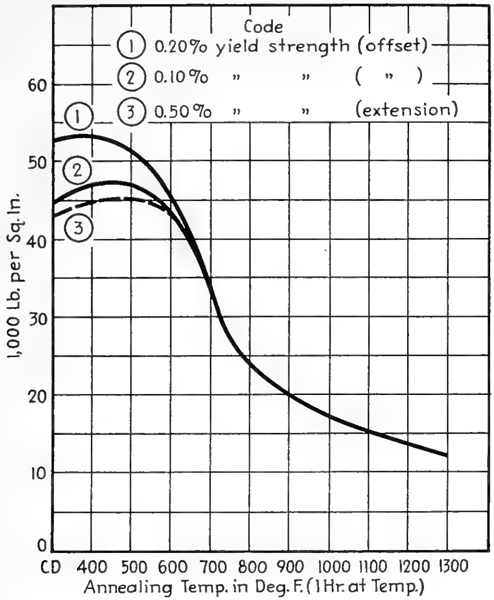


CHART 99.—The effect of annealing on the yield strength of deep-drilling rod, previously cold-drawn 30 per cent (reduction of area) from extruded material having a grain size of 0.050 mm. (62.11 % copper, 4.00 % lead, balance zinc) (rod under 1 in. in diameter).

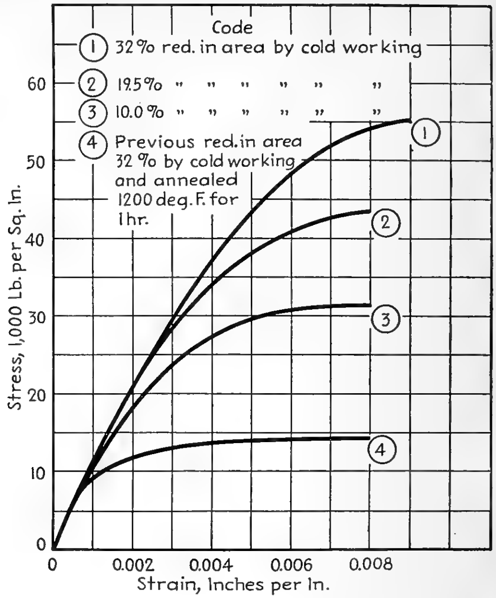


CHART 100.—The effect of cold drawing on the stress-strain characteristics of deep-drilling rod (under 1 in. in diameter), previously extruded to a grain size of 0.050 mm. 100,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (62.11 % copper, 4.00 % lead, balance zinc.)

TABLE 12
BRASS FORGING ROD[a]

Copper, 60.05%; lead, 2.12%; iron, trace; zinc, balance

Property	Rod		Forgings	
	Hard[b]	Soft[c]	Hot	Cold[d]
Tensile strength, p.s.i. (000 omitted)	66	56	50–33	57
Apparent elastic limit, p.s.i. (000 omitted)	44	18	11–15	25
Yield strength, 0.5% extension, p.s.i. (000 omitted)	50	21	16–19	31
Yield strength, 0.2% offset, p.s.i. (000 omitted)	50	21	15–19	28
Yield strength, 0.1% offset, p.s.i. (000 omitted)	39	21	14–18	24
Elongation, % in 2 in.	25	45	55–50	40
Reduction of area, %	50	54	50–57	55
Rockwell hardness F, 1/16-in. ball, 60-kg. load	99	84	73–78	87
Rockwell hardness B, 1/16-in. ball, 100-kg. load	73	43	30–36	50
Brinell hardness, 10-mm. ball, 500-kg. load	116	77	67–71	83
Modulus of elasticity, p.s.i.	15,000,000			
Melting point, °F.	1640			
Coefficient of expansion, per °C. from 25–300°C.	0.0000208			
Electrical conductivity,(87) % I.A.C.S., 68°F.	28.6			
Thermal conductivity,(87) B.t.u. per sq. ft. per hr. per ft. per °F., 68°F.	73			
Density, lb. per cu. in.	0.305			
Forging range, °F.	1250–1450			
Forging quality	Excellent			
Type structure	Two phase, alpha-beta			

[a] This alloy combines excellent hot-forging properties with good machinability.
[b] Refers to rod cold-worked 17.5% from the extruded condition; rod under 1 in. in diameter with a ready-to-finish grain size of 0.010 mm.
[c] Extruded condition (800°F. 1 hr.).
[d] Material cold-struck from hot-forged condition.

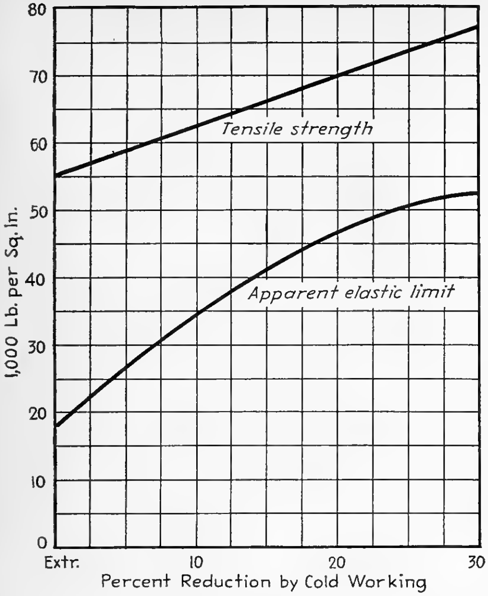


CHART 101.—The effect of cold drawing on the tensile strength and apparent elastic limit of forging rod, previously extruded to a grain size of 0.010 mm. (60.05 % copper, 2.12 % lead, balance zinc) (rod under 1 in. in diameter).

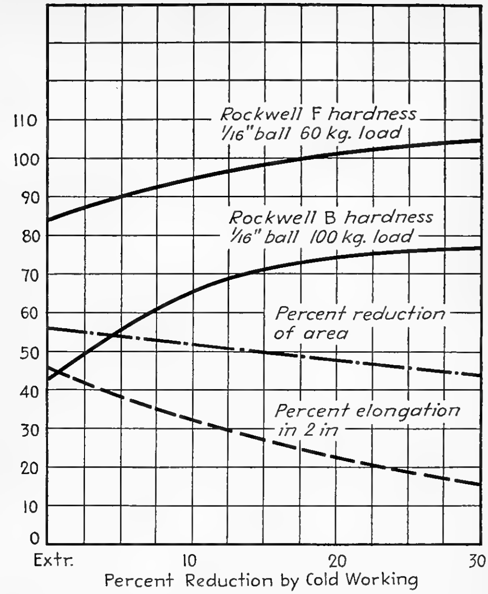


CHART 102.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of forging rod, previously extruded to a grain size of 0.010 mm. (60.05 % copper, 2.12 % lead, balance zinc) (rod under 1 in. in diameter).

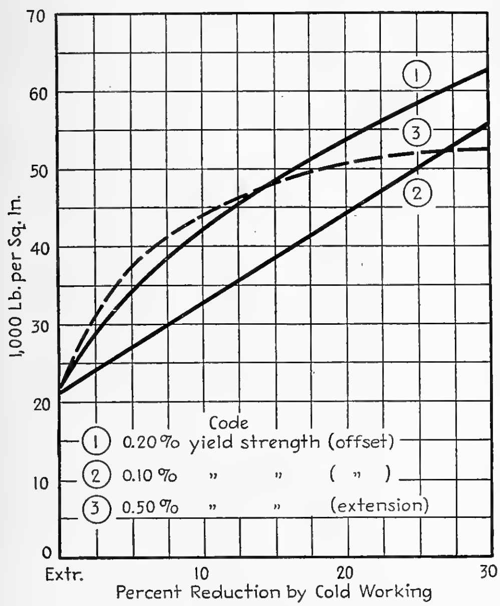


CHART 103.—The effect of cold drawing on the yield strength of forging rod, previously extruded to a grain size of 0.010 mm. (60.05 % copper, 2.12 % lead, balance zinc) (rod under 1 in. in diameter).

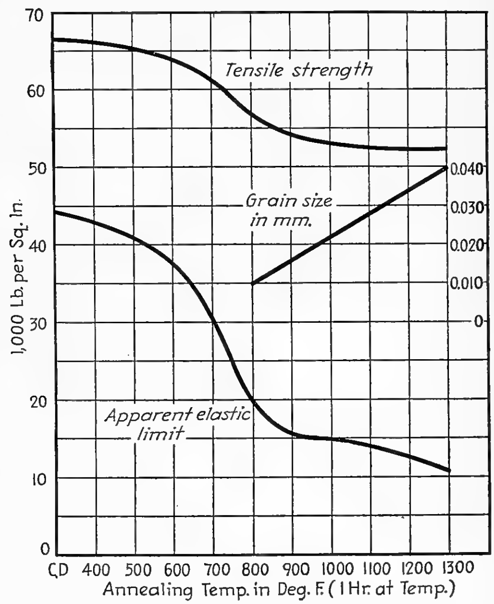


CHART 104.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of forging rod, previously cold-drawn 18 per cent (reduction of area) from extruded material having a grain size of 0.010 mm. (60.05 % copper, 2.12 % lead, balance zinc) (rod under 1 in. in diameter).

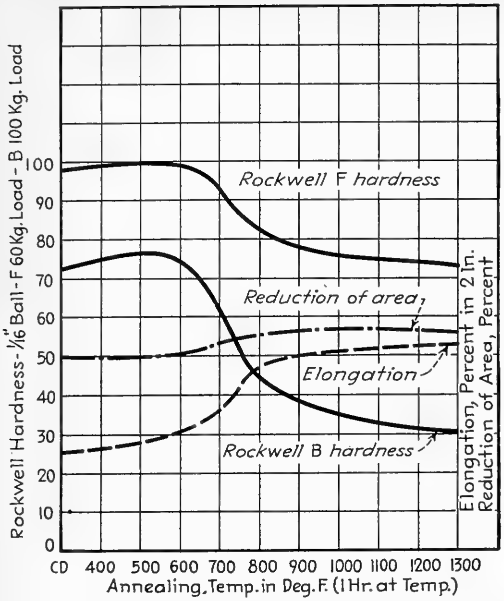


CHART 105.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of forging rod, previously cold-drawn 18 per cent (reduction of area) from extruded material having a grain size of 0.010 mm. (60.05 % copper, 2.12 % lead, balance zinc) (rod under 1 in. in diameter).

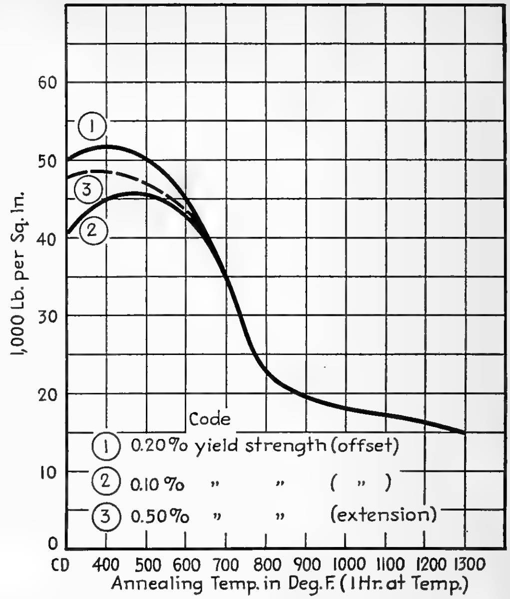


CHART 106.—The effect of annealing on the yield strength of forging rod, previously cold-drawn 18 per cent (reduction of area) from extruded material having a grain size of 0.010 mm. (60.05 % copper, 2.12 % lead, balance zinc) (rod under 1 in. in diameter).

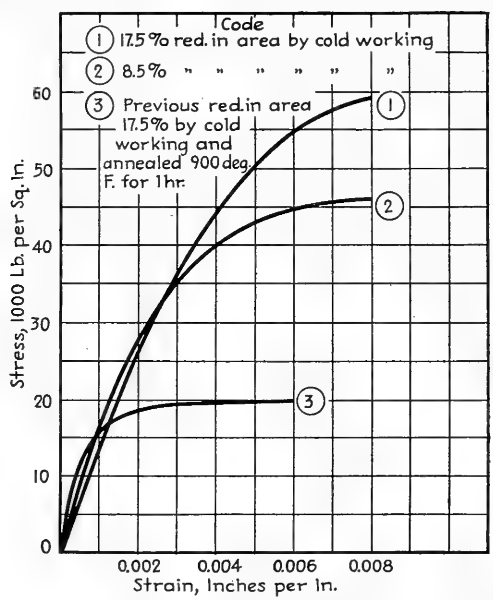


CHART 107.—The effect of cold drawing on the stress-strain characteristics of standard-brass forging rod (under 1 in. in diameter), previously extruded to a grain size of 0.010 mm.; 100,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (60.05 % copper, 2.12 % lead, balance zinc.)

TABLE 13
BRASS ROD FOR EXTRUDED SHAPES[a]
Copper, 59.31%; lead, 2.02%; iron, 0.05%; zinc, balance

Property	Rod		Forgings	
	Hard[b]	Soft[c]	Hot	Cold[d]
Tensile strength, p.s.i. (000 omitted)	74	60	58–60	64
Apparent elastic limit, p.s.i. (000 omitted)	48	19	14–25	35
Yield strength, 0.5% extension, p.s.i. (000 omitted)	55	21	19–24	34
Yield strength, 0.2% offset, p.s.i. (000 omitted)	58	21	18–23	32
Yield strength, 0.1% offset, p.s.i. (000 omitted)	46	21	17–22	28
Elongation, % in 2 in.	23	44	45–40	35
Reduction of area, %	40	49	46–53	45
Rockwell hardness F, 1/16-in. ball, 60-kg. load	100	79	74–84	85
Rockwell hardness B, 1/16-in. ball, 100-kg. load	74	53	35–49	58
Brinell hardness, 10-mm. ball, 500-kg. load	118	86	71–82	92
Modulus of elasticity, p.s.i.	15,000,000			
Melting point, °F.	1640			
Coefficient of expansion, per °C. from 25–300°C.	0.0000208			
Electrical conductivity,[87] % I.A.C.S., 68°F.	28.6			
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	73			
Forging range, °F.	1250–1450			
Forging quality	Excellent			
Type structure	Two phase, alpha-beta			

[a] This alloy combines excellent hot-working properties with good machining properties.
[b] Refers to rod cold-worked 15% from extruded condition; rod under 1 in. in diameter with a ready-to-finish grain size of 0.010 mm.
[c] Extruded condition (850°F. 1 hr.).
[d] Material cold-struck from hot-forged condition.

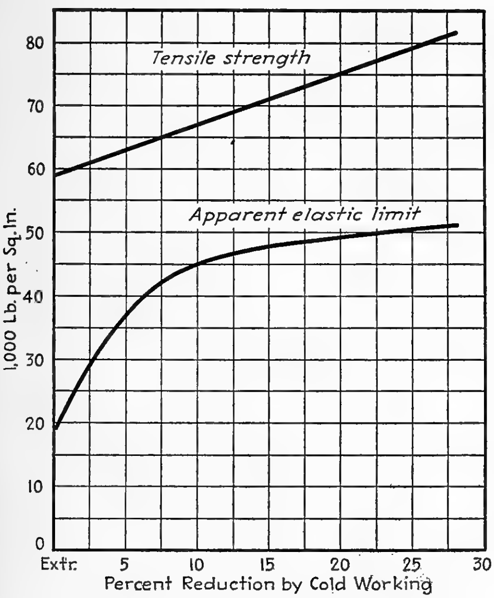


CHART 108.—The effect of cold drawing on the tensile strength and apparent elastic limit of extruded-shapes rod, previously extruded to a grain size of 0.010 mm. (59.31% copper, 2.02% lead, balance zinc) (rod under 1 in. in diameter).

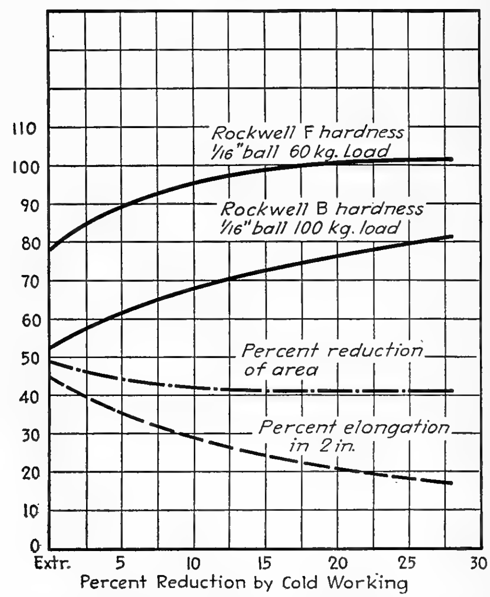


CHART 109.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of extruded-shapes rod, previously extruded to a grain size of 0.010 mm. (59.31% copper, 2.02% lead, balance zinc) (rod under 1 in. in diameter).

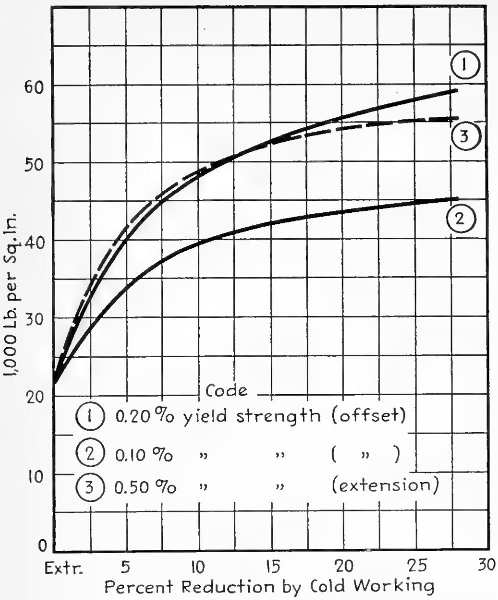


CHART 110.—The effect of cold drawing on the yield strength of extruded-shapes rod, previously extruded to a grain size of 0.010 mm. (59.31 % copper, 2.02 % lead, balance zinc) (rod under 1 in. in diameter).

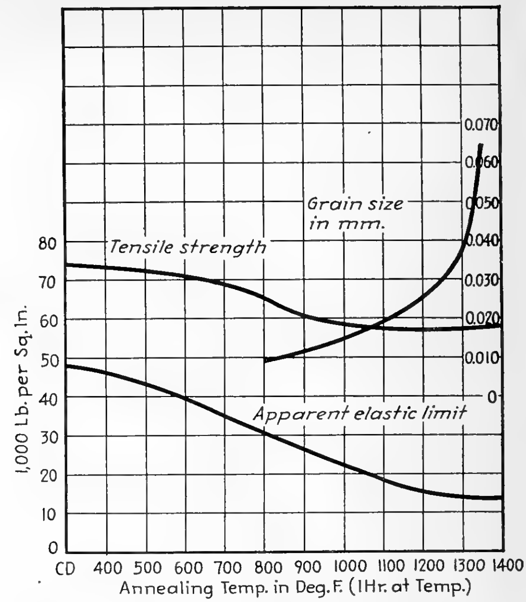


CHART 111.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of extruded-shapes rod, previously cold-drawn 15 per cent (reduction of area) from extruded material having a grain size of 0.010 mm. (59.31 % copper, 2.02 % lead, balance zinc) (rod under 1 in. in diameter).

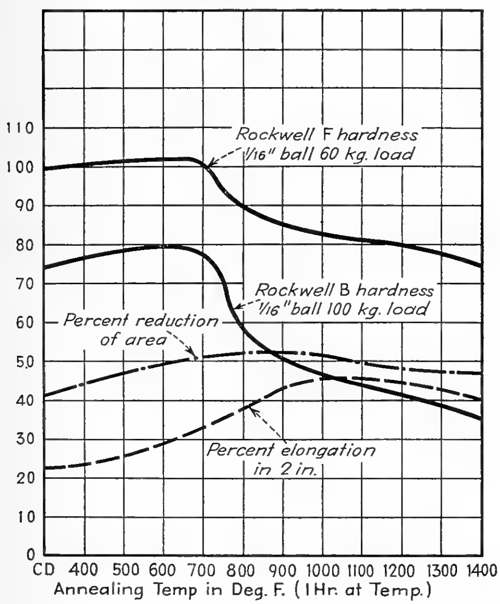


CHART 112.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of extruded-shapes rod, previously cold-drawn 15 per cent (reduction of area) from extruded material having a grain size of 0.010 mm. (59.31 % copper, 2.02 % lead, balance zinc) (rod under 1 in. in diameter).

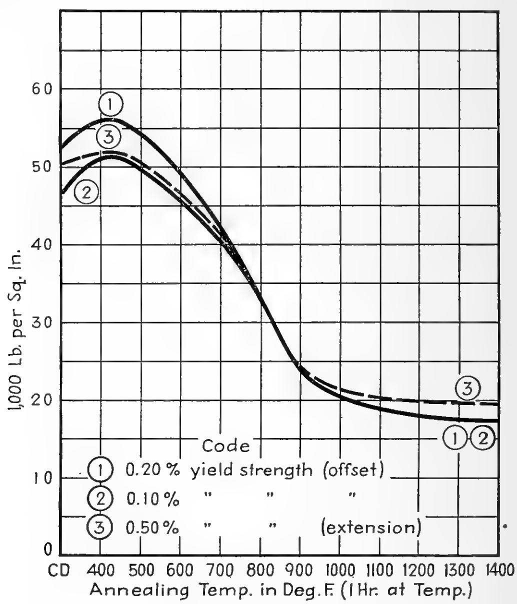


CHART 113.—The effect of annealing on the yield strength of extruded-shapes rod, previously cold-drawn 15 per cent (reduction of area) from extruded material having a grain size of 0.010 mm. (59.31 % copper, 2.02 % lead, balance zinc) (rod under 1 in. in diameter).

TABLE 14
ARCHITECTURAL BRONZE[a]
Copper, 56.64%; lead, 1.91%; zinc, balance; iron, 0.05%

Property	Rod		Forgings
	Hard[b]	Soft[c]	Hot
Tensile strength, p.s.i. (000 omitted)	88	63	68–75
Apparent elastic limit, p.s.i. (000 omitted)	51	25	14–22
Yield strength, 0.5% extension, p.s.i. (000 omitted)	58	35	21–33
Yield strength, 0.2% offset, p.s.i. (000 omitted)	68	35	19–32
Yield strength, 0.1% offset, p.s.i. (000 omitted)	59	33	17–29
Elongation, % in 2 in.	15	25	35–25
Reduction of area, %	25	35	35–25
Rockwell hardness F, 1/16-in. ball, 60-kg. load	105	93	88–92
Rockwell hardness B, 10-mm. ball, 100-kg. load	84	63	51–64
Modulus of elasticity, p.s.i	15,000,000		
Melting point, °F	1625		
Density, lb. per cu. in.	0.305		
Forging range, °F	1250–1350		
Forging quality	Excellent		
Type structure	Two phase, alpha-beta		

[a] This alloy combines excellent hot-forging properties with good machinability.
[b] Refers to rod cold-drawn 18% from the extruded condition; rod under 1 in. in diameter with a ready-to-finish grain size, 0.025 mm.
[c] Refers to extruded condition.

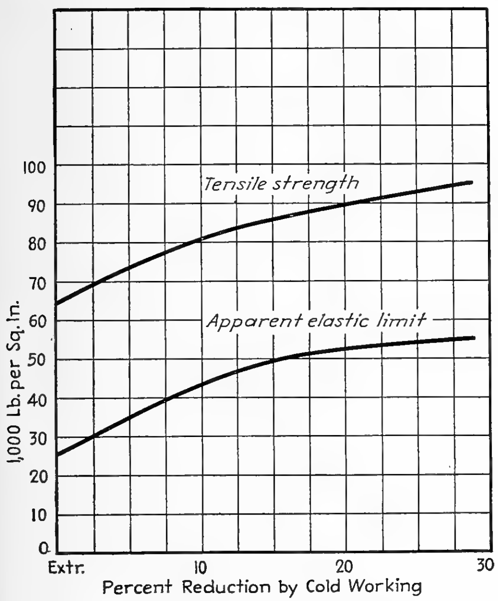


CHART 114.—The effect of cold drawing on the tensile strength and apparent-elastic limit of architectural-bronze rod, previously extruded to a grain size of 0.025 mm. (56.64 % copper, 1.91 % lead, balance zinc) (rod under 1 in. in diameter).

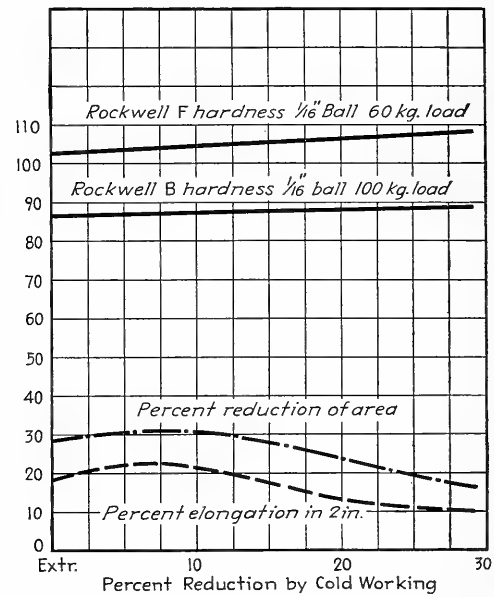


CHART 115.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of architectural-bronze rod, previously extruded to a grain size of 0.025 mm. (56.64 % copper, 1.91 % lead, balance zinc) (rod under 1 in. in diameter).

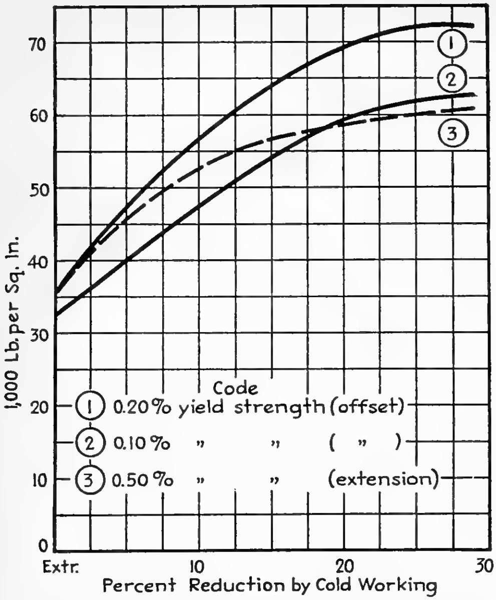


CHART 116.—The effect of cold drawing on the yield strength of architectural-bronze rod, previously extruded to a grain size of 0.025 mm. (56.64 % copper, 1.91 % lead, balance zinc) (rod under 1 in. in diameter).

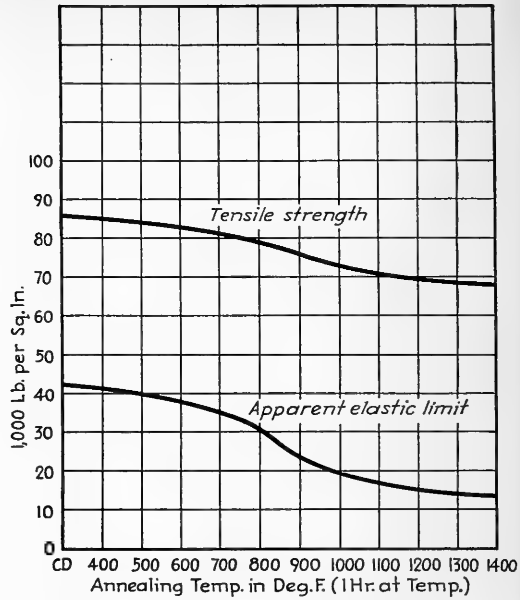


CHART 117.—The effect of annealing on the tensile strength and apparent elastic limit of architectural-bronze rod, previously cold-drawn 18 per cent (reduction of area) from extruded material having a grain size of 0.025 mm. (56.64 % copper, 1.91 % lead, balance zinc) (rod under 1 in. in diameter).

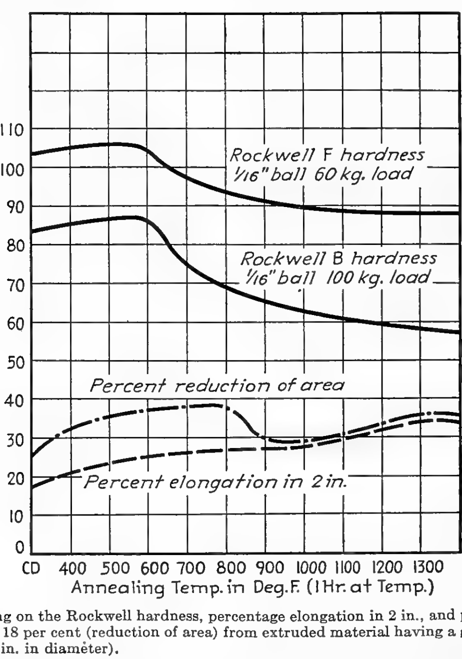


CHART 118.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of architectural-bronze rod, previously cold-drawn 18 per cent (reduction of area) from extruded material having a grain size of 0.025 mm. (56.64 % copper, 1.91 % lead, balance zinc) (rod under 1 in. in diameter).

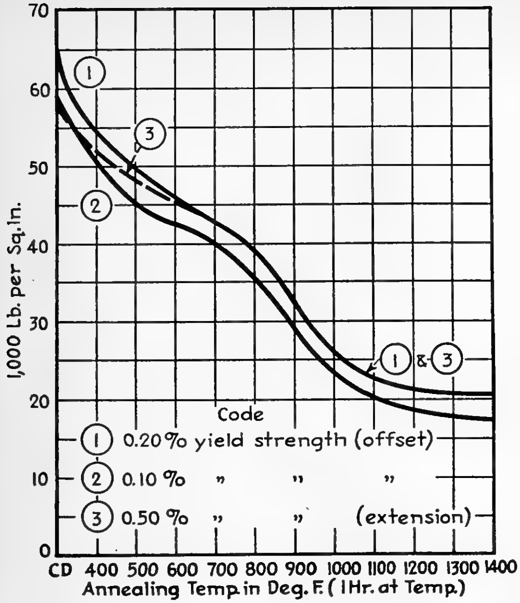


CHART 119.—The effect of annealing on the yield strength of architectural-bronze rod, previously cold-drawn 18 per cent (reduction of area) from extruded material having a grain size of 0.025 mm. (56.64 % copper, 1.91 % lead, balance zinc) (rod under 1 in. in diameter).

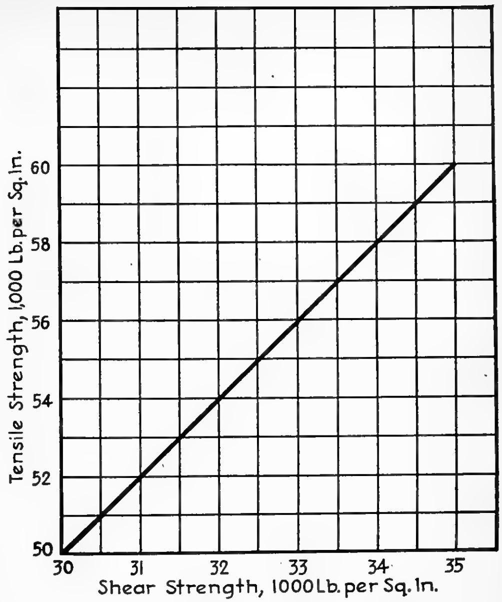


CHART 120.—Conversion chart for determination of shear strength of architectural bronze (56.50 % copper, 2.20 % lead, balance zinc) when tensile strength is known. Accurate to ±5 %[86]

TABLE 15
RED BRASS
Copper, 55.02%; lead, 1.62%; zinc, balance; iron, 0.05%

Property	Rod		Forgings
	Hard[a]	Soft[b]	Hot
Tensile strength, p.s.i. (000 omitted)	100	80	72–81
Apparent elastic limit, p.s.i. (000 omitted)	54	15	15–19
Yield strength, 0.5% extension, p.s.i. (000 omitted)	61	25	20–24
Yield strength, 0.2% offset, p.s.i. (000 omitted)	78	23	18–23
Yield strength, 0.1% offset, p.s.i. (000 omitted)	73	21	17–21
Elongation, % in 2 in.	14	28	27–35
Reduction of area, %	20	30	25–35
Rockwell hardness F, 1/16-in. ball, 60-kg. load	99	33	87–92
Rockwell hardness B, 1/16-in. ball, 100-kg. load	85	70	58–63
Brinell hardness, 10-mm. ball, 500-kg. load	142	110	92–99
Modulus of elasticity, p.s.i.	15,000,000		
Melting point, °F.	1610		
Density, lb. per cu. in.	0.305		
Forging range, °F.	1250–1350		
Forging quality	Excellent		
Type structure	Two phase, alpha-beta		

[a] Refers to rod cold-drawn 17 % from the extruded condition; rod under 1 in. in diameter.
[b] Extruded condition.

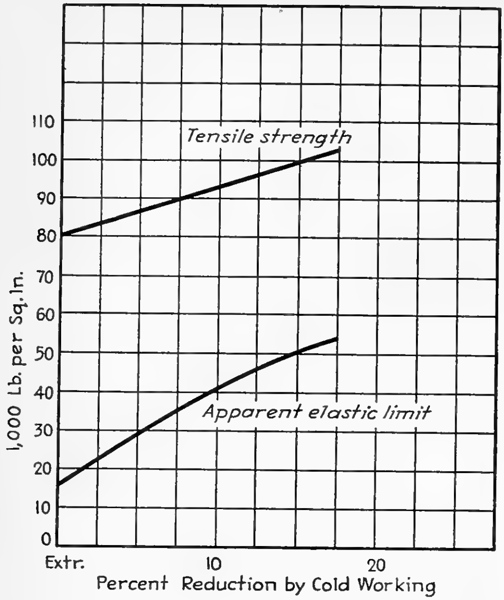


CHART 121.—The effect of cold drawing on the tensile strength and apparent elastic limit of red-brass rod, previously extruded (55.02 % copper, 1.62 % lead, balance zinc) (rod under 1 in. in diameter).

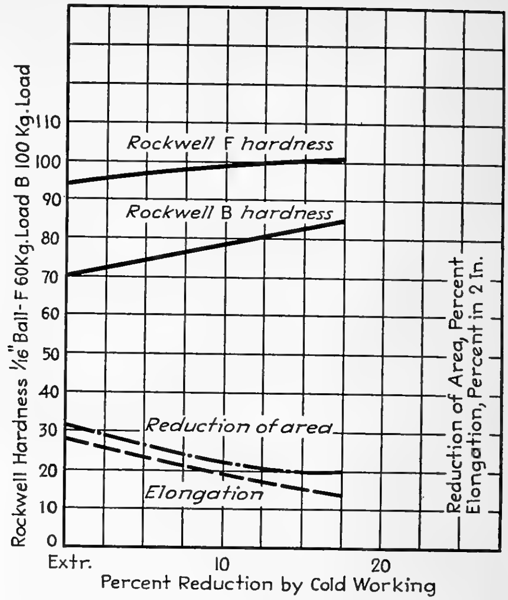


CHART 122.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of red-brass rod, previously extruded (55.02 % copper, 1.62 % lead, balance zinc) (rod under 1 in. in diameter).

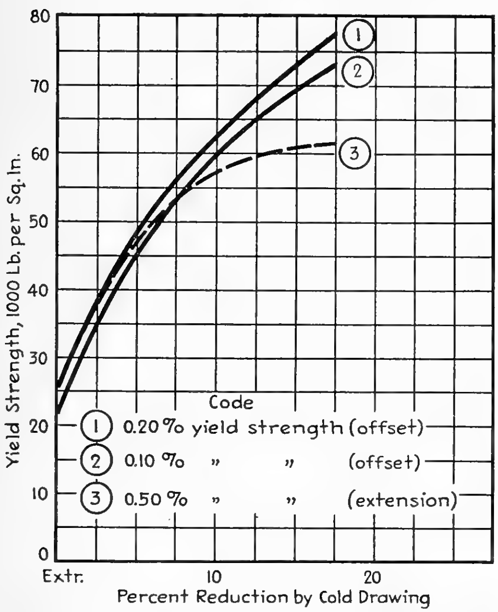


CHART 123.—The effect of cold drawing on the yield strength of red-brass rod, previously extruded (55.02 % copper, 1.62 % lead, balance zinc) (rod under 1 in. in diameter).

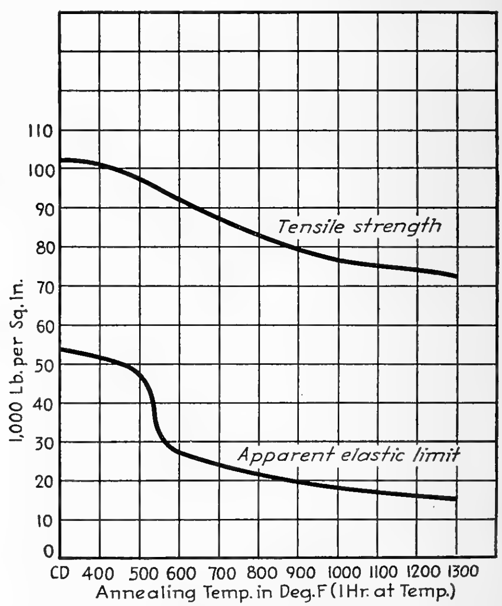


CHART 124.—The effect of annealing on the tensile strength and apparent elastic limit of red-brass rod, previously cold-drawn 17 percent (reduction of area) from extruded material (55.02 % copper, 1.62 % lead, balance zinc) (rod under 1 in. in diameter).

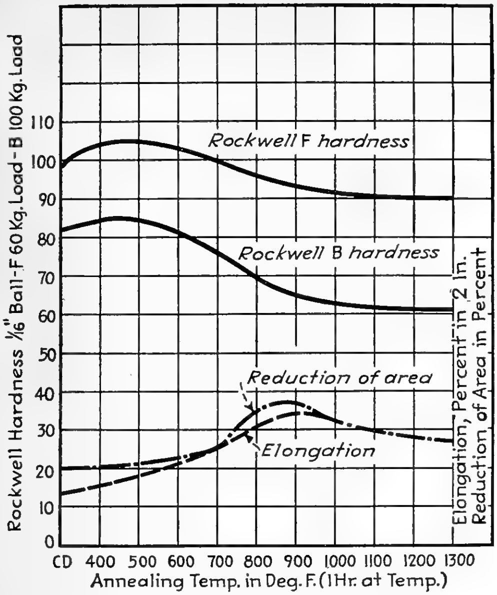


CHART 125.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of red-brass rod, previously cold-drawn 17 per cent (reduction of area) from extruded material (55.02 % copper, 1.62 % lead, balance zinc) (rod under 1 in. in diameter).

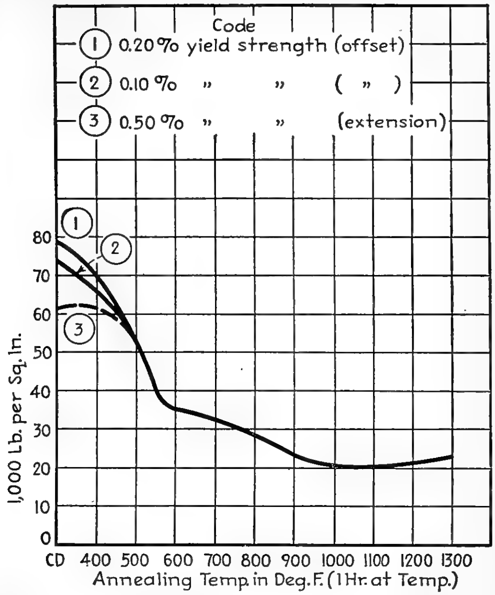


CHART 126.—The effect of annealing on the yield strength of red-brass rod, previously cold-drawn 17 per cent (reduction of area) from extruded material (55.02 % copper, 1.62 % lead, balance zinc) (rod under 1 in. in diameter).

CHAPTER IV

THE TIN BRASSES

Ternary alloys of copper-zinc and tin have been established in commercial use for many years. Many, including Hoyt[18,19], Guillet, Hudson, and Jones[20], and Campbell[21], have investigated their structural characteristics and established phase relationships.

There are many tin brasses in use but the following are the more important of those commercially available in wrought form.

Most common name	Copper, %	Tin, %	Lead, %	Zinc, %
Bearing or weatherstrip bronze	90	0.50	....	Balance
Chain bronze	87	1.25	....	Balance
Pen metal	83.5	1.50	....	Balance
Admiralty metal	71	1.00	....	Balance
Tobin bronze	60	0.75	....	Balance
Government naval brass	60	0.75	0.20	Balance
Hard naval brass	61	0.75	....	Balance
Low-leaded naval brass	60	0.75	0.50	Balance
Medium-leaded naval brass	60	0.75	0.75	Balance
High-leaded naval brass	60	1.00	2.00	Balance

Properly to be included with the above are the so-called "manganese bronzes." These alloys are actually tin brasses in which manganese is present only as a residual deoxidant. The more important alloys of this type are the following.

	"Manganese bronze," %	Modified "manganese bronze," %
Copper	57–60	61
Tin	0.50–1.50	0.75
Lead	0.20 max.	0.30
Manganese	0.50 max.	0.10
Zinc	Balance	Balance

Bearing or *weatherstrip bronze* is largely used as a bushing material involving light bearing loads and also for weatherstrip applications. The presence of the tin in the alloy slightly increases its resistance to atmospheric tarnish and corrosion and moderately improves its tensile strength.

This alloy has excellent cold-working properties and is most commonly fabricated in strip form by cold rolling. The more important physical properties and a summarization of mechanical properties may be found in Table 1. Charts 1 to 10 on pages 134 to 136 give in detail the influence of cold working and the effect of various annealing treatments on the mechanical properties of this alloy.

Chain bronze and *pen metal* are most commonly used for the manufacture of brass chains and pen points. The tin additions are made in both cases for the purpose of improving strength, color, and corrosion resistance. These alloys are also cold-working alloys and can be hot-worked only with difficulty. They are seldom fabricated in other than strip form. Tables 2 and 3 on pages 137 and 140 indicate the more important physical properties and give a general summary of their mechanical properties. Detailed mechanical properties of cold-rolled and annealed material may be found in Charts 11 to 32 on pages 137 to 143.

Admiralty metal was developed as a condenser-tube material by the British Navy in 1890 as an improvement over 70-30 copper-zinc, which up until that time was the most important commercial condenser-tube alloy.

Research indicated that the presence of 1 per cent of tin in 70-30 brass produced an alloy that had slightly better mechanical properties than plain brass and, in addition, had the property of developing a more protective film in contact with salt or brackish waters. Since that time the use of admiralty metal in heat exchanger applications has grown continuously. Today approximately 75 per cent of the total poundage of condenser tubes sold in the United States is admiralty metal.

In 1922, British investigators determined that the presence of 0.02 to 0.05 per cent of arsenic in admiralty metal effectively prevented a type of corrosion known as "dezincification." Since then it has been standard English practice to include a small amount of arsenic in all admiralty-metal condenser tubes. Early in the 1930's American fabricators of this alloy adopted similar practice. The presence of arsenic in no way influences the working or structural properties of the metal.

Admiralty metal is also used extensively for tube sheets in heat exchangers of all types. It is used occasionally in strip form for the fabrication of stamped or drawn articles.

Admiralty metal is essentially a cold-working alloy although it can be fabricated hot if especial care is taken. If hot-working operations, such as rolling, are to be performed, it is absolutely necessary that lead be kept to a trace, otherwise serious cracking will occur. Because of the tin content and also because of the copper-zinc range, hot working can be carried on in a limited temperature range only. Hot extrusion of tubes is usually performed at temperatures of 1350 to 1400°F. and hot rolling at a range of 1350 to 1450°F. Prior to any hot-working operation it is essential that castings be soaked at a temperature of from 1350 to 1450°F. for several hours so that the delta or eutectoid phase, which may be produced during solidification of the casting, may be absorbed. The presence of this phase produces "hot shortness" and causes cracking.

In Table 4 on page 144 are given the important physical properties and general mechanical properties of admiralty-metal tube, sheet, and strip.

FIG. 1.—Hot-rolled Roman-bronze shafting rod (longitudinal section). Etchant $NH_4OH + H_2O_2$. 75×

Naval brass is a generic term for those alloys containing 60 per cent of copper, 1 per cent of tin, and 39 per cent of zinc. When prepared from materials of especially high purity and fabricated by hot rolling rather than extrusion, an increase in resistance to corrosion fatigue is effected, and the alloy is ordinarily offered under various trade names, the best known of which are Tobin bronze, Roman bronze, and Chamet bronze.

In applications involving resistance to corrosion fatigue, such as marine shafting, it has been established that hot-rolled non-ferrous metals have a much higher endurance limit in fatigue than the same alloys produced by the extrusion process. Hot rolling produces a fine-grained uniform structure, while the extruded structure tends to be coarse and non-uniform. Figures 1 and 2 show typical structures of hot-rolled Roman Bronze rod and extruded naval brass.

These hot-rolled bronzes are widely used for marine shafting and similar applications where good resistance to fatigue is required and naval brass for those applications where comparable corrosion resistance and structural strength are necessary but where resistance to fatigue is not a vital factor. Naval brass is extensively used in the manufacture of heat exchangers for tube sheets and plates.

It is common commercial practice to add lead to the naval brasses to improve their machinability. The amount of lead added is dependent upon the nature of the intended application and the amount of machining involved. There are two general types of leaded naval brass: a low-leaded and a high-leaded. The low-leaded has improved machinability over plain naval brass and is ductile enough to withstand light cold heading and upsetting operations. The high-leaded alloy is designed primarily for high-speed machining and is not suitable for bending or upsetting operations. Its machinability compares favorably with free-cutting brass.

FIG. 2.—Extruded naval-brass rod (longitudinal section). Etchant $NH_4OH + H_2O_2$. 75×

When naval brass is intended for cold heading or upsetting operations as in the manufacture of bolts and nuts, it is customary to increase its copper content moderately.

All the tin brasses in the naval-brass range with the exception of the leaded alloys have excellent hot-working as well as reasonably good cold-working properties. They can be fabricated by hot rolling, hot forging, and extrusion. Those naval brasses containing lead are not commercially hot-rollable although they can be hot-extruded without any difficulty. Hot working is best accomplished within the temperature range of 1250 to 1400°F.

Tables 6 to 10 on pages 152 to 165 give detailed data on the effect of cold working and annealing of the naval brasses.

"*Manganese bronze*" is an alloy of the Muntz-metal type modified with tin, iron, and manganese in which manganese is of minor importance. This alloy possesses the highest mechanical properties of all the brasses and at the same time has almost as good resistance to salt-water corrosion as have the naval brasses. It is largely used in the form of rod and finds extensive application in the marine field as shafting, hardware, bolts, and tie rods. Its hot-working properties are similar to those of the naval brasses. Because of its lower copper content it is not ordinarily processed or fabricated by cold working. Table 11 lists the more important physical and mechanical properties. For greater detail see Charts 106 to 127 on pages 168 to 174.

TABLE 1
BEARING OR WEATHERSTRIP BRONZE
GENERAL DATA—STRIP[a]
Copper, 90.49%; tin, 0.48%; iron, trace; zinc, balance

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	70–79	40–41
Elongation, % in 2 in.	4	41–39
Apparent elastic limit, p.s.i. (000 omitted)	53–60	7–8
Yield strength, 0.5% extension, p.s.i. (000 omitted)	65–69	10
Yield strength, 0.2% offset, p.s.i. (000 omitted)	65–73	10
Yield strength, 0.1% offset, p.s.i. (000 omitted)	62–66	10
Rockwell hardness F, 1/16-in. ball, 60-kg. load	103–107	56–53
Rockwell hardness B, 1/16-in. ball, 100-kg. load	79–85	
Rockwell hardness G, 1/16-in. ball, 150-kg. load	48–59	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	86–89	
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	70–74	
Young's modulus of elasticity, p.s.i.	15,000,000	

[a] All tests conducted on 0.040-in. stock.
[b] 6 B. & S. Nos., hard, 0.080–0.015 mm. grain size at ready-to-finish, respectively.
[c] Annealed at 1300°F. for 1 hr.

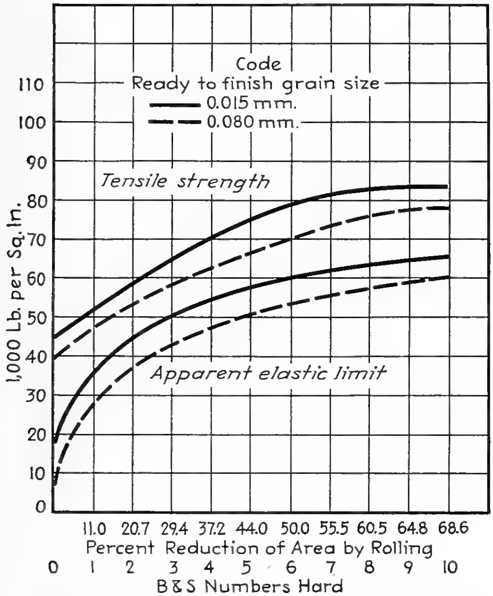


CHART 1.—The effect of cold rolling on the tensile strength and apparent elastic limit of bearing or weatherstrip bronze strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (90.49 % copper, 0.48 % tin, balance zinc) (0.040-in. stock).

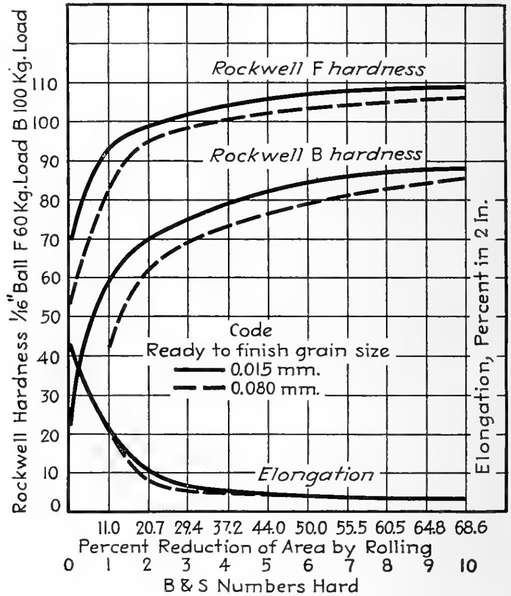


CHART 2.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of bearing or weatherstrip bronze strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (90.49 % copper, 0.48 % tin, balance zinc) (0.040-in. stock).

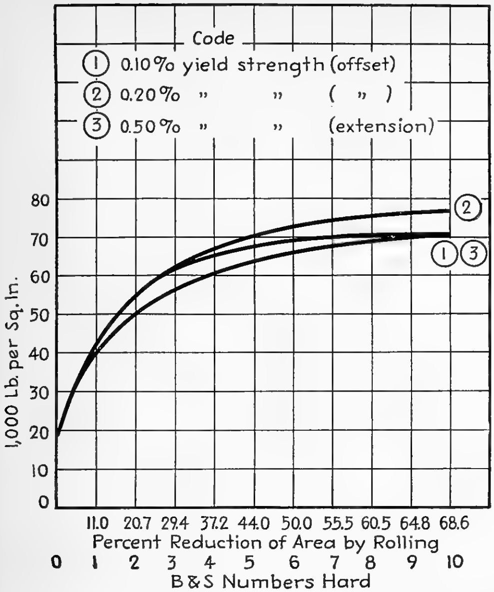


Chart 3.—The effect of cold rolling on the yield strengths of bearing or weatherstrip bronze strip, previously annealed to a grain size of 0.015 mm. (90.49 % copper, 0.48 % tin, balance zinc) (0.040-in. stock).

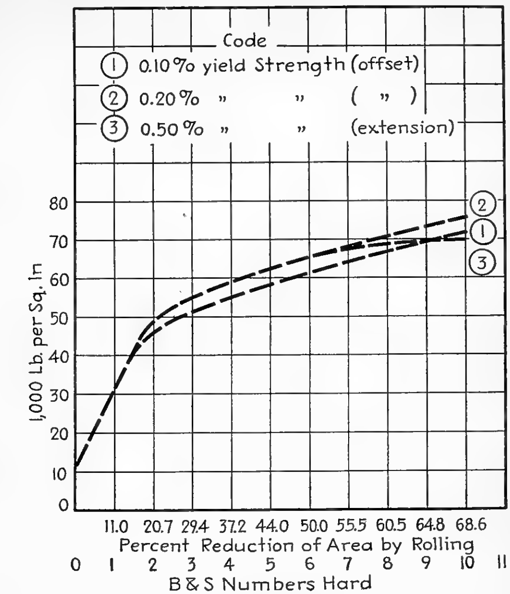


Chart 4.—The effect of cold rolling on the yield strengths of bearing or weatherstrip bronze strip, previously annealed to a grain size of 0.080 mm. (90.49 % copper, 0.48 % tin, balance zinc) (0.040-in. stock).

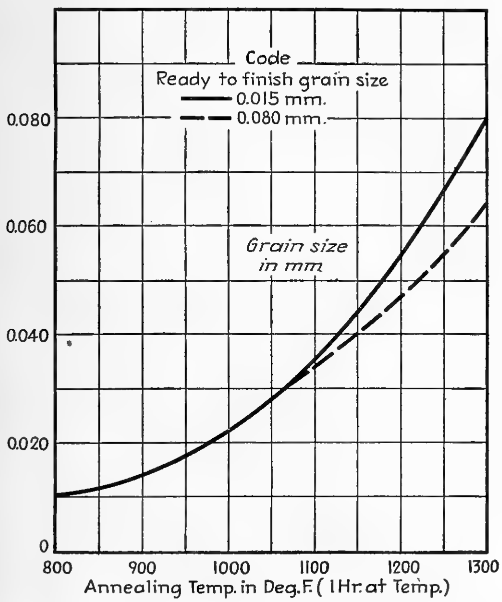


Chart 5.—The effect of annealing on the grain-growing characteristics of bearing or weatherstrip bronze strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (90.49 % copper, 0.48 % tin, balance zinc) (0.040-in. stock).

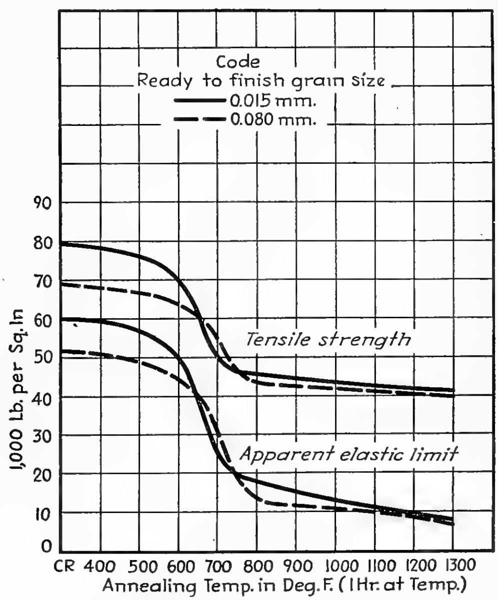


Chart 6.—The effect of annealing on the tensile strength and apparent elastic limit of bearing or weatherstrip bronze strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (90.49 % copper, 0.48 % tin, balance zinc) (0.040-in. stock).

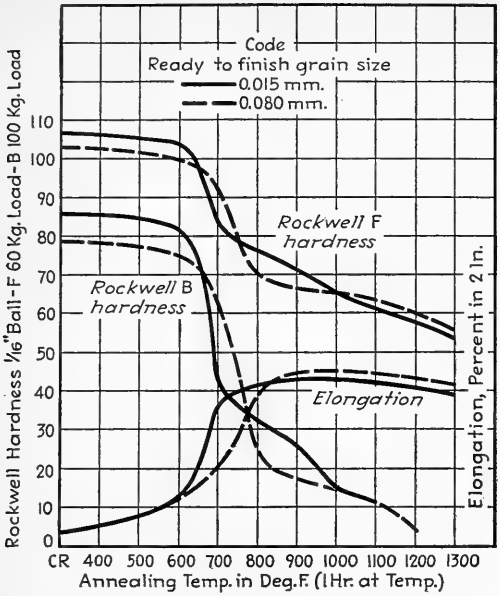


Chart 7.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of bearing or weatherstrip bronze strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (90.49 % copper, 0.48 % tin, balance zinc) (0.040-in. stock).

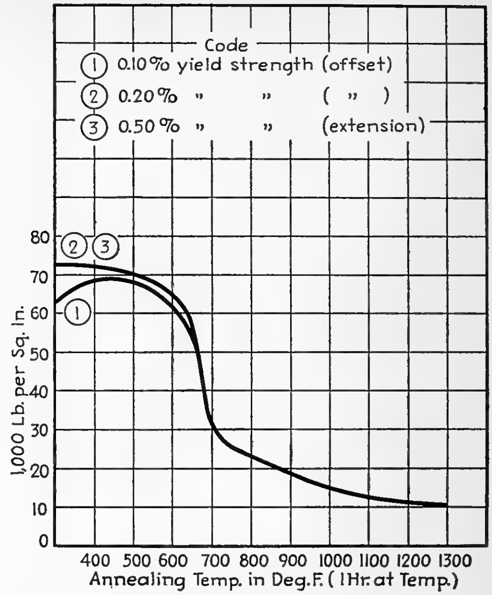


Chart 8.—The effect of annealing on the yield strength of bearing or weatherstrip bronze strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (90.49 % copper, 0.48 % tin, balance zinc) (0.040-in. stock).

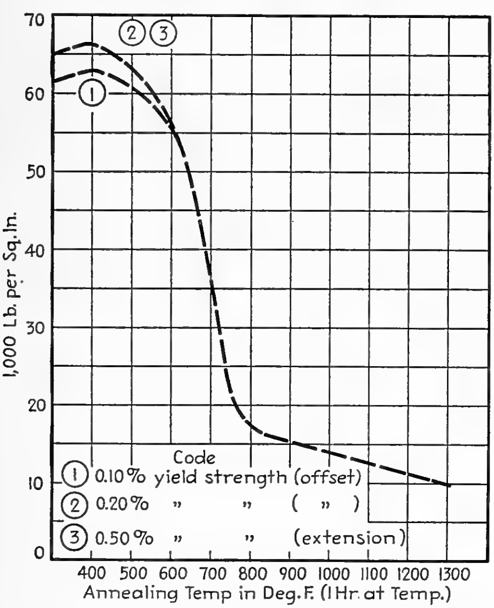


Chart 9.—The effect of annealing on the yield strength of bearing or weatherstrip bronze strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.080 mm. (90.49 % copper, 0.48 % tin, balance zinc (0.040-in. stock).

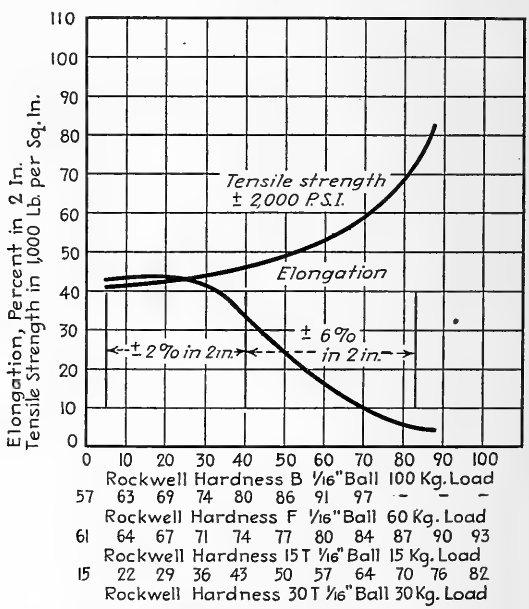


Chart 10.—This chart can be employed to determine the approximate tensile strength and percentage elongation of bearing or weatherstrip bronze strip (90.49 % copper, 0.48 % tin, balance zinc) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

TABLE 2
CHAIN BRONZE
General Data—Strip[a]
Copper, 87.58%; tin, 0.86%; lead, nil; zinc, balance

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	72–84	39–42
Elongation, % in 2 in.	5	58–48
Apparent elastic limit, p.s.i. (000 omitted)	56–63	9
Yield strength, 0.5% extension, p.s.i. (000 omitted)	61–66	10–11
Yield strength, 0.2% offset, p.s.i. (000 omitted)	65–79	10–11
Yield strength, 0.1% offset, p.s.i. (000 omitted)	59–72	10–11
Rockwell hardness F, 1/16-in. ball, 60-kg. load	105–109	55–57
Rockwell hardness B, 1/16-in. ball, 100-kg. load	84–88	
Rockwell hardness G, 1/16-in. ball, 150-kg. load	56–66	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	88–90	
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	73–76	

[a] All tests conducted on 0.040-in. stock.
[b] 6 B. & S. Nos., hard, 0.080–0.015 mm. grain size at ready-to-finish, respectively.
[c] Annealed at 1400°F. for 1 hr.

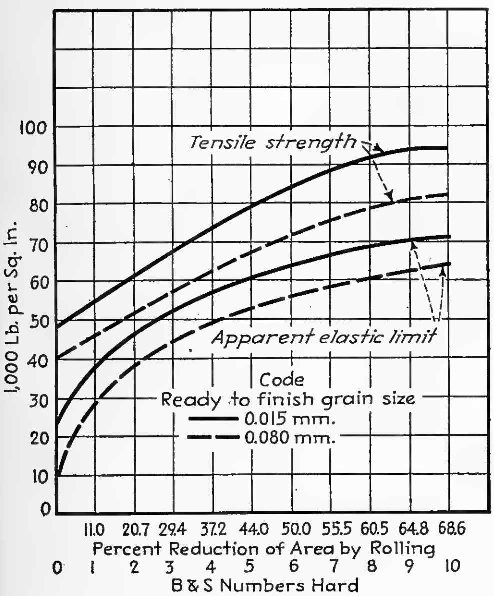


Chart 11.—The effect of cold rolling on the tensile strength and apparent elastic limit of chain-bronze strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (87.58 % copper, 0.86 % tin, balance zinc) (0.040-in. stock).

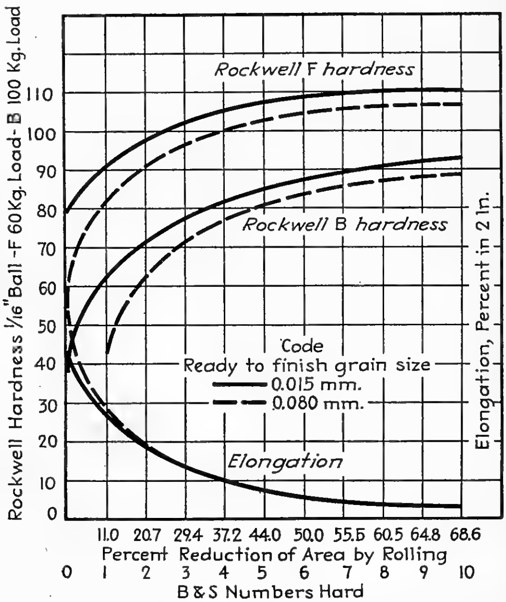


Chart 12.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of chain-bronze strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (87.58 % copper, 0.86 % tin, balance zinc) (0.040-in. stock).

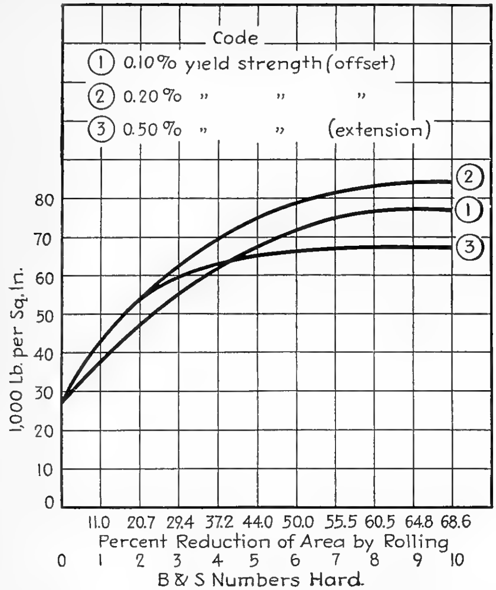


CHART 13.—The effect of cold rolling on the yield strengths of chain-bronze strip, previously annealed to a grain size of 0.015 mm. (87.58 % copper, 0.86 % tin, balance zinc) (0.040-in. stock).

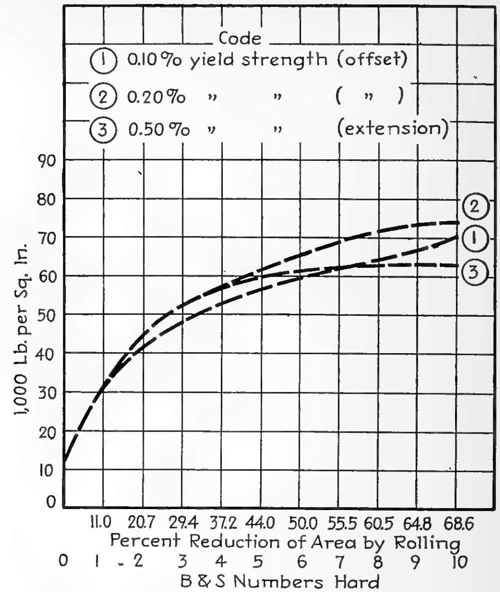


CHART 14.—The effect of cold rolling on the yield strengths of chain-bronze strip, previously annealed to a grain size of 0.080 mm. (87.58 % copper, 0.86 % tin, balance zinc) (0.040-in. stock).

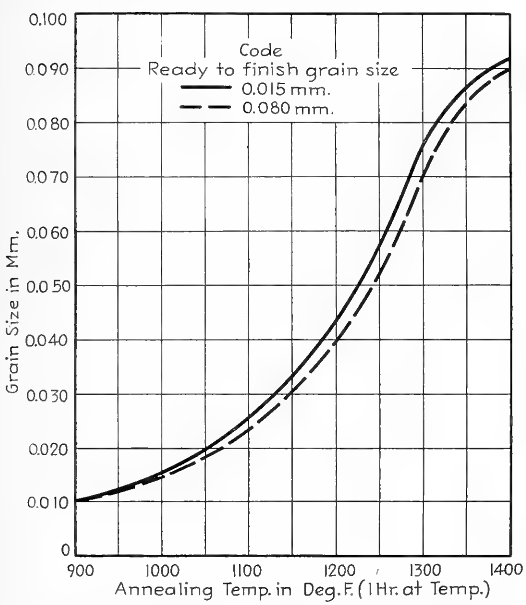


CHART 15.—The effect of annealing on the grain-growing characteristics of chain-bronze strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (87.58 % copper, 0.86 % tin, balance zinc (0.040-in. stock).

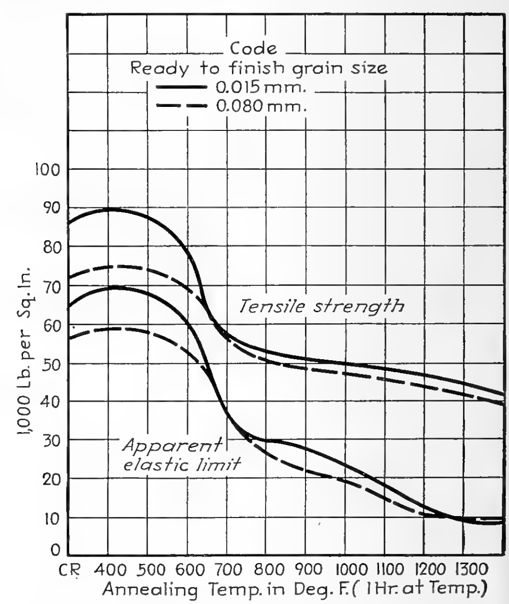


CHART 16.—The effect of annealing on the tensile strength and apparent elastic limit of chain-bronze strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (87.58 % copper, 0.86 % tin, balance zinc) (0.040-in. stock).

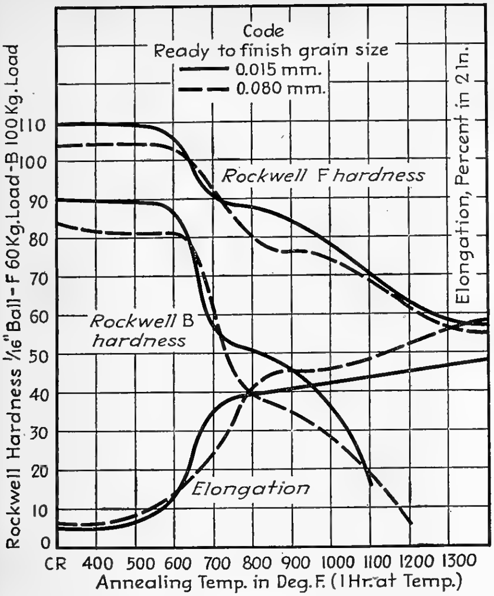


CHART 17.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of chain-bronze strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (87.58 % copper, 0.86 % tin, balance zinc) (0.040-in. stock).

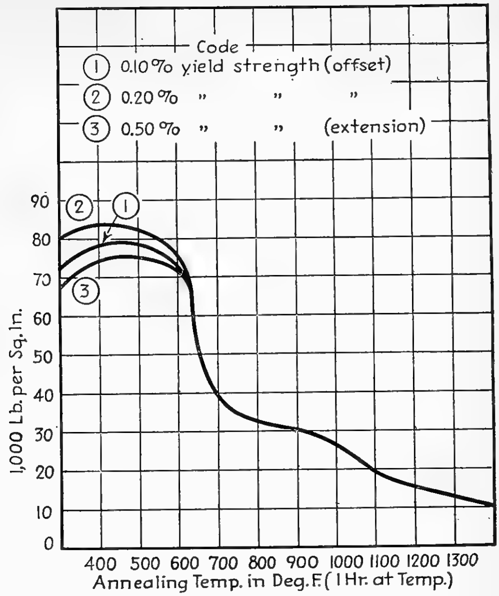


CHART 18.—The effect of annealing on the yield strength of chain-bronze strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (87.58 % copper, 0.86 % tin, balance zinc (0.040-in. stock).

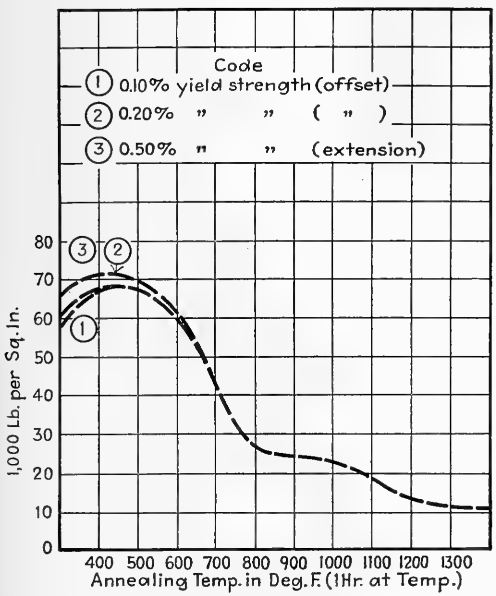


CHART 19.—The effect of annealing on the yield strength of chain-bronze strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.080 mm. (87.58 % copper, 0.86 % tin, balance zinc (0.040-in. stock).

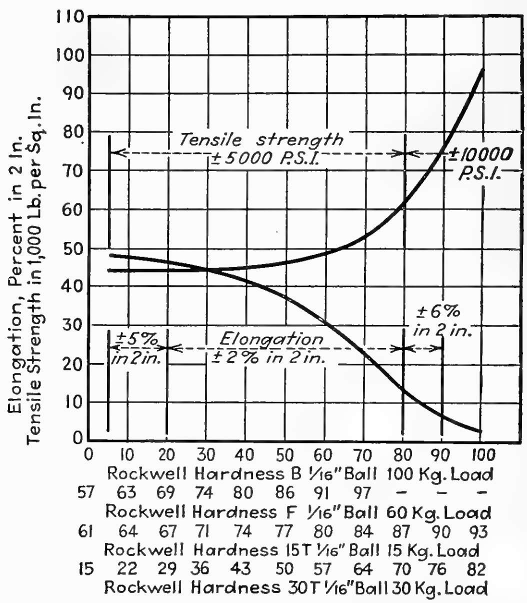


CHART 20.—This chart can be employed to determine the approximate tensile strength and percentage elongation of chain-bronze strip (87.58 % copper, 0.86 % tin, balance zinc) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

TABLE 3
PEN METAL
GENERAL DATA—STRIP[a]
Copper, 83.32%; tin, 1.32%; lead, 0.03%; iron, trace; zinc, balance

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	85–98	43–56
Elongation, % in 2 in.	5–3	66–57
Apparent elastic limit, p.s.i. (000 omitted)	62–75	10
Yield strength, 0.5% extension, p.s.i. (000 omitted)	68–74	12–13
Yield strength, 0.2% offset, p.s.i. (000 omitted)	75–88	12–13
Yield strength, 0.1% offset, p.s.i. (000 omitted)	67–74	12–13
Rockwell hardness F, 1/16-in. ball, 60-kg. load	108–111	62–64
Rockwell hardness B, 1/16-in. ball, 100-kg. load	88–95	13–17
Rockwell hardness G, 1/16-in. ball, 150-kg. load	64–74	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	90–92	65–66
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	76–79	24–26

[a] All tests conducted on 0.040-in. stock.
[b] 6 B. & S. Nos., hard, 0.080–0.015 mm. grain size at ready-to-finish, respectively.
[c] Annealed at 1300°F. for 1 hr.

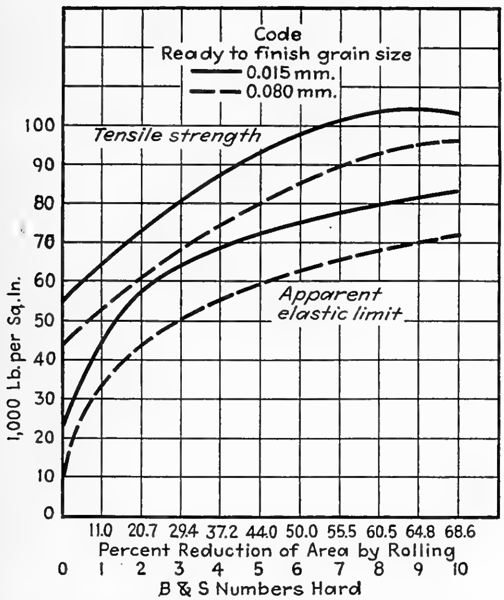


CHART 21.—The effect of cold rolling on the tensile strength and apparent elastic limit of pen-metal strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (83.32 % copper, 1.32 % tin, balance zinc (0.040-in. stock).

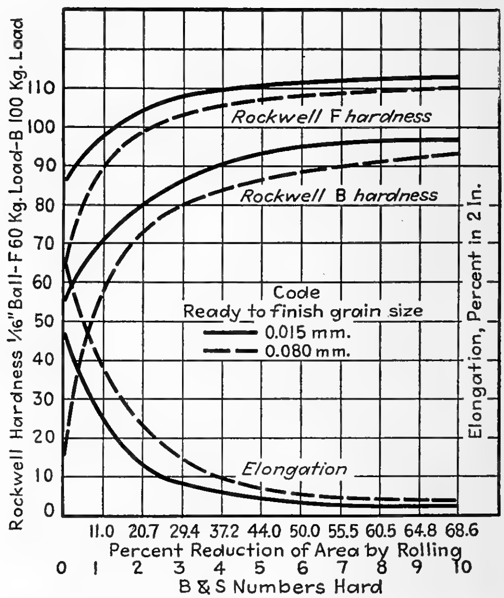


CHART 22.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 inches of pen-metal strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (83.32 % copper, 1.32 % tin, balance zinc) (0.040-in. stock).

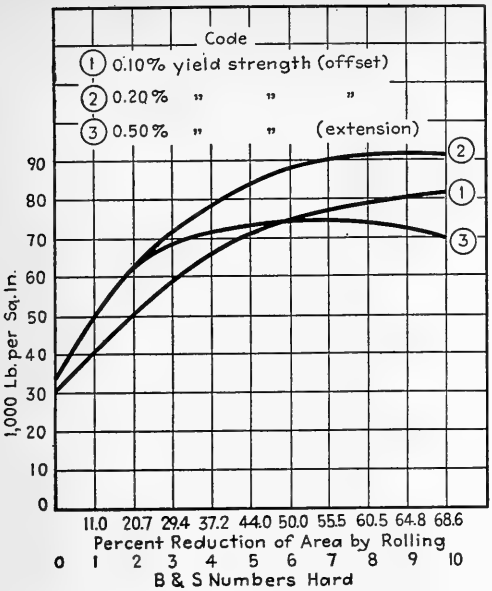


CHART 23.—The effect of cold rolling on the yield strengths of pen-metal strip, previously annealed to a grain size of 0.015 mm. (83.32 % copper, 1.32 % tin, balance zinc) (0.040-in. stock).

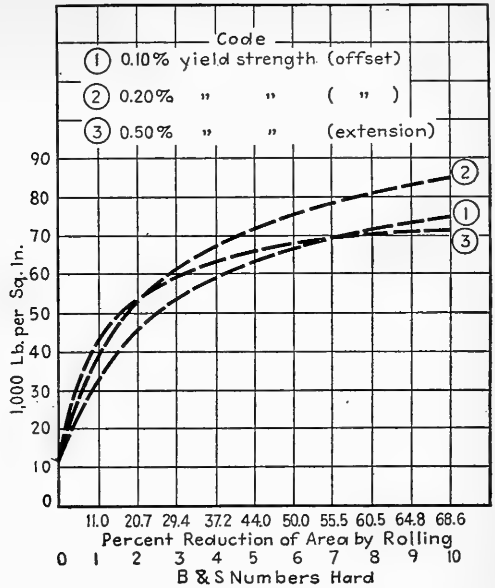


CHART 24.—The effect of cold rolling on the yield strengths of pen-metal strip, previously annealed to a grain size of 0.080 mm. (83.32 % copper, 1.32 % tin, balance zinc) (0.040-in. stock).

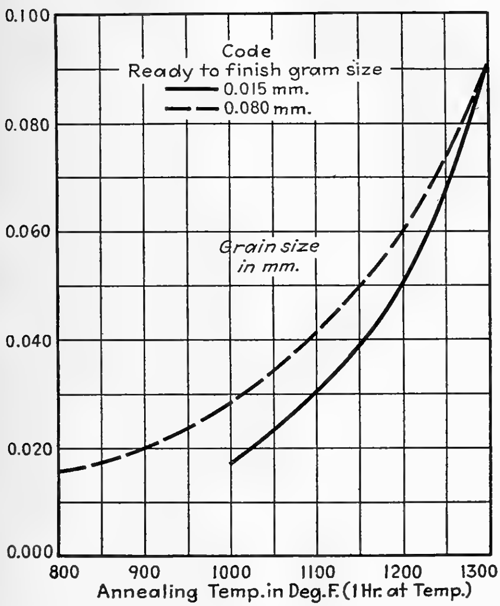


CHART 25.—The effect of annealing on the grain-growing characteristics of pen-metal strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (83.32 % copper, 1.32 % tin, balance zinc) (0.040-in. stock).

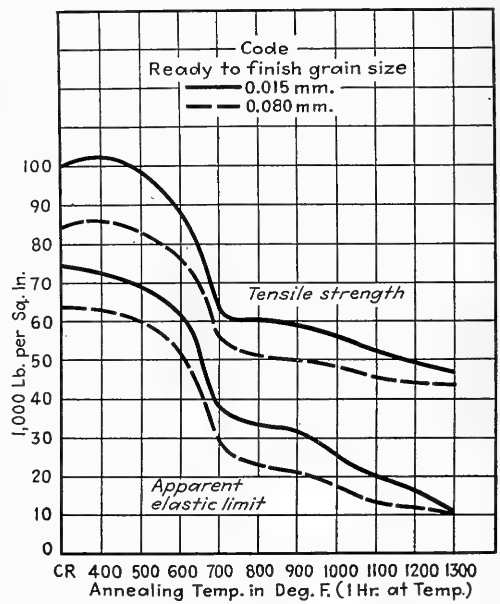


CHART 26.—The effect of annealing on the tensile strength and apparent elastic limit of pen-metal strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (83.32 % copper, 1.32 % tin, balance zinc) (0.040-in. stock).

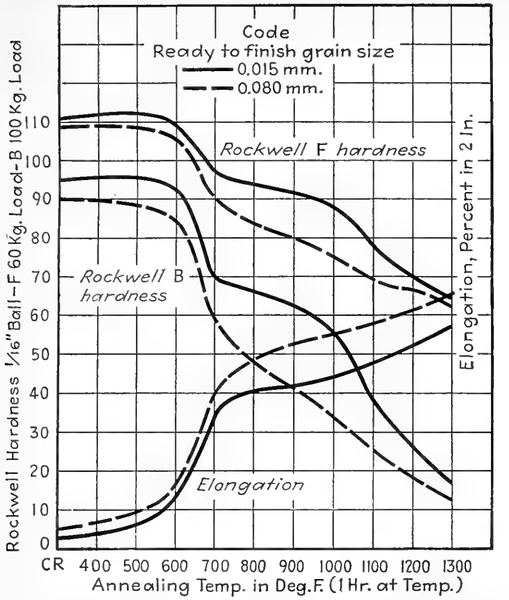


Chart 27.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of pen-metal strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (83.32 % copper, 1.32 % tin, balance zinc) (0.040-in. stock).

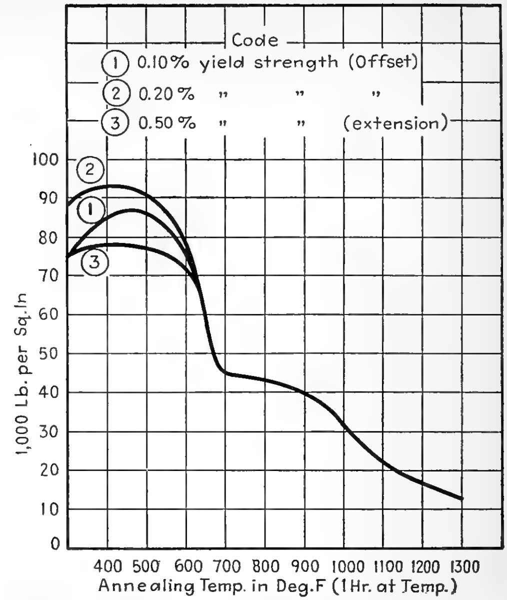


Chart 28.—The effect of annealing on the yield strength of pen-metal strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (83.32 % copper, 1.32 % tin, balance zinc) (0.040-in. stock).

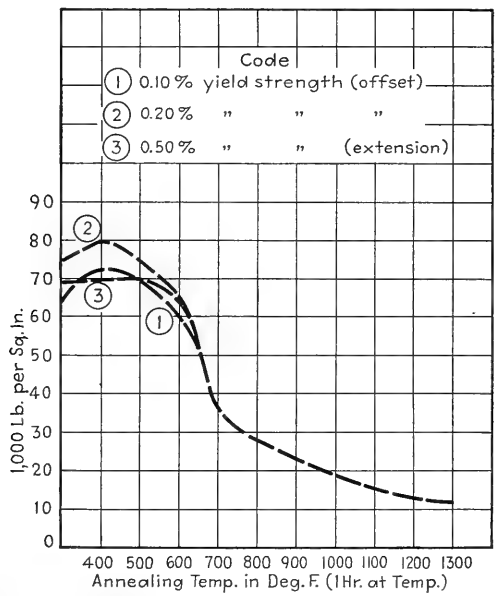


Chart 29.—The effect of annealing on the yield strength of pen-metal strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.080 mm. (83.32 % copper, 1.32 % tin, balance zinc) (0.040-in. stock).

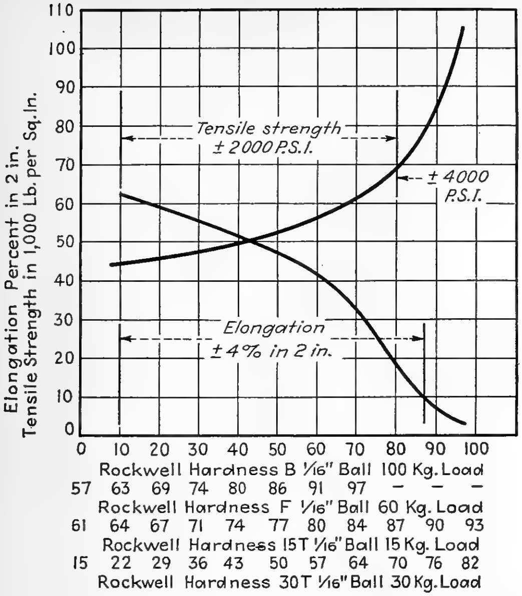


Chart 30.—This chart can be employed to determine the approximate tensile strength and percentage elongation of pen-metal strip (83.32 % copper, 1.32 % tin, balance zinc) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

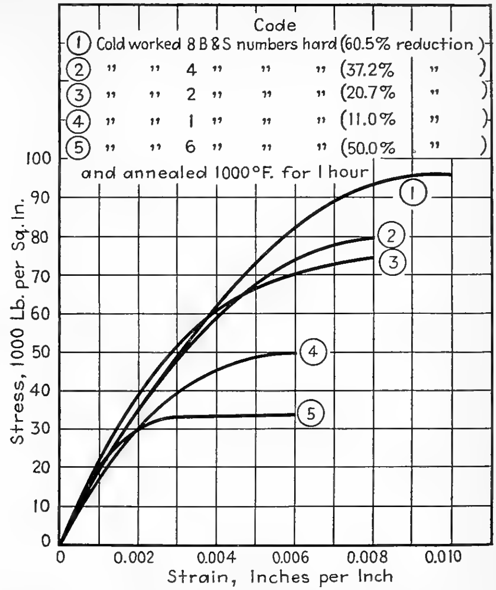


Chart 31.—The effect of cold rolling on the stress-strain characteristics of pen-metal strip (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm.; 5,000 lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (83.32 % copper, 1.32 % tin, balance zinc.)

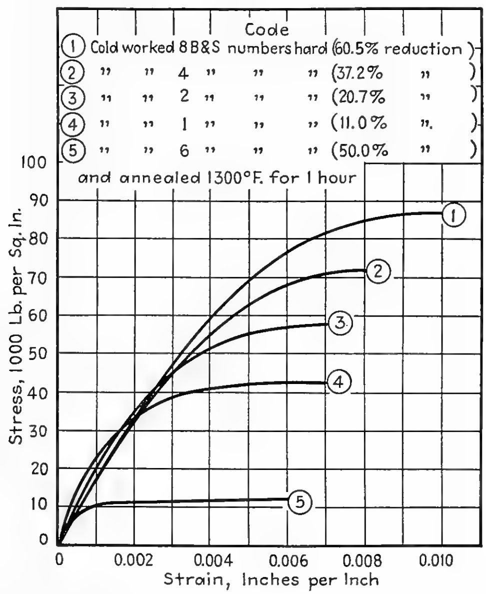


Chart 32.—The effect of cold rolling on the stress-strain characteristics of pen-metal strip (0.040 in. thick) having a ready-to-finish grain size of 0.080 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (83.32 % copper, 1.32 % tin, balance zinc.)

TABLE 4
ADMIRALTY METAL

General Data—Tube

Copper, 71.34%; tin, 0.97%; lead, nil; iron, trace; zinc, balance

Property	Hard[a]	Soft[b]
Tensile strength, p.s.i. (000 omitted)	100	53
Elongation, % in 2 in.	4	67
Apparent elastic limit, p.s.i. (000 omitted)	98	18
Rockwell hardness F, 1/16-in. ball, 60-kg. load	111	67
Young's modulus of elasticity, p.s.i	15,000,000	

General Data—Strip[c]

Copper, 70.37%; tin, 1.01%; lead, 0.02%; iron, 0.01%; zinc, balance

Property	Hard[d]	Soft[e]
Tensile strength, p.s.i. (000 omitted)	88–114	45–48
Elongation, % in 2 in.	1–4	62–69
Apparent elastic limit, p.s.i. (000 omitted)	58–73	10–13
Yield strength, 0.5% extension, p.s.i (000 omitted)	72–74	13–14
Yield strength, 0.2% offset, p.s.i (000 omitted)	80–95	13–14
Yield strength, 0.1% offset, p.s.i (000 omitted)	69–82	13–14
Rockwell hardness F, 1/16-in. ball, 60-kg. load	109–113	59–60
Rockwell hardness B, 1/16-in. ball, 100-kg. load	90–97	9
Rockwell hardness G, 1/16-in. ball, 150-kg. load	66–78	
Rockwell superficial 15-T, 1/16-in. ball, 15-kg. load	90–92	64
Rockwell superficial 30-T, 1/16-in. ball, 30-kg. load	76–81	20

Physical Data

Melting point, °F.	1715
Density, lb. per cu. in.	0.308
Coefficient of expansion, per °C. from 25 to 300°C.	0.0000202
Electrical conductivity,(87) % I.A.C.S. at 68°F.	24.65
Thermal conductivity,(87) B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	64
Specific gravity	8.53

Available Creep Data(3)

Previous history: rod hot-rolled to 0.875 in.; cold-drawn to 0.750 in.

Temperature °F.	No measurable flow	Stress, p.s.i., required to produce designated rate of creep per 1,000 hr.		
		0.01%	0.10%	1.00%
400	10,000	13,000	19,000	27,000
600	Approaching zero	1,000	1,950	3,800
800	Approaching zero	54	160	500

[a] Admiralty condenser tube 3/4 by 0.049 in.—extruded, reduced, and cold-drawn.
[b] Same as footnote *a* after 900°F. anneal (1 hr.).
[c] All tests conducted on 0.040-in. stock.
[d] 6 B. & S. Nos., hard, 0.080–0.015 mm. grain size at ready-to-finish.
[e] 1200°F. anneal (1 hr. at temperature of material described in footnote *d*).

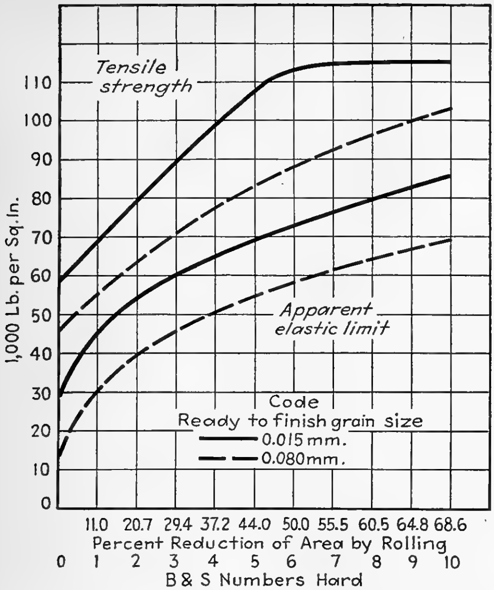


CHART 33.—The effect of cold rolling on the tensile strength and apparent elastic limit of admiralty-metal strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (70.37 % copper, 1.01 % tin, balance zinc) (0.040-in. stock).

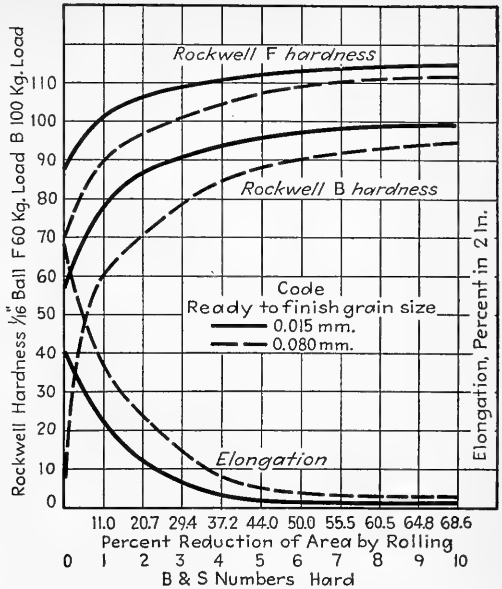


CHART 34.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of admiralty-metal strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (70.37 % copper, 1.01 % tin, balance zinc) (0.040-in. stock).

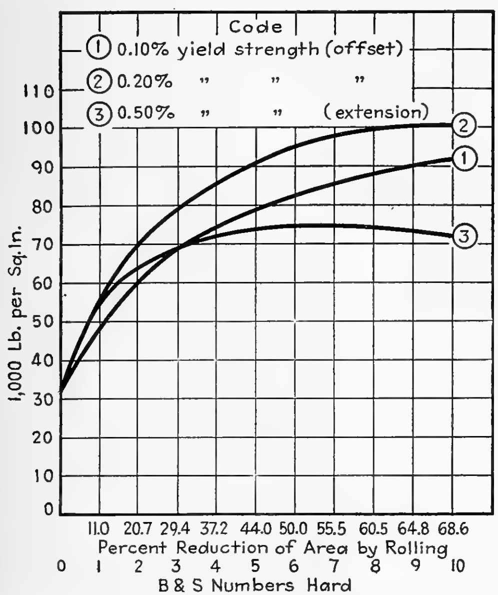


CHART 35.—The effect of cold rolling on the yield strength of admiralty-metal strip, previously annealed to a grain size of 0.015 mm. (70.37 % copper, 1.01 %, balance zinc) (0.040-in. stock).

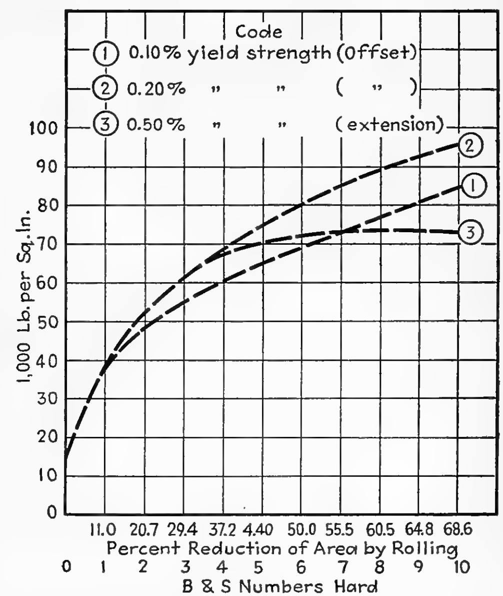


CHART 36.—The effect of cold rolling on the yield strength of admiralty-metal strip, previously annealed to a grain size of 0.080 mm. (70.37 % copper, 1.01 % tin, balance zinc) (0.040-in. stock).

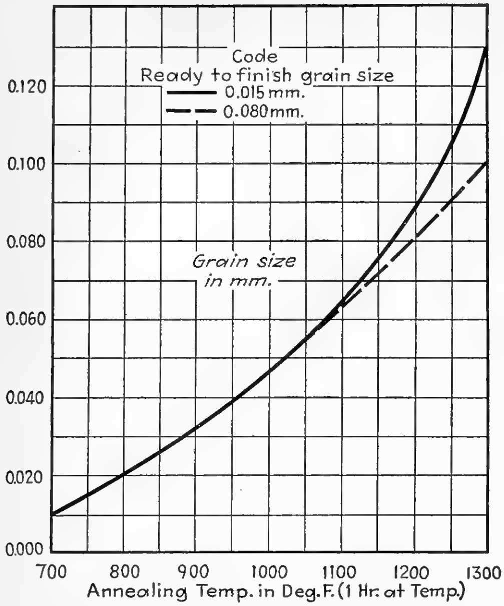


CHART 37.—The effect of annealing on the grain-growing characteristics of admiralty-metal strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (70.37 % copper, 1.01 % tin, balance zinc) (0.040-in. stock).

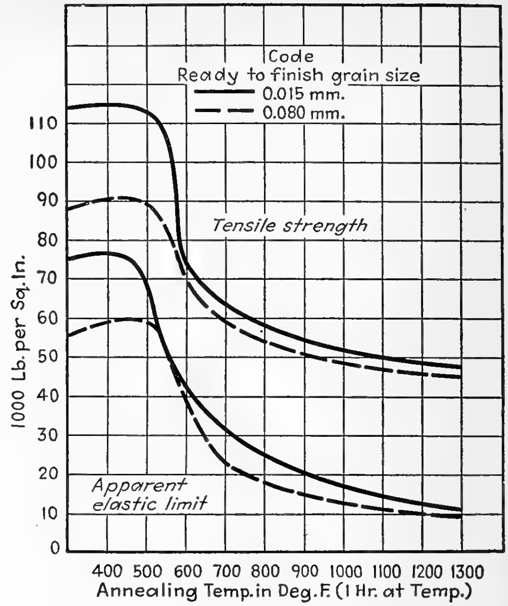


CHART 38.—The effect of annealing on the tensile strength and apparent elastic limit of admiralty-metal strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (70.37 % copper, 1.01 % tin, balance zinc) (0.040-in. stock).

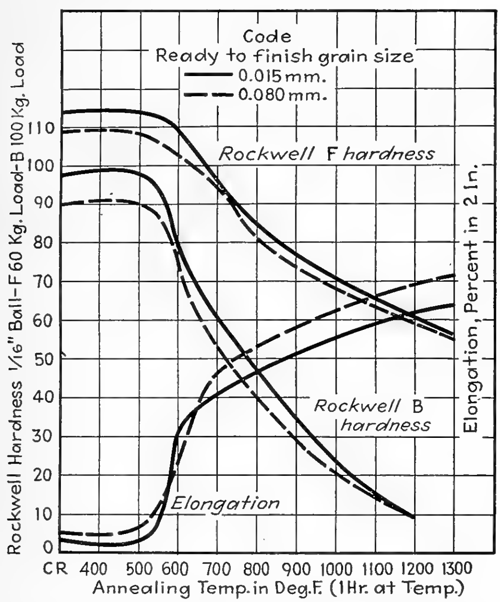


CHART 39.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of admiralty-metal strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (70.37 % copper, 1.01 % tin, balance zinc) (0.040-in. stock).

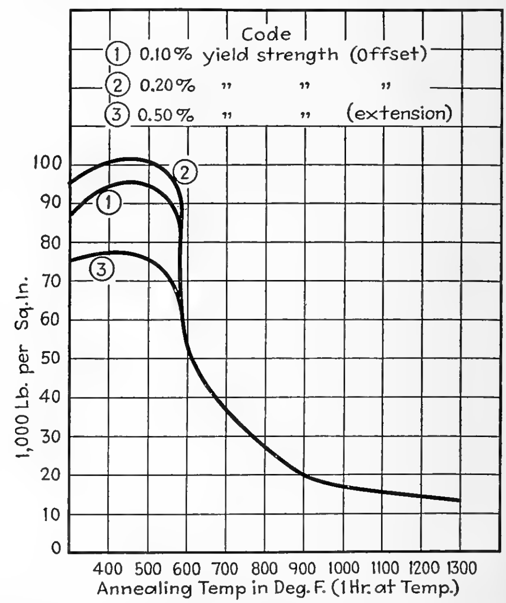


CHART 40.—The effect of annealing on the yield strength of admiralty-metal strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (70.37 % copper, 1.01 % tin, balance zinc) (0.040-in. stock).

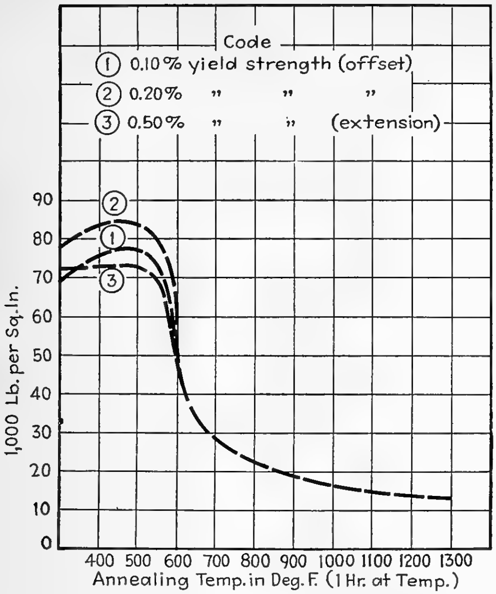


CHART 41.—The effect of annealing on the yield strength of admiralty-metal strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.080 mm. (70.37 % copper, 1.01 % tin, balance zinc) (0.040-in. stock).

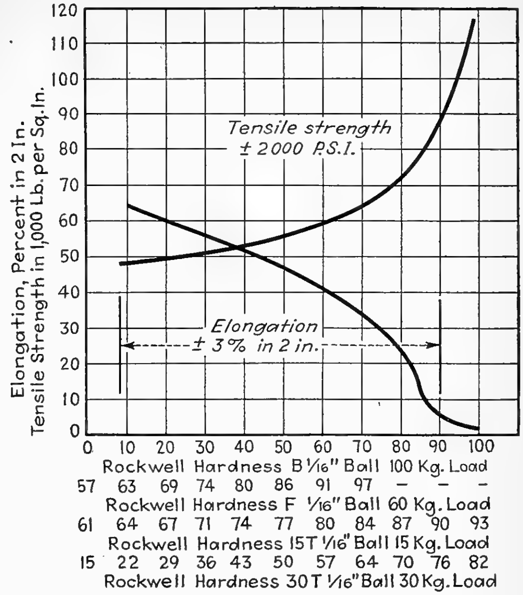


CHART 42.—This chart can be employed to determine the approximate tensile strength and percentage elongation of admiralty-metal strip (70.37 % copper, 1.01 % tin, balance zinc) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

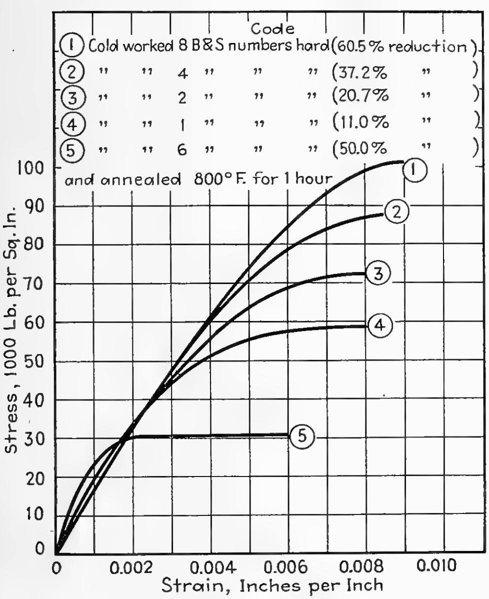


CHART 43.—The effect of cold rolling on the stress-strain characteristics of admiralty-metal strip (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (70.37 % copper, 1.01 % tin, balance zinc.)

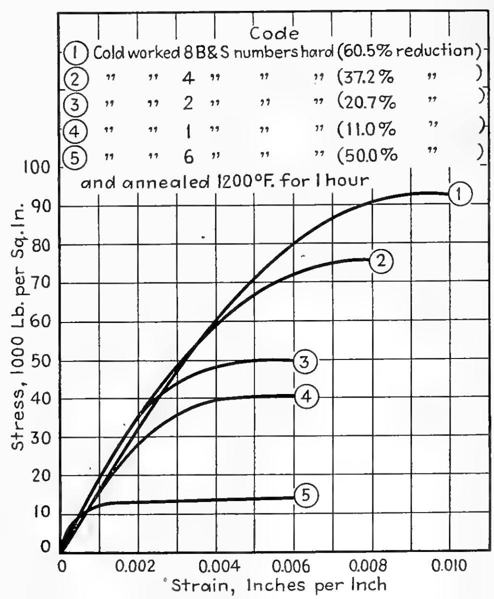


CHART 44.—The effect of cold rolling on the stress-strain characteristics of admiralty-metal strip (0.040 in. thick) having a ready-to-finish grain size of 0.080 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (70.37 % copper, 1.01 % tin, balance zinc.)

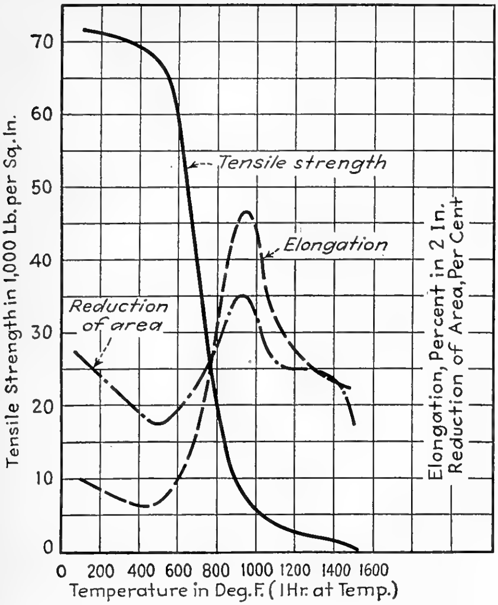


CHART 45.—The effect of elevated temperature on the tensile strength, percentage reduction of area, and percentage elongation in 2 in. of admiralty-metal rod (70.52 % copper, 1.27 % tin, balance zinc), previously cold-worked 35 per cent (reduction of area) according to W. B. Price[7] (rod under 1 in. in diameter).

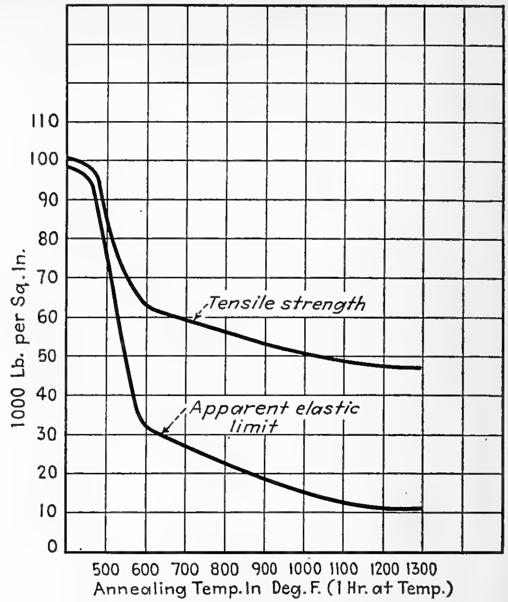


CHART 46.—The effect of annealing on the tensile strength and apparent elastic limit of admiralty condenser tube, previously cold-drawn 50 per cent (reduction of area) (71.34 % copper, 0.97 % tin, balance zinc).

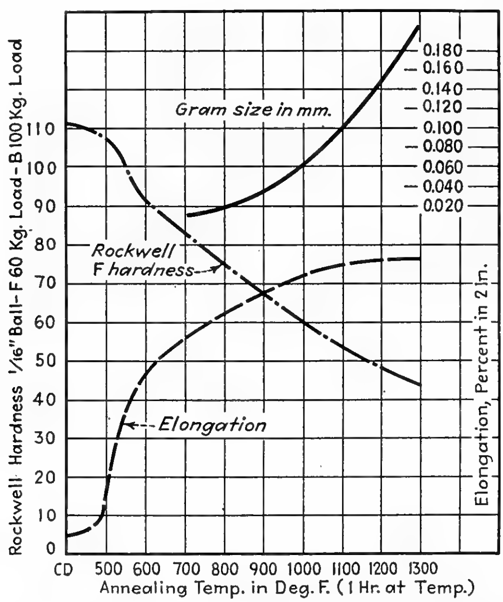


CHART 47.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and grain size of admiralty condenser tube, previously cold-drawn 50 per cent (reduction of area) (71.34 % copper, 0.97 % tin, balance zinc).

TABLE 5
ROMAN OR TOBIN BRONZE

Copper, 60.00%; tin, 0.74%; iron, 0.04%; lead, trace; zinc, balance

Property	Rod		Forgings	
	Hard[a]	Soft[b]	Hot	Cold[c]
Tensile strength, p.s.i. (000 omitted)	86	59	59–62	64
Apparent elastic limit, p.s.i. (000 omitted)	69	16	16–20	32
Yield strength, 0.5% extension, p.s.i. (000 omitted)	58	22	22–25	35
Yield strength, 0.1% offset, p.s.i. (000 omitted)	56	20	19–24	32
Yield strength, 0.2% offset, p.s.i. (000 omitted)	60	22	22–25	35
Elongation, % in 2 in.	15	48	48–40	40
Reduction of area, %	46	52	50–59	50
Endurance limit, p.s.i. (000 omitted)	27	22		
Rockwell hardness F, 1/16-in. ball, 60-kg. load		88	78–85	92
Rockwell hardness B, 1/16-in. ball, 100-kg. load	84	55	50–55	62
Brinell hardness, 10-mm. ball, 500-kg. load	140	89	83–89	98
Modulus of elasticity, p.s.i.	15,000,000			
Melting point, °F.	1635			
Coefficient of expansion, per °C. from 25–300°C.	0.0000214			
Electrical conductivity,[87] % I.A.C.S, 68°F.	26.1			
Thermal conductivity,[87] B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	70			
Density, lb. per cu. in.	0.304			
Forging range, °F.	1250–1450			
Forging quality	Excellent			
Type structure	Two phase, alpha-beta			

Available Creep Data[3]

Previous history: hot-rolled to 0.750-in. rod; average grain size 0.025 mm.

Temperature °F.	No measurable flow	Stress, p.s.i., required to produce designated rate of creep per 1,000 hr.		
		0.01%	0.10%	1.00%
300	10,000	12,000	15,000	21,500
500	Approaching zero	3,500	5,700	9,400

[a] Refers to rod cold-drawn 30%; rod under 1 in. in diameter, ready-to-finish grain size, 0.025 mm.
[b] Refers to 1200°F. anneal (for 1 hr.).
[c] Material cold-struck from hot-forged condition.

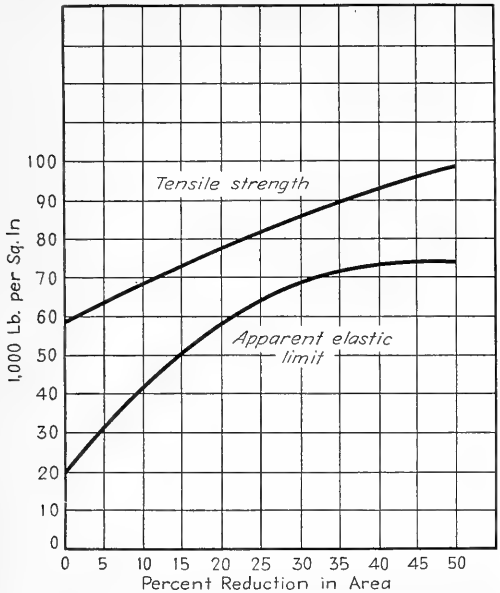


CHART 48.—The effect of cold drawing on the tensile strength and apparent elastic limit of Tobin-bronze rod, previously annealed to a grain size of 0.025 mm. (60.00 % copper, 0.74 % tin, balance zinc (rod under 1 in. in diameter).

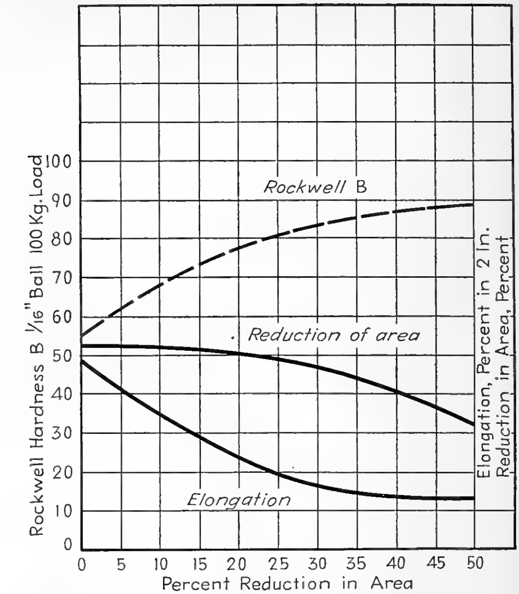


CHART 49.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of Tobin-bronze rod, previously annealed to a grain size of 0.025 mm. (60.00 % copper, 0.74 % tin, balance zinc) (rod under 1 in. in diameter).

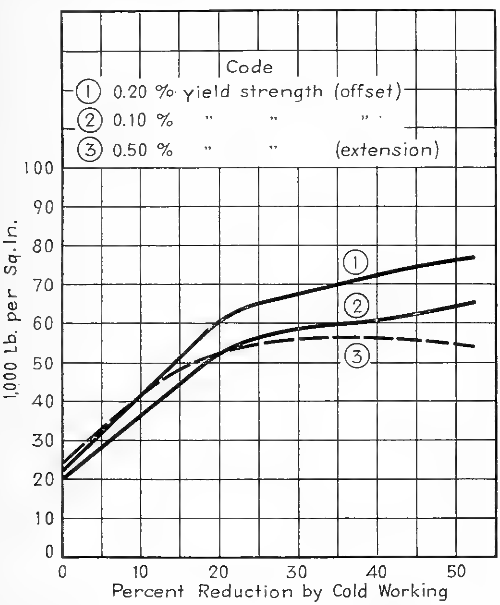


CHART 50.—The effect of cold drawing on the yield strength of Tobin-bronze rod, previously annealed to a grain size of 0.025 mm. (60.00 % copper, 0.74 % tin, balance zinc) (rod under 1 in. in diameter).

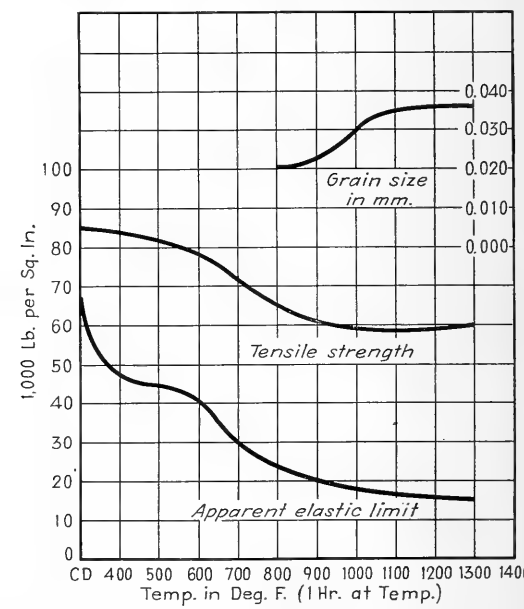


CHART 51.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of Tobin-bronze rod, previously cold-drawn 30 per cent (reduction of area) from material having a grain size of 0.025 mm. (60.00 % copper, 0.74 % tin, balance zinc) (rod under 1 in. in diameter).

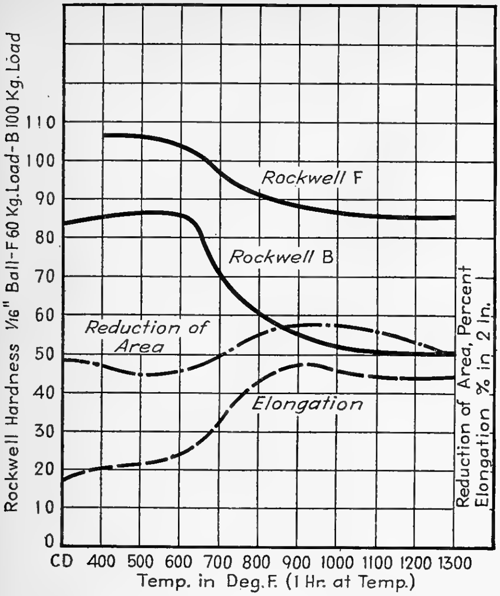


Chart 52.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of Tobin-bronze rod, previously cold-drawn 30 per cent from material having a grain size of 0.025 mm. (60.00 % copper, 0.74 % tin, balance zinc) (rod under 1 in. in diameter).

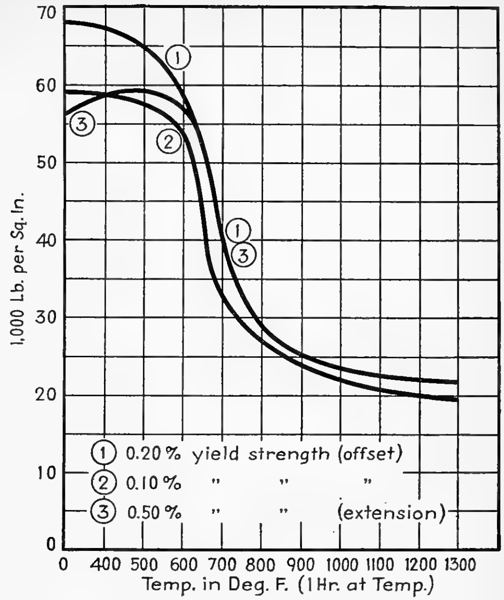


Chart 53.—The effect of annealing on the yield strength of Tobin-bronze rod, previously cold-drawn 30 per cent (reduction of area) from material having a grain size of 0.025 mm. (60.00 % copper, 0.74 % tin, balance zinc) (rod under 1 in. in diameter).

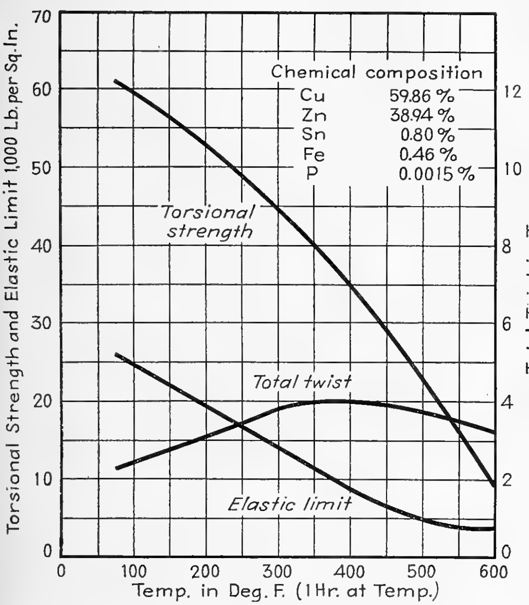


Chart 54.—The effect of elevated temperature on the torsional properties of Tobin-bronze rod (59.86 % copper, 0.80 % tin, 0.46 % iron, balance zinc) according to Bregousky and Spring[9][22] (rod under 1 in. in diameter).

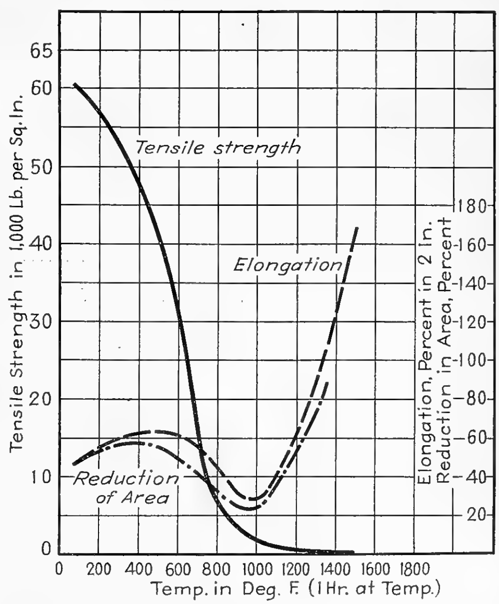


Chart 55.—The effect of elevated temperature on the tensile strength, percentage elongation in 2 in., and percentage reduction of area of Tobin-bronze rod (60.14 % copper, 0.75 % tin, balance zinc) according to W. B. Price[7] (rod under 1 in. in diameter).

TABLE 6
NAVAL BRASS
GENERAL DATA—ROD
Copper, 59.64%; tin, 0.66%; lead, 0.12%; iron, 0.08%; zinc, balance

Property	Rod		Forgings	
	Hard[a]	Soft[b]	Hot	Cold[c]
Tensile strength, p.s.i. (000 omitted)	86	59	59–62	64
Elongation, % in 2 in.	15	48	48–40	40
Apparent elastic limit, p.s.i. (000 omitted)	69	16	16–20	32
Yield strength, 0.5% extension, p.s.i. (000 omitted)	58	22	22–25	35
Yield strength, 0.2% offset, (p.s.i. (000 omitted)	60	22	22–25	35
Yield strength, 0.1% offset, p.s.i. (000 omitted)	56	20	19–24	35
Reduction of area, %	46	52	50–59	50
Endurance limit, p.s.i. (000 omitted)	26	21		
Rockwell hardness F, 1/16-in. ball, 60-kg. load		88	78–85	92
Rockwell hardness B, 1/16-in. ball, 100-kg. load	84	55	50–55	62
Brinell hardness, 10-mm. ball, 500-kg. load	140	89	83–89	98
Modulus of elasticity, p.s.i	15,000,000			
Forging range, °F	1250–1450			
Forging quality	Excellent			
Type structure	Two phase, alpha-beta			

GENERAL DATA—STRIP[d]
Copper, 61.51%; zinc, balance; tin, 0.57%; lead, 0.08%; iron, trace

Property	Hard[e]	Soft[f]
Tensile strength, p.s.i. (000 omitted)	96–103	58
Elongtion, % in 2 in.	3–4	33–40
Apparent elastic limit, p.s.i. (000 omitted)	69–75	15–17
Yield strength, 0.5% extension, p.s.i. (000 omitted)	70–73	19–22
Yield strength, 0.2% offset, p.s.i. (000 omitted)	86–87	19–22
Yield strength, 0.1% offset, p.s.i. (000 omitted)	76–79	19–22
Rockwell hardness F, 1/16-in. ball, 60-kg. load	111–112	80
Rockwell hardness B, 1/16-in. ball, 100-kg. load	94–95	44–46
Rockwell hardness G, 1/16-in. ball, 150-kg. load	73–74	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	91–92	75–76
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	79	46–47
Young's modulus of elasticity, p.s.i	15,000,000	

PHYSICAL DATA

Melting point, °F	1640
Coefficient of expansion, per °C. from 25–300°C	0.0000214
Electrical conductivity,(87) % I.A.C.S, 68°F	25.8
Thermal conductivity,(87) B.t.u. per sq. ft. per ft. per hr. per °F., 68°F	68
Density, lb. per cu. in.	0.304

[a] Refers to rod cold-drawn 28%; rod under 1 in. in diameter only—ready-to-finish grain size, 0.025 mm.
[b] Refers to 1200°F. anneal (1 hr.).
[c] Material cold-struck from forged condition.
[d] All tests conducted on 0.040-in. stock.
[e] 6 B. & S.Nos., hard, 0.080–0.015 mm. grain size at ready-to-finish.
[f] 1300°F. anneal (1 hr. at temperature) of material described in footnote *c*.

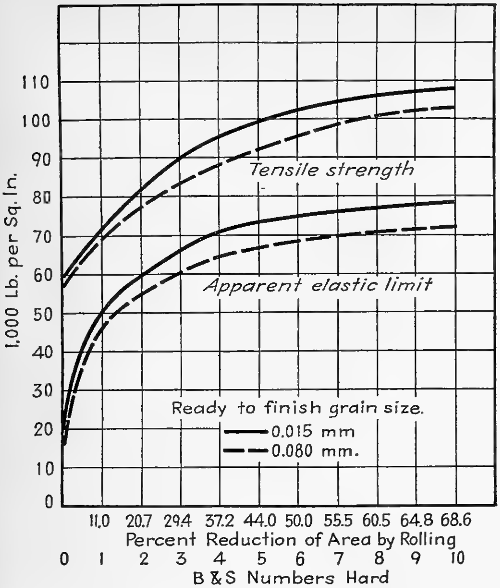


CHART 56.—The effect of cold rolling on the tensile strength and apparent elastic limit of Government naval-brass strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (61.51 % copper, 0.57 % tin, balance zinc) (0.040-in. stock).

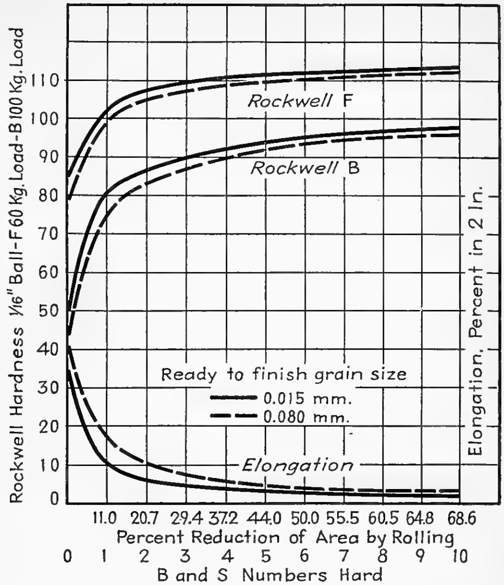


CHART 57.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of Government naval-brass strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (61.51 % copper, 0.57 % tin, balance zinc) (0.040-in. stock).

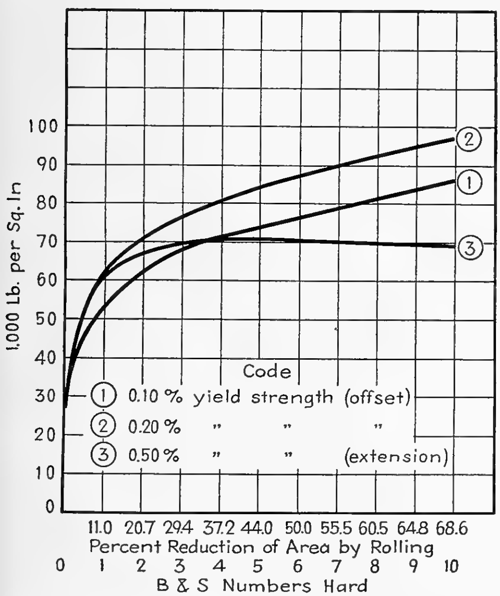


CHART 58.—The effect of cold rolling on the yield strengths of Government naval-brass strip, previously annealed to a grain size of 0.015 mm. (61.51 % copper, 0.57 % tin, balance zinc) (0.040-in. stock).

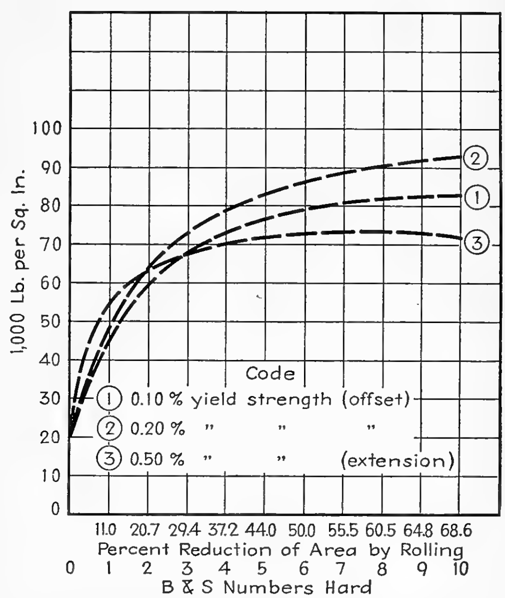


CHART 59.—The effect of cold rolling on the yield strengths of Government naval-brass strip, previously annealed to a grain size of 0.080 mm. (61.51 % copper, 0.57 % tin, balance zinc) (0.040-in. stock).

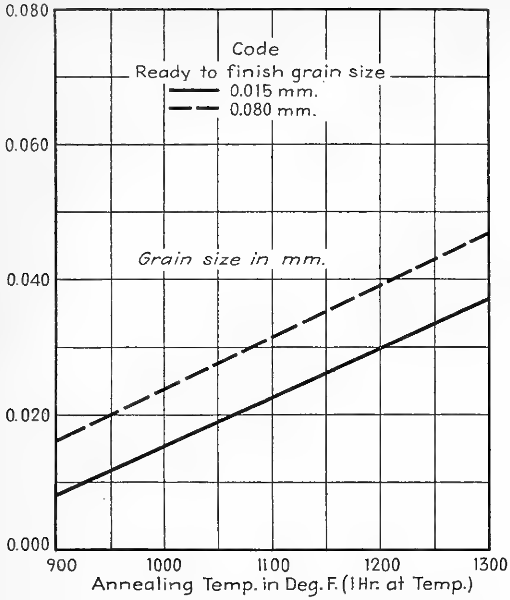


CHART 60.—The effect of annealing on the grain-growing characteristics of Government naval-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (61.51 % copper, 0.57 % tin, balance zinc) (0.040-in. stock).

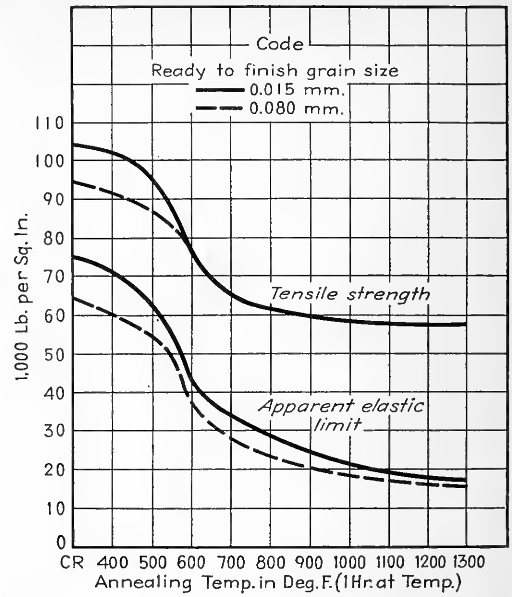


CHART 61.—The effect of annealing on the tensile strength and apparent elastic limit of Government naval-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (61.51 % copper, 0.57 % tin, balance zinc) (0.040-in. stock).

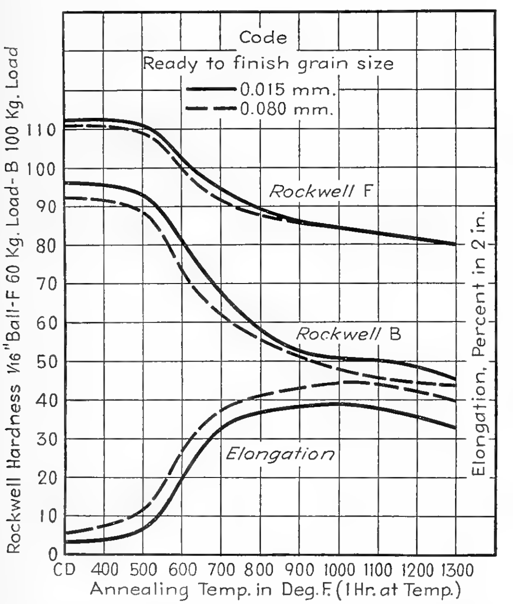


CHART 62.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of Government naval-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (61.51 % copper, 0.57 % tin, balance zinc) (0.040-in. stock).

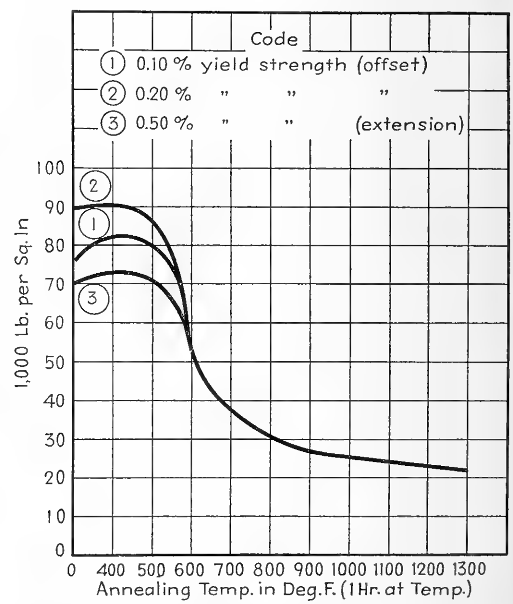


CHART 63.—The effect of annealing on the yield strength of Government naval-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (61.51 % copper, 0.57 % tin, balance zinc) (0.040-in. stock).

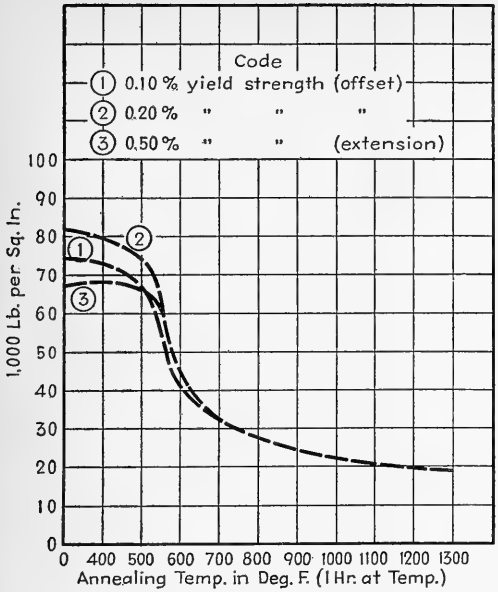


Chart 64.—The effect of annealing on the yield strength of Government naval-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.080 mm. (61.51 % copper, 0.57 % tin, balance zinc) (0.040-in. stock).

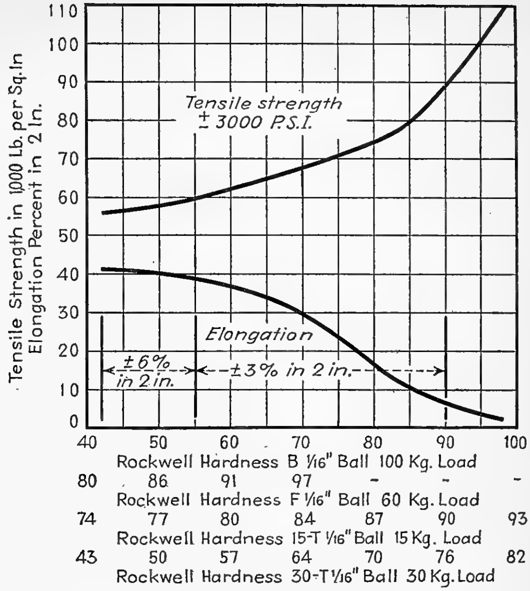


Chart 65.—This chart can be employed to determine the approximate tensile strength and percentage elongation of Government naval-brass strip (61.51 % copper, 0.57 % tin, balance zinc) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

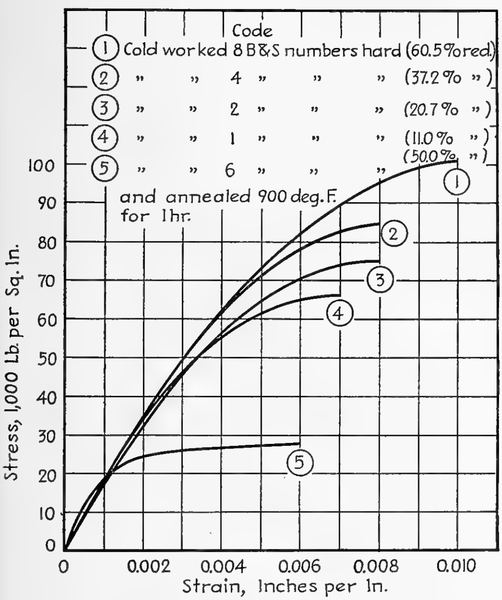


Chart 66.—The effect of cold rolling on the stress-strain characteristics of Government naval-brass strip (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (61.51 % copper, 0.57 % tin, balance zinc.)

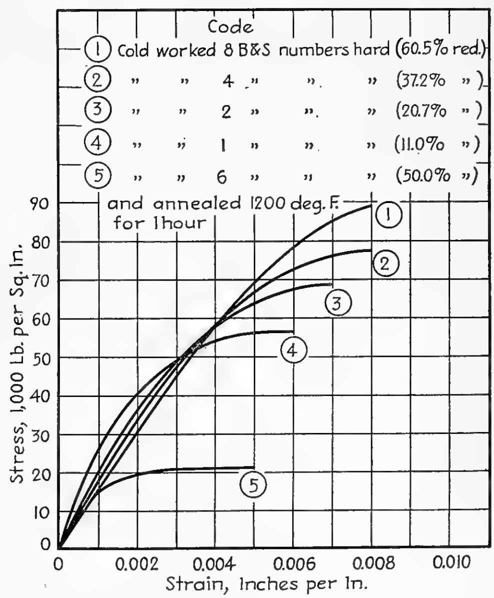


Chart 67.—The effect of cold rolling on the stress-strain characteristics of Government naval-brass strip (0.040 in. thick) having a ready-to-finish grain size of 0.080 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (61.51 % copper, 0.57 % tin, balance zinc.)

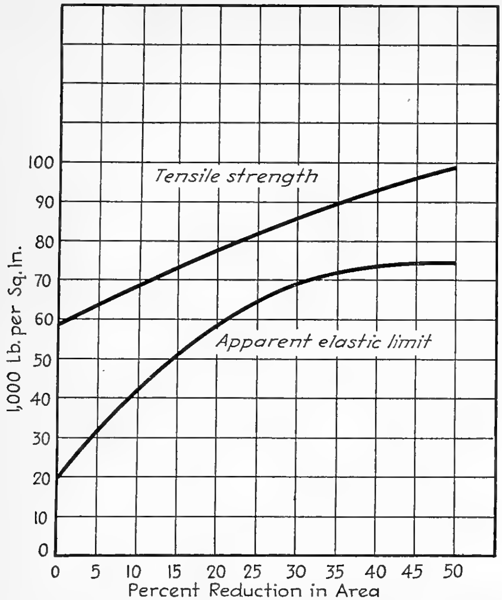


Chart 68.—The effect of cold drawing on the tensile strength and apparent elastic limit of Government naval-brass rod, previously annealed to a grain size of 0.025 mm. (59.64 % copper, 0.66 % tin, balance zinc (rod under 1 in. in diameter).

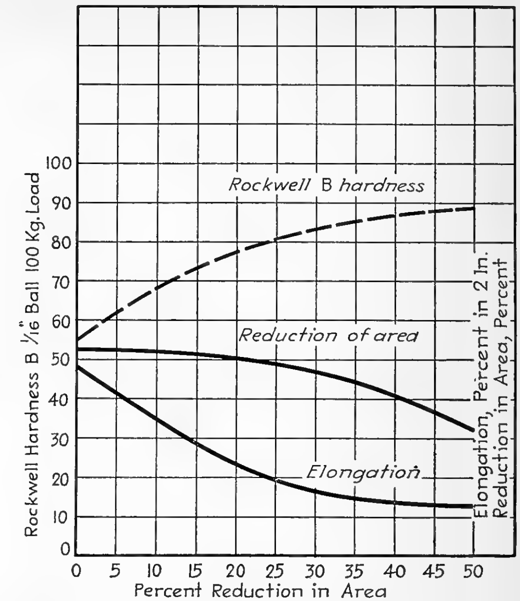


Chart 69.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of Government naval-brass rod, previously annealed to a grain size of 0.025 mm. (59.64 % copper, 0.66 % tin, balance zinc) (rod under 1 in. in diameter).

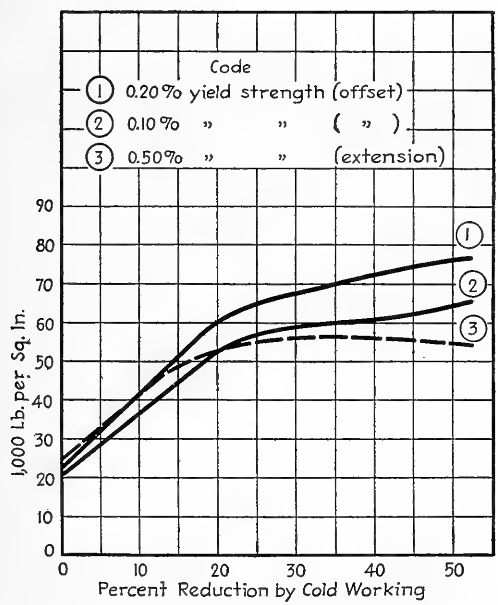


Chart 70.—The effect of cold drawing on the yield strength of Government naval-brass rod, previously annealed to a grain size of 0.025 mm. (59.64 % copper, 0.66 % tin, balance zinc) (rod under 1 in. in diameter).

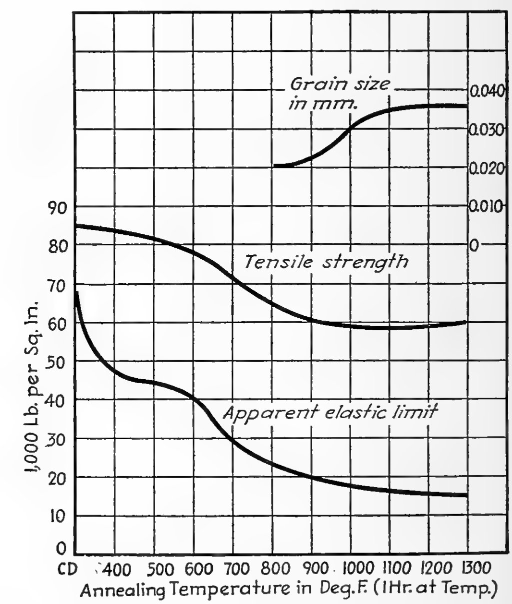


Chart 71.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of Government naval-brass rod, previously cold-drawn 28 per cent (reduction of area) from material having a grain size of 0.025 mm. (59.64 % copper, 0.66 % tin, balance zinc) (rod under 1 in. in diameter).

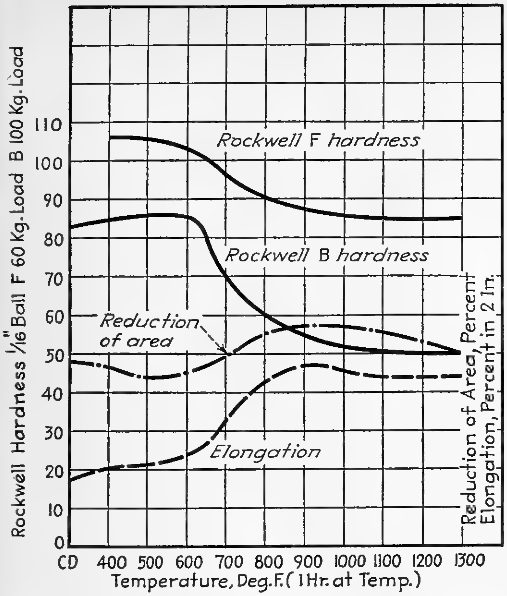


CHART 72.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., percentage reduction of area of Government naval-brass rod, previously cold-drawn 28 per cent (reduction of area) from material having a grain size of 0.025 mm. (59.64 % copper 0.66 % tin, balance zinc) (rod under 1 in. in diameter).

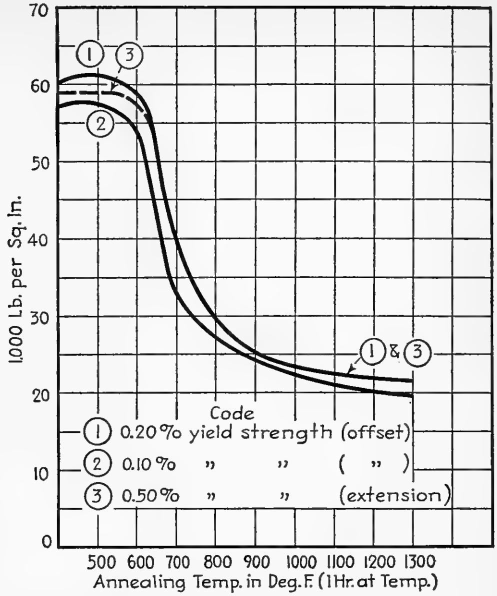


CHART 73.—The effect of annealing on the yield strength of Government naval-brass rod, previously cold-drawn 28 per cent (reduction of area) from material having a grain size of 0.025 mm. (59.64 % copper, 0.66 % tin, balance zinc) (rod under 1 in. in diameter).

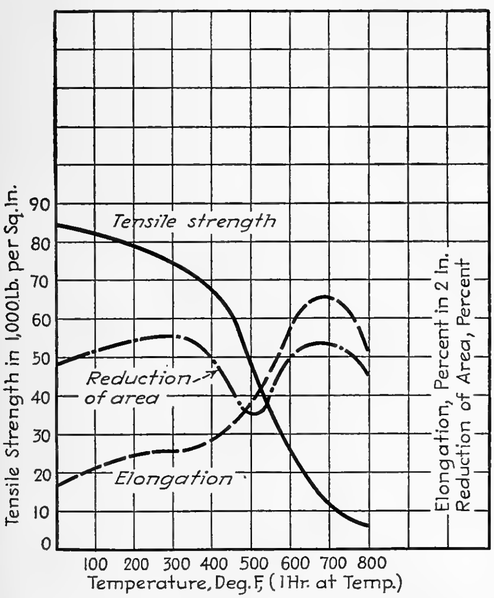


CHART 74.—The effect of elevated temperature on the tensile strength, percentage elongation in 2 in., and percentage reduction of area of Government naval-brass rod, previously cold-worked 28 per cent (reduction of area) from a grain size of 0.025 mm. (59.64 % copper, 0.66 % tin, balance zinc) (rod under 1 in. in diameter).

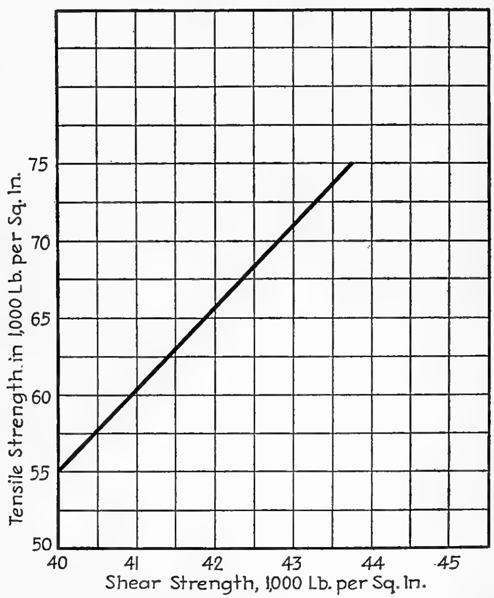


CHART 75.—Conversion chart for determination of shear strength of Government naval brass (60 % copper, 0.75 % tin, balance zinc) when tensile strength is known. Accurate to ±5 %.[86]

TABLE 7

HARD NAVAL BRASS

GENERAL DATA—STRIP[a]

Copper, 61.50%; tin, 0.75%; lead, 0.20%; iron, trace; zinc, balance

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	96–103	58
Elongation, % in 2 in.	3–4	33–40
Apparent elastic limit, p.s.i. (000 omitted)	69–75	15–17
Yield strength, 0.5% extension, p.s.i. (000 omitted)	70–71	20–22
Yield strength, 0.2% offset, p.s.i. (000 omitted)	85–87	20–22
Yield strength, 0.1% offset, p.s.i. (000 omitted)	78–79	20–22
Rockwell hardness F, 1/16-in. ball, 60-kg. load	111–112	80
Rockwell hardness B, 1/16-in. ball, 100-kg. load	94–95	44–46
Rockwell hardness G, 1/16-in. ball, 150-kg. load	73–74	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	91–92	75–76
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	79	46–47
Young's modulus of elasticity, p.s.i.	15,000,000	
Melting point, °F.	1640	
Density, lb. per cu. in.	0.304	
Coefficient of expansion, per °C. from 25–300°C.	0.0000214	
Electrical conductivity,(87) % I.A.C.S., 68°F.	25.8	
Thermal conductivity,(87) B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	68	

[a] All tests conducted on 0.040-in. stock.

[b] 6 B. & S. Nos., hard, 0.080–0.015 mm. grain size at ready-to-finish.

[c] 1300°F. anneal (1 hr. at temperature) of material described in footnote *b*.

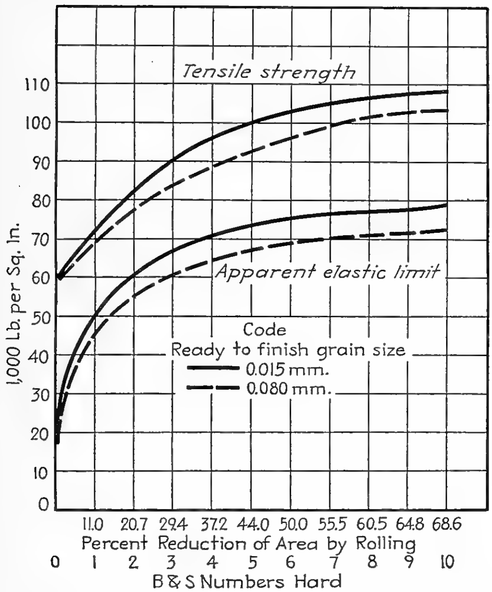


CHART 76.—The effect of cold rolling on the tensile strength and apparent elastic limit of hard-naval-brass strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (61.50 % copper, 0.75 % tin, balance zinc) (0.040-in. stock).

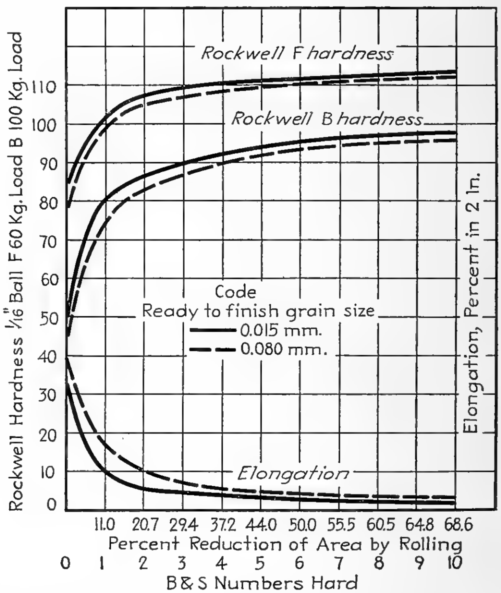


CHART 77.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of hard-naval-brass strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (61.50 % copper, 0.75 % tin, balance zinc) (0.040-in. stock).

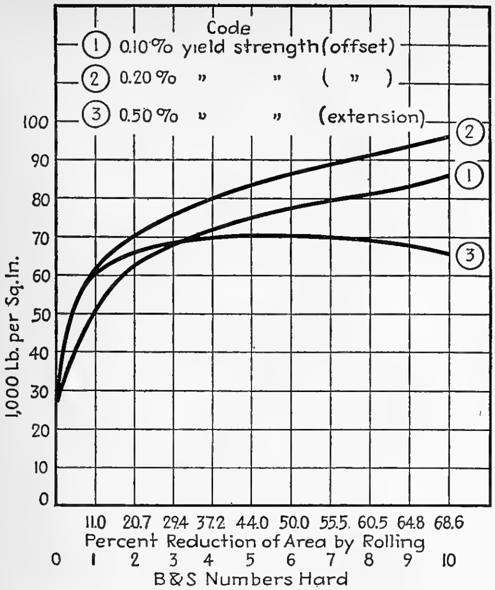


Chart 78.—The effect of cold rolling on the yield strengths of hard-naval-brass strip, previously annealed to a grain size of 0.015 mm. (61.50 % copper, 0.75 % tin, balance zinc) (0.040-in. stock).

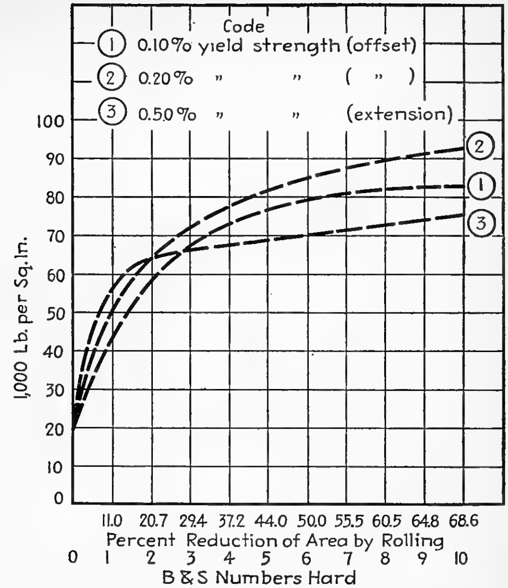


Chart 79.—The effect of cold rolling on the yield strengths of hard-naval-brass strip, previously annealed to a grain size of 0.080 mm. (61.50 % copper, 0.75 % tin, balance zinc) (0.040-in. stock).

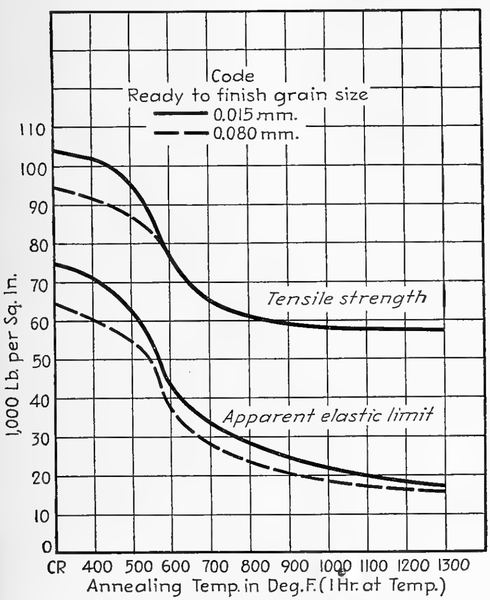


Chart 80.—The effect of annealing on the tensile strength and apparent elastic limit of hard-naval-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (61.50 % copper, 0.75 % tin, balance zinc) (0.040-in. stock).

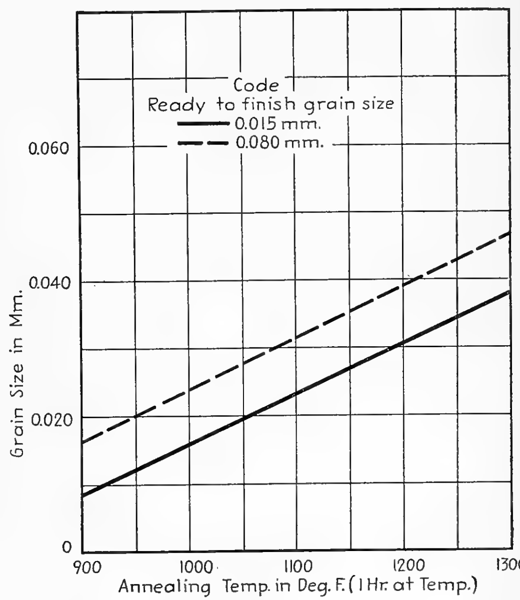


Chart 81.—The effect of annealing on the grain-growing characteristics of hard-naval-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (61.50 % copper, 0.75 % tin, balance zinc) (0.040-in. stock).

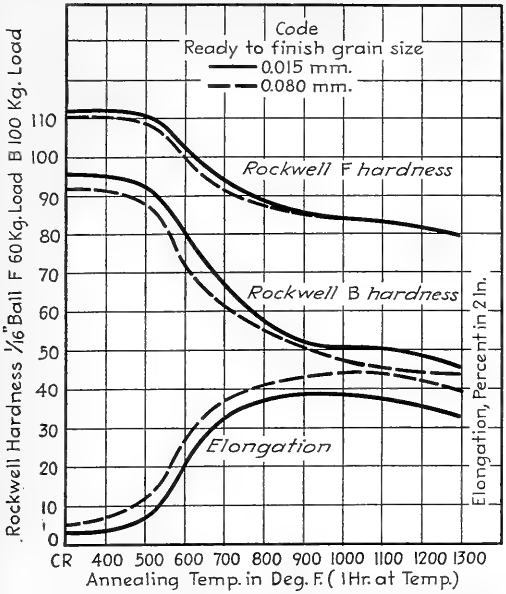


CHART 82.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of hard-naval-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (61.50 % copper, 0.75 % tin, balance zinc (0.040-in. stock).

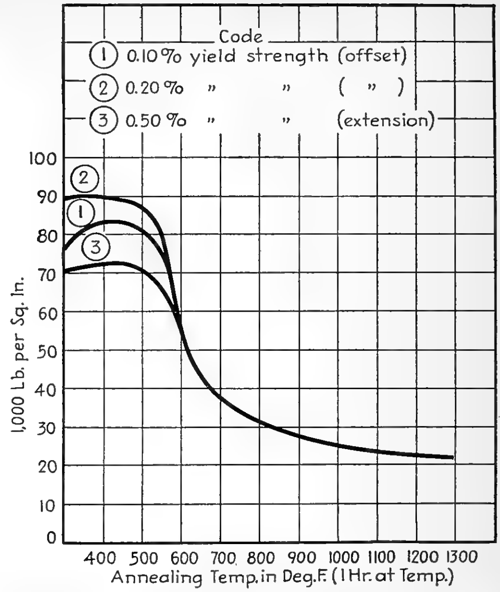


CHART 83.—The effect of annealing on the yield strength of hard-naval-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (61.50 % copper, 0.75 % tin, balance zinc) (0.040-in. stock).

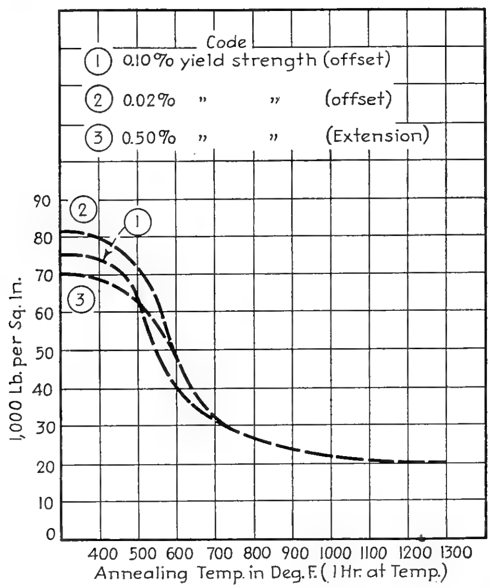


CHART 84.—The effect of annealing on the yield strength of hard-naval-brass strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.080 mm. (61.50 % copper, 0.75 % tin, balance zinc) (0.040-in. stock).

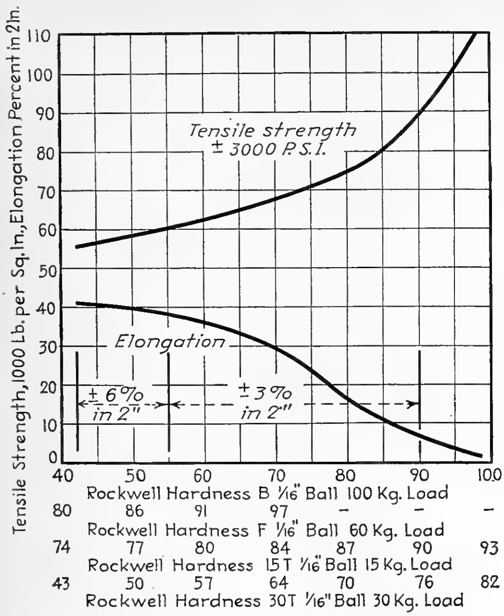


CHART 85.—This chart can be employed to determine the approximate tensile strength and percentage elongation of hard-naval-brass strip (61.50 % copper, 0.75 % tin, balance zinc) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

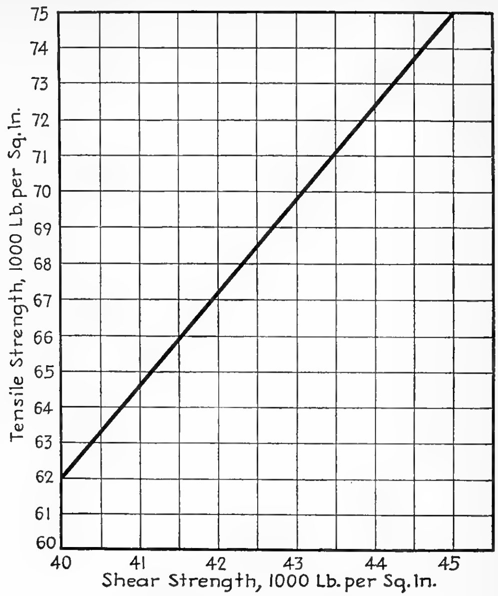


CHART 86.—Conversion chart for determination of shear strength of hard naval brass (61 % copper, 0.75 % tin, balance zinc) when tensile strength is known. Accurate to ±5 %.[86]

TABLE 8
NAVAL BRASS—LOW LEAD
Copper, 60.95%; tin, 1.03%; lead, 0.39%; iron, 0.02%; zinc, balance

Property	Rod		Forgings	
	Hard[a]	Soft[b]	Hot	Cold[c]
Tensile strength, p.s.i. (000 omitted)	86	63	55–60	63
Apparent elastic limit, p.s.i. (000 omitted)	55	21	14–20	29
Yield strength, 0.5% extension, p.s.i. (000 omitted)	59	26	20–24	37
Yield strength, 0.2% offset, p.s.i. (000 omitted)	73	26	19–23	39
Yield strength, 0.1% offset, p.s.i. (000 omitted)	65	26	16–22	35
Elongation, % in 2 in.	10	35	40–45	34
Reduction of area, %	35	50	45–50	45
Rockwell hardness F, 1/16-in. ball, 60-kg. load	102	90	82–87	93
Rockwell hardness B, 1/16-in. ball, 100-kg. load	82	55	49–52	63
Brinell hardness, 10-mm. ball, 500-kg. load	135	89	82–85	99
Modulus of elasticity, p.s.i.	15,000,000			
Melting point, °F	1635			
Coefficient of expansion, per °C. from 25–300°C	0.0000214			
Electrical conductivity,[87] % I.A.C.S., 68°F	25.8			
Thermal conductivity,[87] B.t.u. per sq. ft. per ft. per hr. per °F., 68°F	68			
Density, lb. per cu. in.	0.305			
Forging range, °F	1250–1450			
Forging quality	Excellent			
Type structure	Two phase, alpha-beta			

[a] Refers to rod cold-drawn 30%; rod under 1 in. in diameter, ready-to-finish grain size, 0.025 mm.
[b] Refers to 800°F. anneal (1 hr.).
[c] Material cold-struck from forged condition.

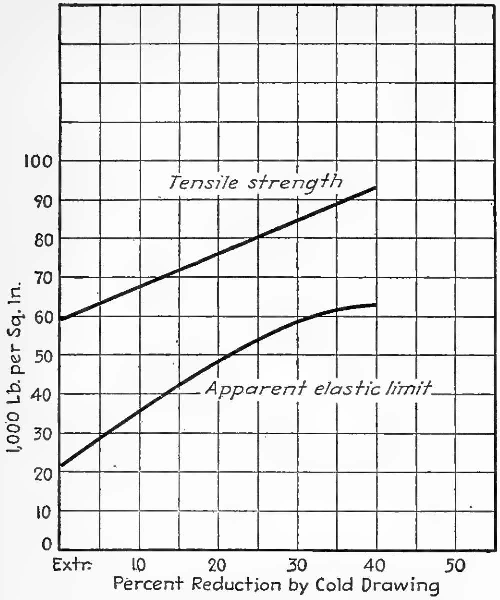


CHART 87.—The effect of cold drawing on the tensile strength and apparent elastic limit of low-lead naval-brass rod, previously annealed to a grain size of 0.025 mm. (60.95 % copper, 1.03 % tin, 0.39 % lead, balance zinc) (rod under 1 in. in diameter).

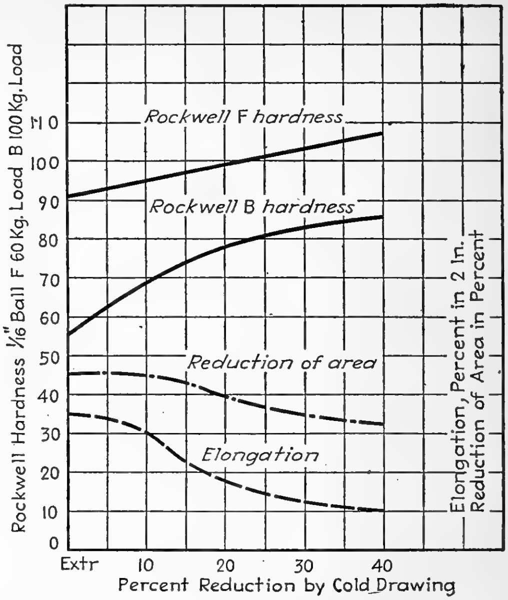


CHART 88.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of low-lead naval-brass rod, previously annealed to a grain size of 0.025 mm. (60.95 % copper, 1.03 % tin, 0.39 % lead, balance zinc) (rod under 1 in. in diameter).

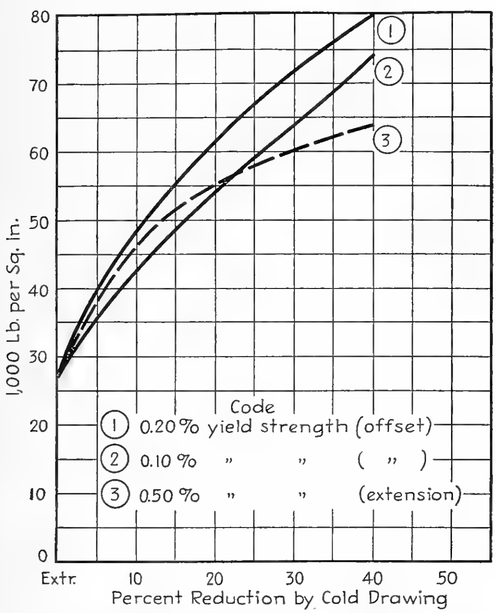


CHART 89.—The effect of cold drawing on the yield strength of low-lead naval-brass rod, previously annealed to a grain size of 0.025 mm. (60.95 % copper, 1.03 % tin, 0.39 % lead, balance zinc) (rod under 1 in. in diameter).

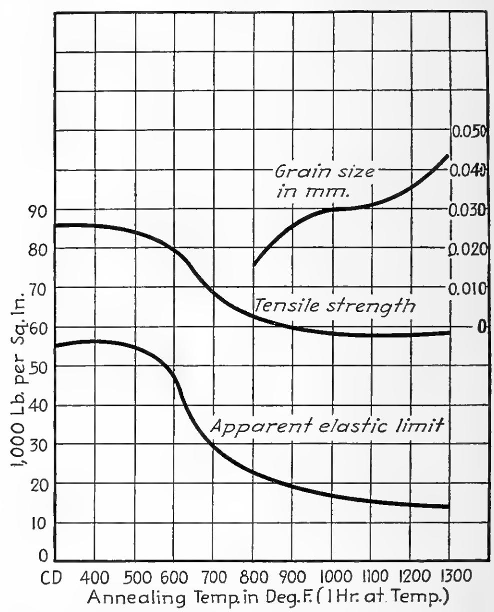


CHART 90.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of low-lead naval-brass rod, previously cold-drawn 28 per cent (reduction of area) from material having a grain size of 0.025 mm. (60.95 % copper, 1.03 % tin, 0.39 % lead balance zinc) (rod under 1 in. in diameter).

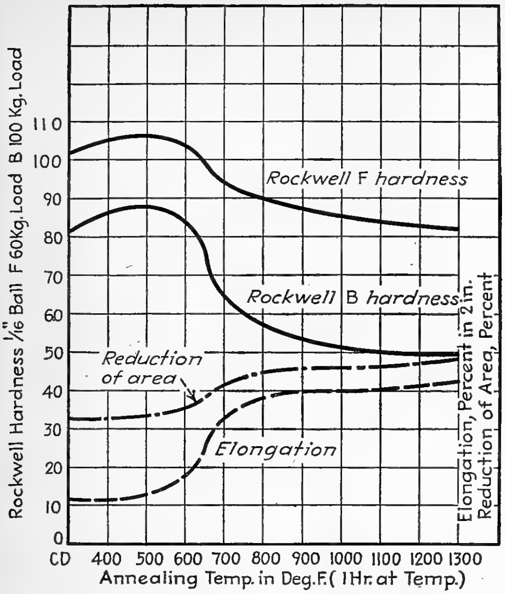


CHART 91.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of low-lead naval brass rod, previously cold drawn 28 per cent (reduction of area) from material having a grain size of 0.025 mm. (60.95 % copper, 1.03 % tin, 0.39 % lead, balance zinc) (rod under 1 in. in diameter).

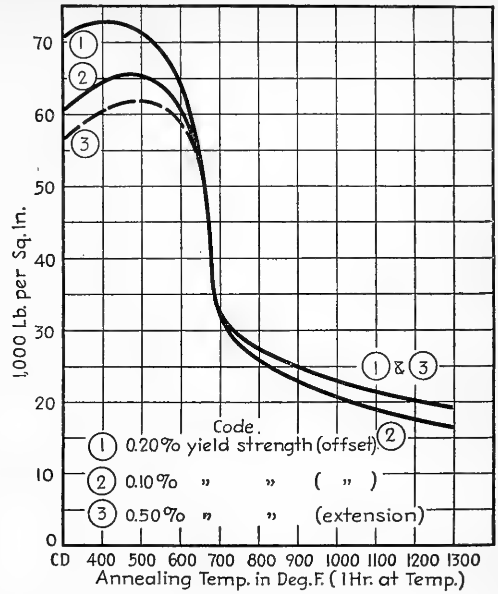


CHART 92.—The effect of annealing on the yield strength of low-lead naval brass rod, previously cold-drawn 28 per cent (reduction of area) from material having a grain size of 0.025 mm. (60.95 % copper, 1.03 % tin, 0.39 % lead, balance zinc) (rod under 1 in. in diameter).

TABLE 9
MEDIUM-LEADED NAVAL BRASS
Copper, 60.95%; tin, 1.03%; lead, 0.72%; iron, 0.02%; zinc, balance

Property	Rod	
	Hard[a]	Soft[b]
Tensile strength, p.s.i. (000 omitted)	86	63
Apparent elastic limit, p.s.i. (000 omitted)	55	21
Yield strength, 0.5% extension, p.s.i. (000 omitted)	59	26
Yield strength, 0.2% offset, p.s.i. (000 omitted)	73	26
Yield strength, 0.1% offset, p.s.i. (000 omitted)	62	26
Elongation, % in 2 in.	10	35
Reduction of area, %	35	50
Rockwell hardness F, 1/16-in. ball, 60-kg. load	102	90
Rockwell hardness B, 1/16-in. ball, 100-kg. load	82	55
Brinell hardness, 10-mm. ball, 500-kg. load	135	89
Modulus of elasticity, p.s.i.	15,000,000	
Melting point, °F.	1635	
Coefficient of expansion, per °C. from 25–300°C.	0.0000214	
Electrical conductivity,[87] % I.A.C.S., 68°F.	25.8	
Thermal conductivity,[87] B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	68	
Density, lb. per cu. in.	0.306	
Type structure	Two phase, alpha-beta	

[a] Refers to rod cold-drawn 30 %; rod under 1 in. in diameter, ready-to-finish grain size, 0.025 mm.
[b] Refers to 800°F. anneal (1 hr.).

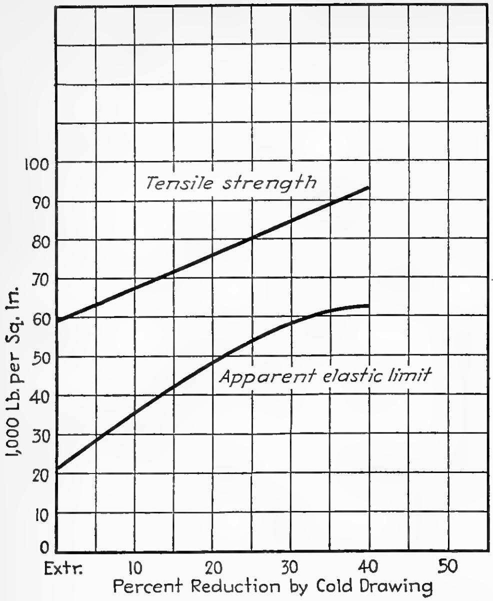


CHART 93.—The effect of cold drawing on the tensile strength and apparent elastic limit of medium-leaded naval-brass rod, previously annealed to a grain size of 0.025 mm. (60.95 % copper, 1.03 % tin, 0.72 % lead, balance zinc) (rod under 1 in. in diameter).

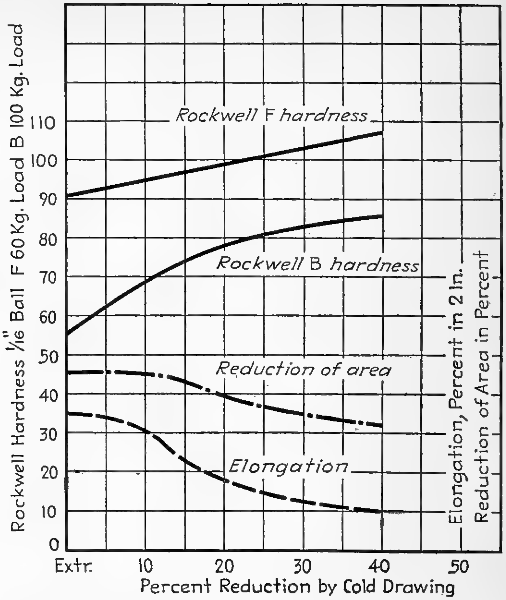


CHART 94.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of medium-leaded naval-brass rod, previously annealed to a grain size of 0.025 mm. (60.95 % copper, 0.03 % tin, 0.72 % lead, balance zinc) (rod under 1 in. in diameter).

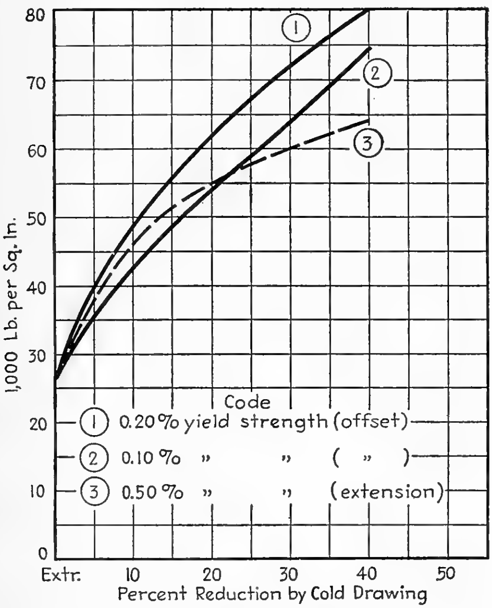


CHART 95.—The effect of cold drawing on the yield strength of medium-leaded naval-brass rod, previously annealed to a grain size of 0.025 mm. (60.95 % copper, 1.03 % tin, 0.72 % lead, balance zinc) (rod under 1 in. in diameter).

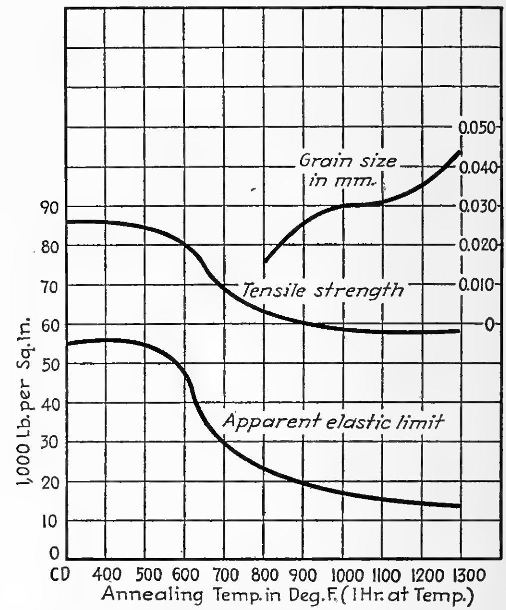


CHART 96.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of medium-leaded naval-brass rod, previously cold-drawn 30 per cent (reduction of area) from material having a grain size of 0.025 mm. (60.95 % copper, 1.03 % tin, 0.72 % lead, balance zinc) (rod under 1 in. in diameter).

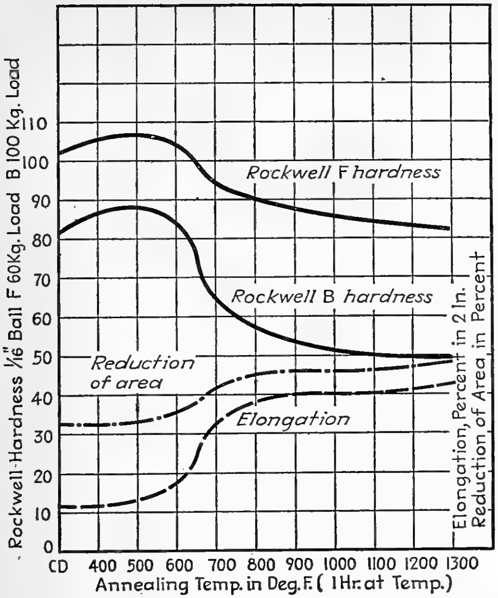


CHART 97.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., percentage reduction of area of medium-leaded naval-brass rod, previously cold-drawn 30 per cent (reduction of area) from material having a grain size of 0.025 mm. (60.95 % copper, 1.03 % tin, 0.72 % lead, balance zinc) (rod under 1 in. in diameter).

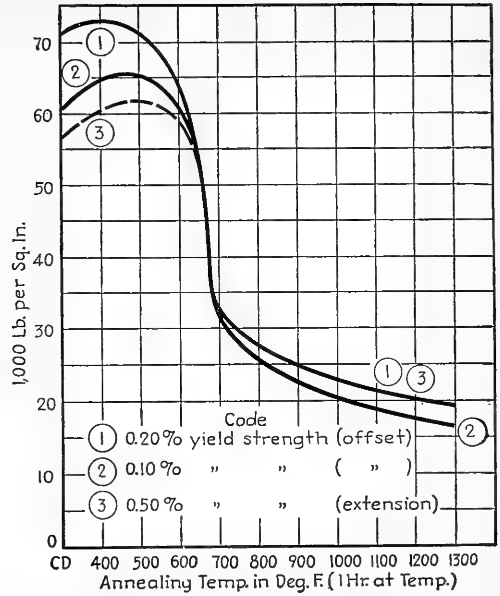


CHART 98.—The effect of annealing on the yield strength of medium-leaded naval-brass rod, previously cold-drawn 30 per cent (reduction of area) from material having a grain size of 0.025 mm. (60.95 % copper, 1.03 % tin, 0.72 % lead, balance zinc) (rod under 1 in. in diameter).

TABLE 10
HIGH-LEADED NAVAL BRASS
Copper, 59.66%; tin, 1.02%; lead, 2.06%; iron, 0.05%; zinc, balance

Property	Rod	
	Hard[a]	Soft[b]
Tensile strength, p.s.i. (000 omitted)	88	58
Apparent elastic limit, p.s.i. (000 omitted)	57	21
Yield strength, 0.5% extension, p.s.i. (000 omitted)	59	26
Yield strength, 0.2% offset, p.s.i. (000 omitted)	73	25
Yield strength, 0.1% offset, p.s.i. (000 omitted)	62	24
Elongation, % in 2 in.	9	29
Reduction of area, %	25	30
Rockwell hardness F, 1/16-in. ball, 60-kg. load	103	89
Rockwell hardness B, 1/16-in. ball, 100-kg. load	89	54
Brinell hardness, 10-mm. ball, 500-kg. load	154	87
Modulus of elasticity, p.s.i.	15,000,000	
Coefficient of expansion, per °C. from 25–300°C	0.0000214	
Melting point, °F	1640	
Electrical conductivity,(87) % I.A.C.S., 68°F	25.8	
Thermal conductivity,(87) B.t.u. per sq. ft. per ft. per hr. per °F., 68°F	68	
Density, lb. per cu. in	0.306	
Type structure	Two phase, alpha-beta	

[a] Refers to rod cold-drawn 30%; rod under 1 in. in diameter, ready-to-finish grain size, 0.025 mm.
[b] Refers to anneal at 1000°F. for 1 hr.

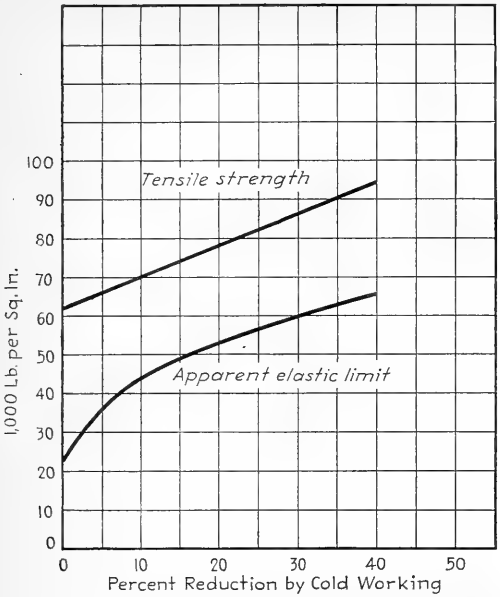


CHART 99.—The effect of cold drawing on the tensile strength and apparent elastic limit of high-lead naval-brass rod, previously annealed to a grain size of 0.025 mm. (59.66 % copper, 1.02 % tin, 2.06 % lead, balance zinc) (rod under 1 in. in diameter).

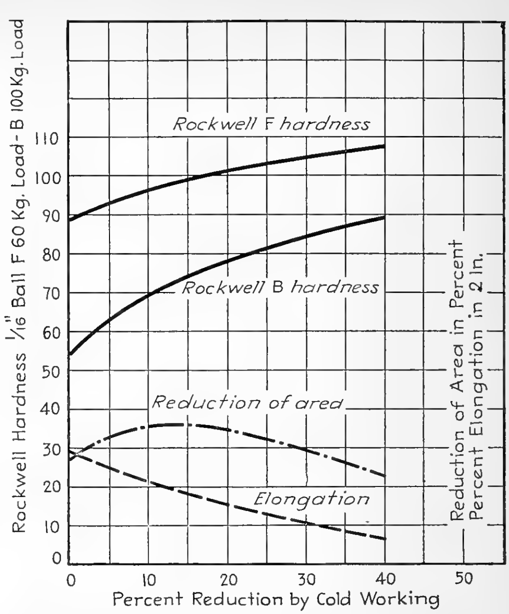


CHART 100.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of high-lead naval-brass rod, previously annealed to a grain size of 0.025 mm. (59.66 % copper, 1.02 % tin, 2.06 % lead, balance zinc) (rod under 1 in. in diameter).

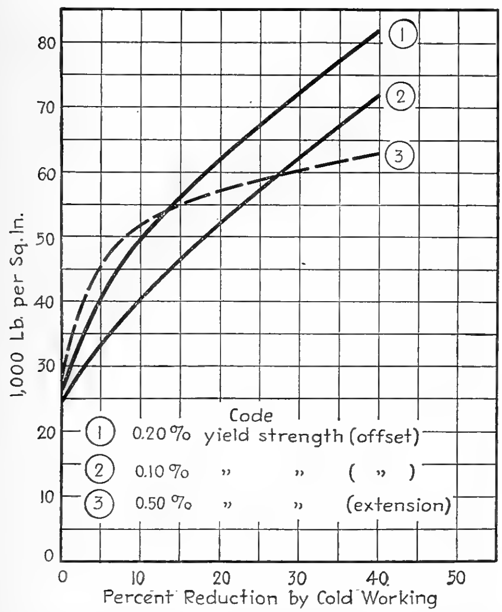


CHART 101.—The effect of cold drawing on the yield strength of high-lead naval-brass rod, previously annealed to a grain size of 0.025 mm. (59.66 % copper, 1.02 % tin, 2.06 % lead, balance zinc) (rod under 1 in. in diameter).

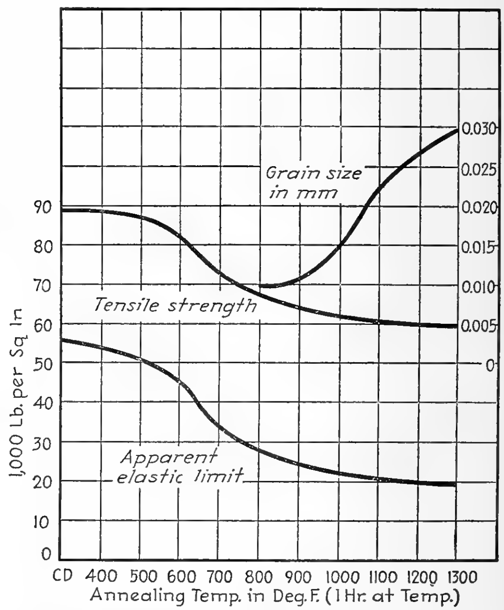


CHART 102.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of high-lead naval-brass rod, previously cold-drawn 30 per cent (reduction of area) from material having a grain size of 0.025 mm. (59.66 % copper, 1.02 % tin, 2.06 % lead, balance zinc) (rod under 1 in. in diameter).

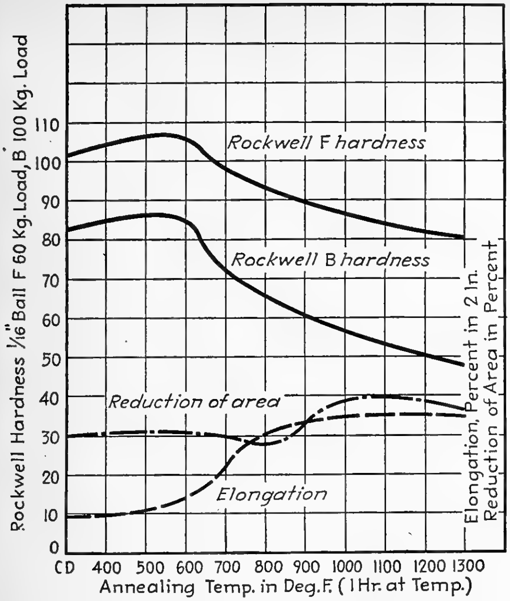


CHART 103.—The effect of annealing in the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of high-lead naval-brass rod, previously cold-drawn 30 per cent (reduction of area) from material having a grain size of 0.025 mm. (59.66 % copper, 1.02 % tin, 2.06 % lead, balance zinc) (rod under 1 in. in diameter).

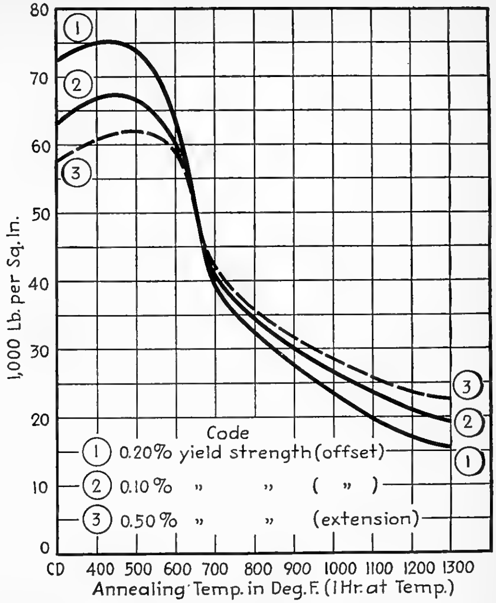


CHART 104.—The effect of annealing on the yield strength of high-lead naval-brass rod, previously cold-drawn 30 per cent (reduction of area) from material having a grain size of 0.025 mm. (59.66 % copper, 1.02 % tin, 2.06 % lead, balance zinc) (rod under 1 in. in diameter).

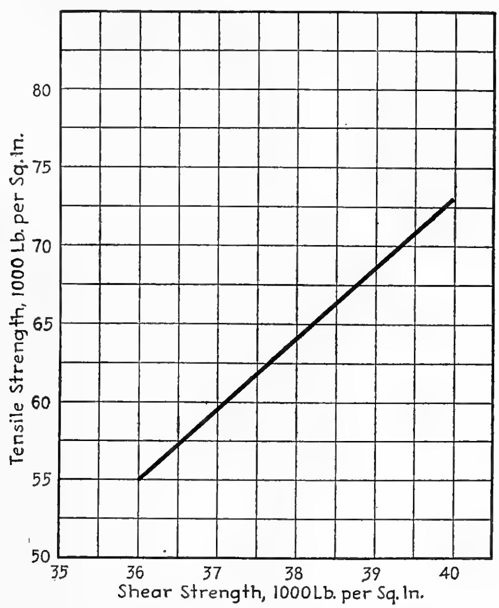


CHART 105.—Conversion chart for determination of shear strength of high-leaded naval brass (60 % copper, 1.00 % tin, 2.00 % lead, balance zinc) when tensile strength is known. Accurate to ±5 %.[86]

TABLE 11
MANGANESE BRONZE
Copper, 58.64%; iron, 1.13%; tin, 0.75%; manganese, 0.02%; zinc, balance

Property	Rod		Forgings	
	Hard[a]	Soft[b]	Hot	Cold[c]
Tensile strength, p.s.i. (000 omitted)	90	65	64–67	68
Apparent elastic limit, p.s.i. (000 omitted)	65	22	17–27	35
Yield strength, 0.5% extension, p.s.i. (000 omitted)	65	27	27–47	35
Yield strength, 0.2% offset, p.s.i. (000 omitted)	65	28	22–50	40
Yield strength, 0.1% offset, p.s.i. (000 omitted)	55	24	18–45	29
Elongation, % in 2 in.	10	35	25–40	40
Reduction of area, %	20	48	45–50	65
Rockwell hardness F, 1/16-in. ball, 60-kg. load		93	92–100	93
Rockwell hardness B, 1/16-in. ball, 100-kg. load	86	64	64–75	64
Brinell hardness, 10-mm. ball, 500-kg. load	145	101	101–120	101
Modulus of elasticity, p.s.i.	15,000,000			
Electrical conductivity,(89) % I.A.C.S., 68°F.	23.6			
Thermal conductivity,(89) B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	58			
Density, lb. per cu. in.	0.302			
Forging range, °F.	1250–1450			
Forging quality	Excellent			
Type structure	Two phase, alpha-beta			

[a] Refers to rod cold-drawn 30%; rod under 1 in. in diameter, previously annealed 1100°F. for 1 hr. with a ready-to-finish grain size, 0. 025 mm.
[b] Refers to 1200°F. anneal (1 hr.).
[c] Material cold-struck from forged condition.

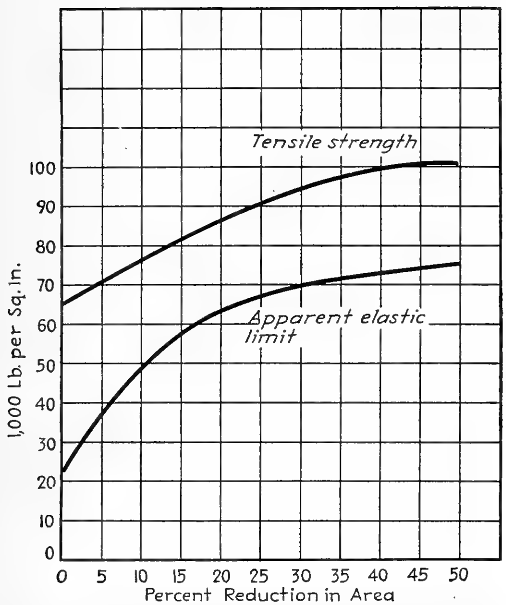


CHART 106.—The effect of cold drawing on the tensile strength and apparent elastic limit of manganese-bronze rod, previously annealed to a grain size of 0.025 mm. (58.64 % copper, 1.13 % iron, 0.75 % tin, 0.02 % manganese, balance zinc) (rod under 1 in. in diameter).

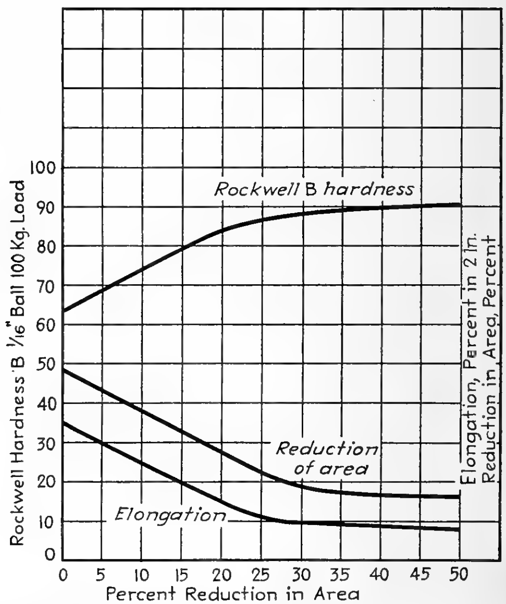


CHART 107.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of manganese-bronze rod, previously annealed to a grain size of 0.025 mm. (58.64 % copper, 1.13 % iron, 0.75 % tin, 0.02 % manganese, balance zinc) (rod under 1 in. in diameter).

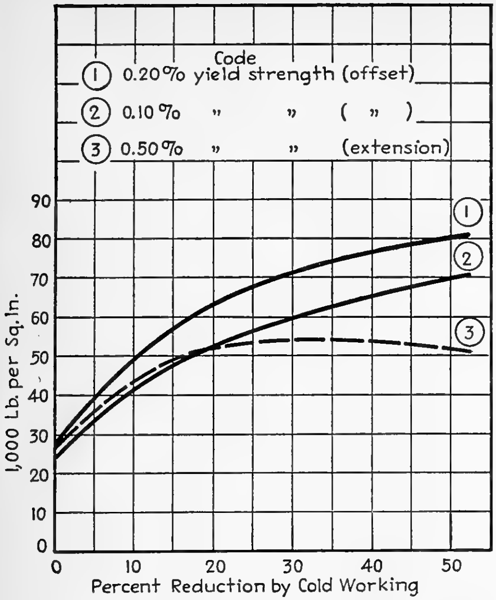


CHART 108.—The effect of cold drawing on the yield strength of manganese-bronze rod, previously annealed to a grain size of 0.025 mm. (58.64 % copper, 1.13 % iron, 0.75 % tin, 0.02 % manganese, balance zinc) (rod under 1 in. in diameter).

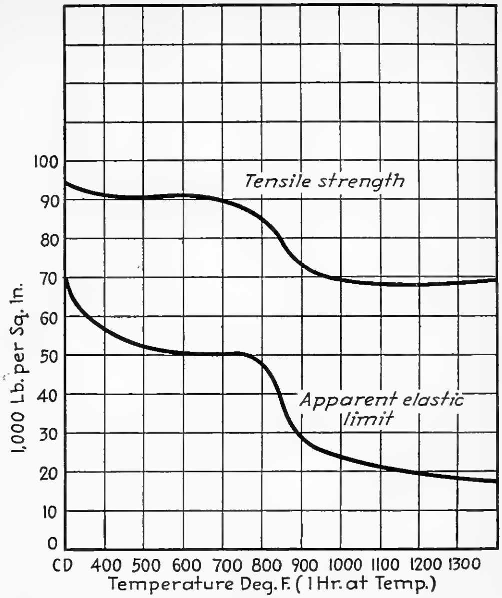


CHART 109.—The effect of annealing on the tensile strength, and apparent elastic limit, of manganese-bronze rod, previously cold-drawn 30 per cent (reduction of area) from material having a grain size of 0.025 mm. (58.64 % copper, 1.13 % iron, 0.75 % tin, 0.02 % manganese, balance zinc) (rod under 1 in. in diameter).

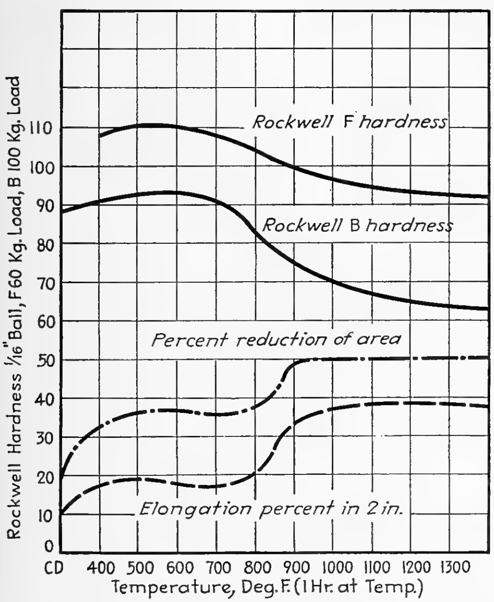


CHART 110.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of manganese-bronze rod, previously cold-drawn 30 per cent (reduction of area) from material having a grain size of 0.025 mm. (58.64 % copper, 1.13 % iron, 0.75 % tin, 0.02 % manganese, balance zinc) (rod under 1 in. in diameter).

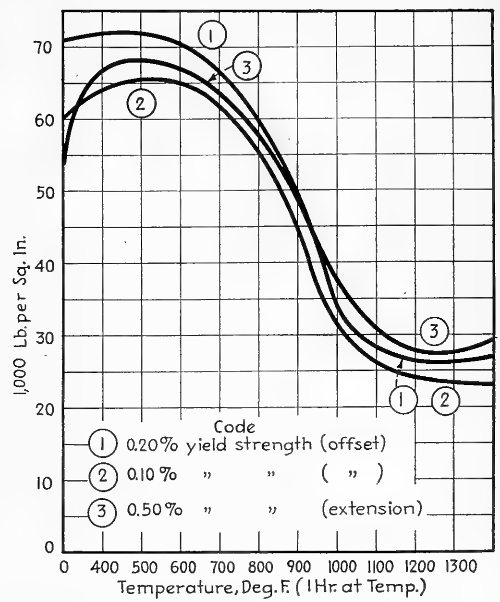


CHART 111.—The effect of annealing on the yield strength of manganese-bronze rod, previously cold-drawn 30 per cent (reduction of area) from material having a grain size of 0.025 mm. (58.64 % copper, 1.13 % iron, 0.75 % tin, 0.02 % manganese, balance zinc) (rod under 1 in. in diameter).

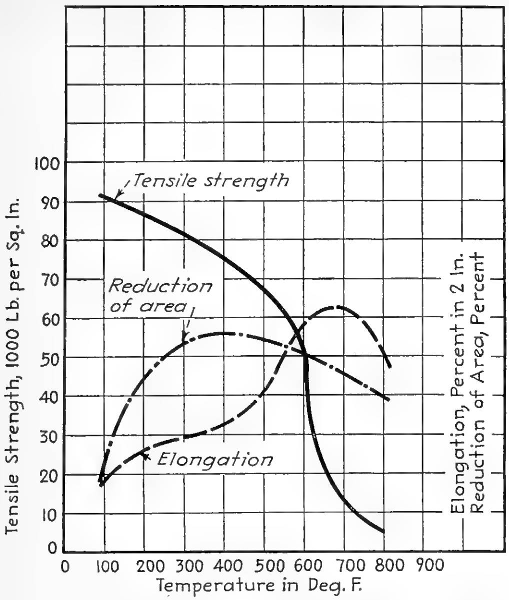


CHART 112.—The effect of elevated temperature on the tensile strength, percentage elongation in 2 in., and percentage reduction of area of manganese-bronze rod, previously cold-worked 30 per cent (reduction of area) from a grain size of 0.025 mm. (58.64 % copper, 1.13 % iron, 0.75 % tin, 0.02 % manganese, balance zinc) (rod under 1 in. in diameter).

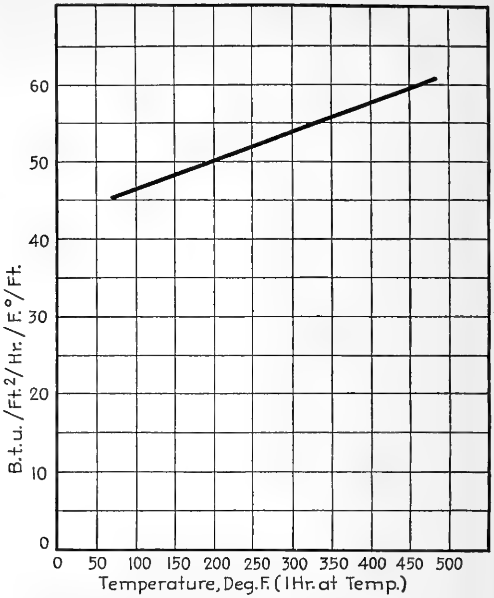


CHART 113.—The effect of temperature on the thermal conductivity of a manganese bronze (60.70 % copper, 0.50 % tin, 0.30 % manganese, balance zinc) according to Griffiths and Schoefield.[23]

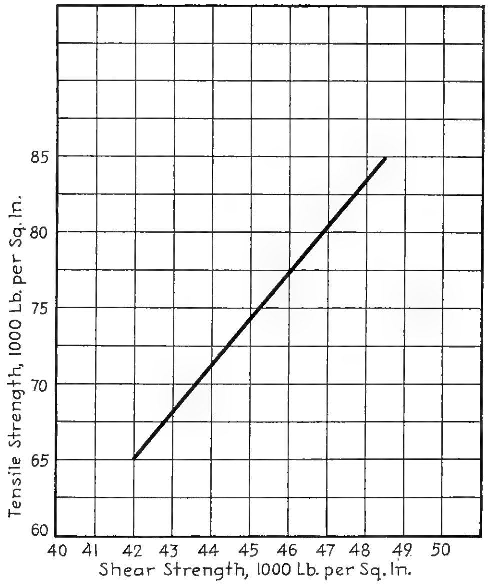


CHART 114.—Conversion chart for determination of shear strength of manganese bronze (58.50 % copper, 0.75 % tin, 1.25 % iron, balance zinc) when tensile strength is known. Accurate to ±5 %.[86]

TABLE 12
MODIFIED MANGANESE BRONZE
General Data—Strip[a]
Copper, 61.51%; tin, 0.47%; lead, 0.08%; iron, 0.10%; manganese, 0.05%; zinc, balance

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	96–102	58
Apparent elastic limit, p.s.i. (000 omitted)	69–75	15–17
Elongation, % in 2 in.	3–4	33–40
Yield strength, 0.5% extension, p.s.i. (000 omitted)	69–71	19–22
Yield strength, 0.2% offset, p.s.i. (000 omitted)	85–88	19–22
Yield strength, 0.1% offset, p.s.i. (000 omitted)	74–77	19–22
Rockwell hardness F, 1/16-in. ball, 60-kg. load	111–112	80
Rockwell hardness B, 1/16-in. ball, 100-kg. load	94–95	44–46
Rockwell hardness G, 1/16-in. ball, 150-kg. load	73–74	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	91–92	75–76
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	79	46–47
Young's modulus of elasticity, p.s.i.	15,000,000	
Melting point, °F.	1645	
Density, lb. per cu. in.	0.304	
Coefficient of expansion, per °C. from 25–300°C.	0.0000214	
Electrical conductivity, % I.A.C.S., 68°F.	24.9	
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	68	

[a] All tests conducted on 0.040-in. stock.
[b] 6 B. & S. Nos., 0.080–0.015 mm. grain size at ready-to-finish.
[c] 1300°F. anneal (1 hr. at temperature) of material described in footnote *a*.

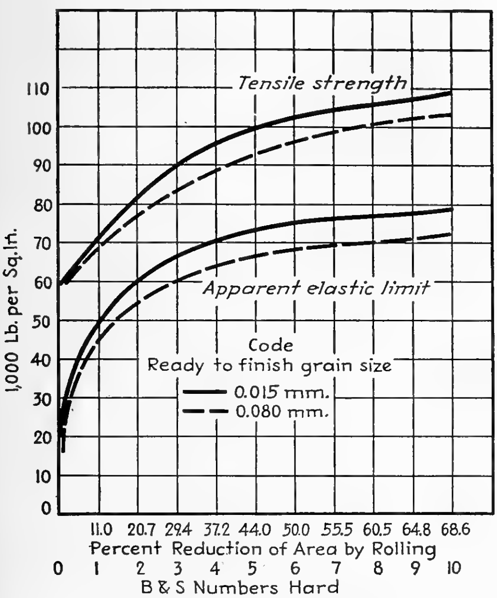


Chart 115.—The effect of cold rolling on the tensile strength and apparent elastic limit of modified manganese-bronze strip, previously annealed to two different grain sizes, 0.015 mm. and 0.080 mm. (61.51 % copper, 0.47 % tin, 0.15 % iron and manganese, balance zinc) (0.040-in stock).

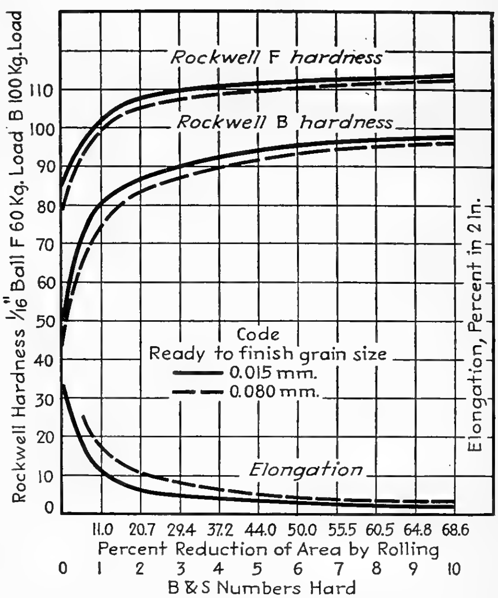


Chart 116.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of modified manganese-bronze strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (61.51 % copper, 0.47 % tin, 0.15 % iron and manganese, balance zinc) (0.040-in. stock).

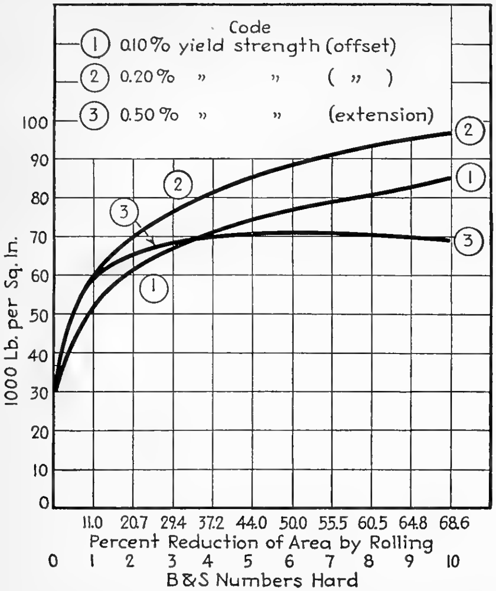


CHART 117.—The effect of cold rolling on the yield strengths of modified manganese-bronze strip, previously annealed to a grain size of 0.015 mm. (61.51 % copper, 0.47 % tin, 0.15 % iron and manganese, balance zinc) (0.040-in. stock).

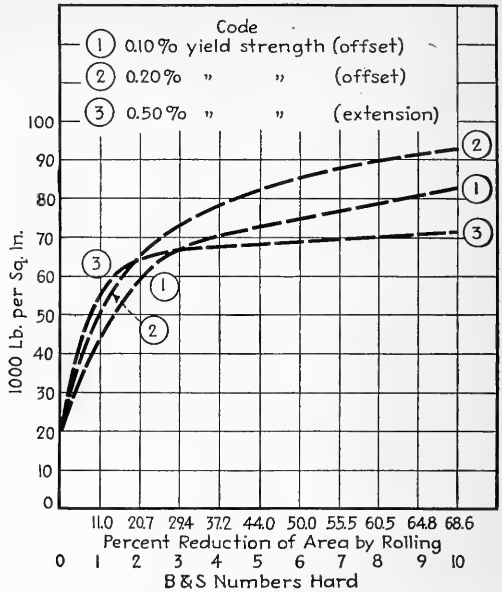


CHART 118.—The effect of cold rolling on the yield strengths of modified manganese-bronze strip, previously annealed to a grain size of 0.080 mm. (61.51 % copper, 0.47 % tin, 0.15 % iron and manganese, balance zinc) (0.040-in. stock).

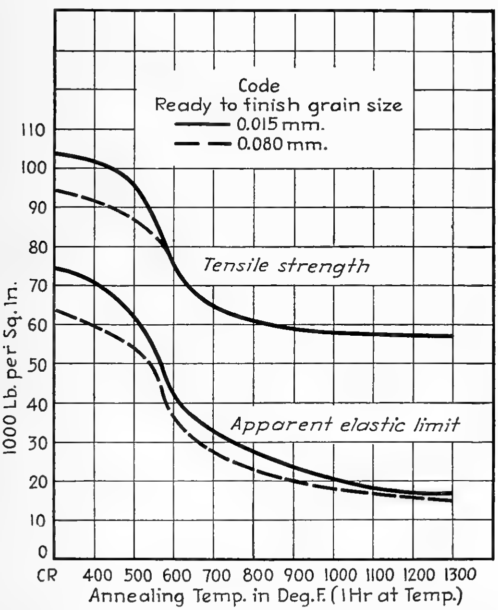


CHART 119.—The effect of annealing on the tensile strength and apparent elastic limit of modified manganese-bronze strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (61.51 % copper, 0.47 % tin, 0.15 % iron and manganese, balance zinc) (0.040-in. stock).

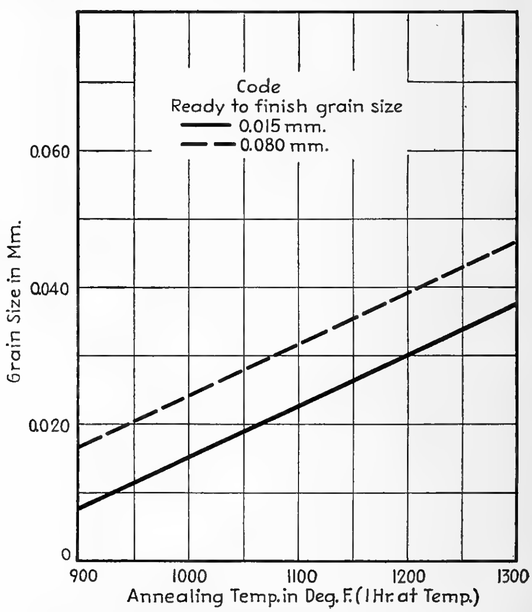


CHART 120.—The effect of annealing on the grain-growing characteristics of modified manganese-bronze strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (61.51 % copper, 0.47 % tin, 0.15 % iron and manganese, balance zinc) (0.040-in. stock).

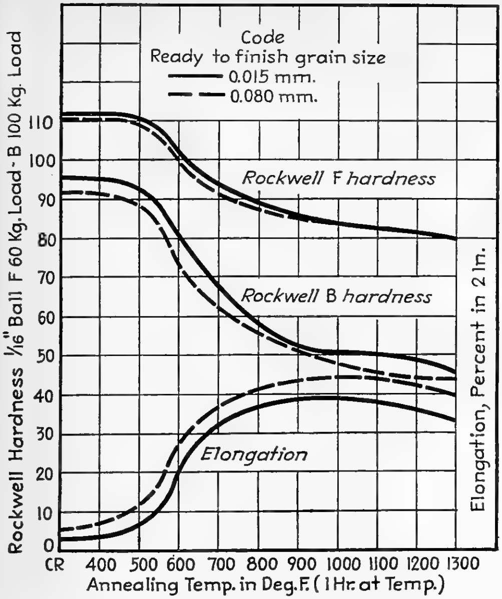


CHART 121.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of modified manganese-bronze strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (61.51 % copper, 0.47 % tin, 0.15 % iron and manganese, balance zinc) (0.040-in. stock).

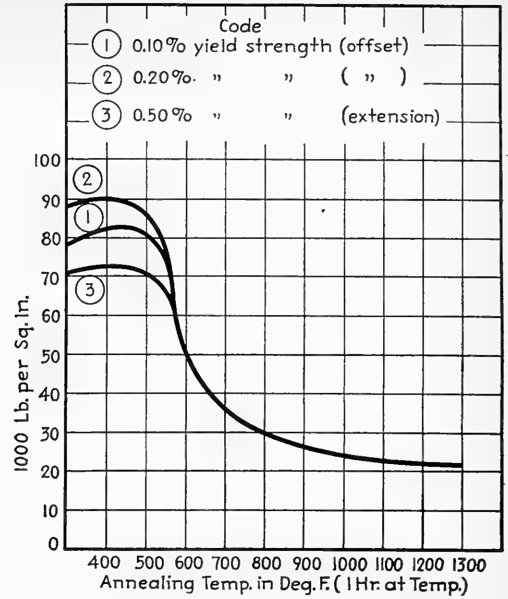


CHART 122.—The effect of annealing on the yield strength of modified manganese-bronze strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (61.51 % copper, 0.47 % tin, 0.15 % iron and manganese, balance zinc) (0.040-in. stock).

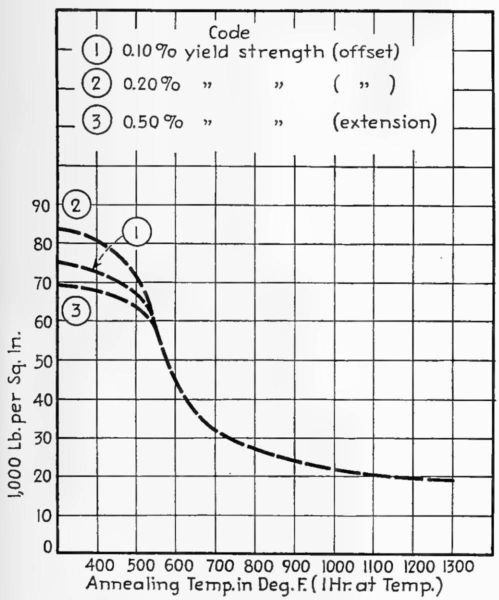


CHART 123.—The effect of annealing on the yield strength of modified manganese-bronze strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.080 mm. (61.51 % copper, 0.47 % tin, 0.15 % iron and manganese, balance zinc) (0.040-in. stock).

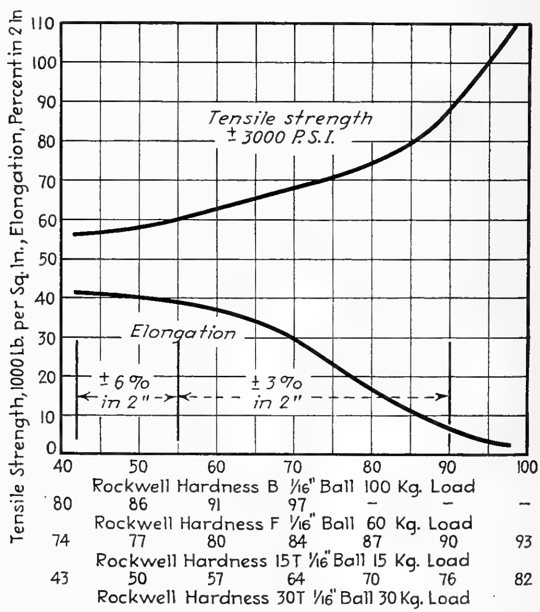


CHART 124.—This chart can be employed to determine the approximate tensile strength and percentage elongation of modified manganese-bronze strip (61.51 % copper, 0.47 % tin, 0.15 % iron and manganese, balance zinc) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

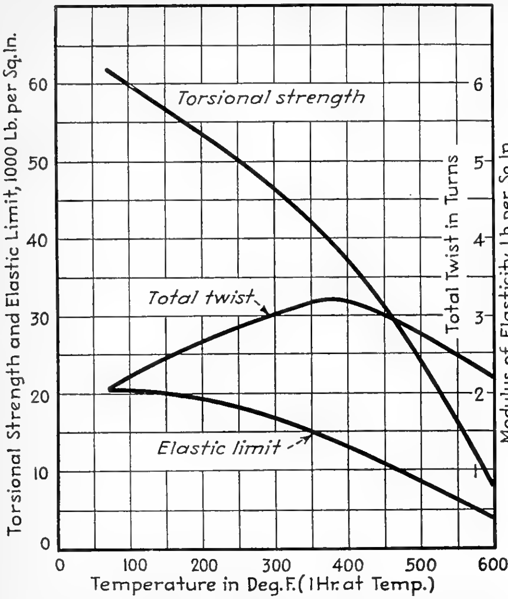


CHART 125.—Effect of elevated temperature on torsional properties of Parson's manganese bronze (59.58 % copper, 1.22 % iron, 0.64 % tin, 0.34 % aluminum, balance zinc) according to Bregousky and Spring.(9,22)

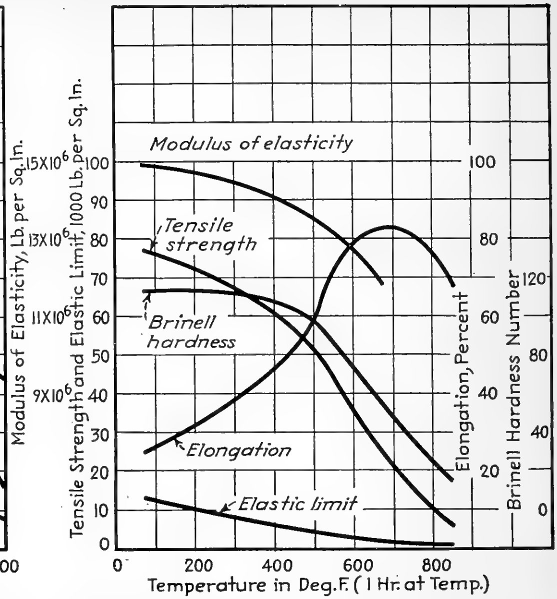


CHART 126.—Effect of elevated temperature on the tensile properties and Brinell hardness of a cold-worked manganese bronze (56.91 % copper, 0.75 % tin, 0.19 % manganese, 0.82 % iron, 0.66 % lead, 0.18 % aluminum, 0.21 % nickel) according to Lea.(9,12,13)

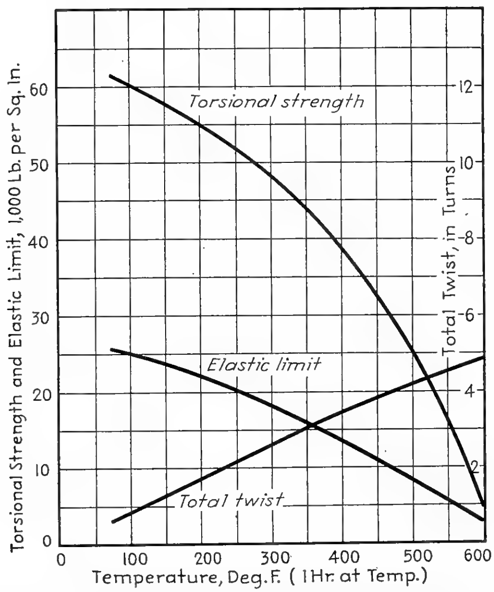


CHART 127.—Effect of elevated temperature on torsional properties of delta metal (56.56 % copper, 2.40 % iron, 0.76 % tin, 0.56 % lead, 0.004 % phosphorus) according to Bregousky and Spring.(9,22)

CHAPTER V

THE SPECIAL BRASSES

Many special or modified brasses have been developed to meet specific requirements. Nickel has been added to produce desirable color characteristics, aluminum to improve corrosion-resisting properties, silicon to improve hot-working properties and to increase tensile properties and electrical resistivity. Arsenic has been added in more than trace amounts to improve tensile strength and corrosion resistance. The more important of the special brasses are

1. The nickel brasses.
2. Aluminum brass.
3. Silicon brass.
4. Arsenical brass.

NICKEL BRASSES

There is a wide commercial range of alloys of copper, nickel, and zinc used primarily because of their color characteristics. These alloys are known commonly as the "nickel silvers" or "German silvers." A complete discussion of the properties of these alloys will be found in Chap. VI under Nickel Silvers.

ALUMINUM BRASS

In 1928 in the Eighth Report of the Corrosion Committee of the British Non-ferrous Research Association[24], data are given on an aluminum brass containing 76 per cent of copper, 2 per cent of aluminum, and the balance zinc. This alloy was developed specifically as a condenser-tube material for use under conditions of high water velocity. Experimental evidence developed at that time indicated that it possessed unusually good resistance to the type of attack known as "impingement." Practical experience since that time with millions of pounds has thoroughly substantiated the original conclusion.

This aluminum brass was introduced to the United States about 1930. Since that time an increasingly large amount of this alloy in the form of condenser tubes has been consumed annually by the heat exchanger industry. It has been determined that the inclusion of 2 per cent of aluminum with 77 per cent of copper produced an alloy with mechanical and structural properties closely approximating 70-30 brass. It further had been proved that the aluminum conferred on the brass the property of forming quickly when exposed to corrosive media such as salt or brackish water, a highly protective film that was tenacious, impervious, and self-healing.

Aluminum-brass condenser tubes are used extensively in this country for handling salt or brackish waters in both stationary and marine condensers where cooling water velocities are high.

In the development of this alloy it was found desirable to maintain an arsenic content of from 0.02 to 0.05 per cent. The function of the arsenic is to prevent dezincification particularly during stand-by periods. Since arsenic acts as an oxygen carrier, the presence of the above amount in aluminum brass also renders it more resistant to pitting as a consequence of oxygen-concentration cell action.

A summarization of mechanical properties and the most important physical properties may be found in Table 1. Complete mechanical properties in the annealed and at elevated temperatures may be found on page 177.

SILICON BRASSES

An investigation on the effect of silicon on copper-zinc alloys containing up to 70 per cent of copper was first made by Guillet in 1909. He determined that 1 per cent of silicon exercised as much effect structurally as 10 per cent of zinc. Although his work indicated that there were many interesting alloys possible, there was little if any commercial interest shown in the silicon brasses until about 1935.

With the development of refrigeration, particularly as it pertained to domestic installations, a need arose for a material of moderate cost, which could be fabricated economically, would possess reasonably good corrosion resistance, and could be spot- or seam-welded. After considerable experimental effort, on the part of both metal fabricators and refrigerator manufacturers, two silicon brasses were developed. These alloys are the only ones in commercial use today. One of these contains 77 per cent of copper, 1 per cent of silicon, and the balance zinc; the other contains 70 per cent of copper, 0.50 per cent of silicon, and the balance zinc.

The higher copper-silicon brass has been the most popular since it possesses physical properties and spot- and seam-welding characteristics very closely approximating those of the silicon coppers, which in turn, by reason of their low electrical conductivity, approach the performance of mild steel.[25]

More recently, primarily because of economic reasons, the lower copper-silicon brass has been used more extensively in the manufacture of evaporators for refrigerators.

Both of these alloys possess better hot-working properties than equivalent copper-zinc alloys and, in addition, are nearly as plastic in the cold condition as their copper-zinc alloy counterpart. These two alloys are usually supplied in sheet and strip form. Because of the presence of the silicon, specialized methods for cleaning or removing oxide scales, produced during annealing operations, are necessary in order to obtain a surface suitable for most welding.

A summarization of mechanical properties and the more important physical properties may be found in Tables 2 and 3. Detailed mechanical properties of the silicon brasses may be found in Charts 4 to 27 on pages 178 to 185.

ARSENICAL BRASS

Within the past several years there has been developed an alloy of copper and zinc in the alpha and beta range, modified with 2 per cent of nickel, 1.25 per cent of iron, and 0.60 per cent of arsenic. Lead is present to improve machinability. This alloy is known as "arsenical brass" and finds wide application in the manufacture of valve stems. It has excellent wear-resisting properties and, by reason of its arsenic content, it is much more resistant to failure by dezincification than arsenic-free alloys in the same composition range. In addition, the presence of the arsenic greatly improves the mechanical properties.

Arsenical brass has excellent hot-working properties and can be cold-worked lightly. Owing to its lead content, its machinability is about 75 per cent that of free-cutting brass. Its more important physical properties and its general mechanical properties may be found in Table 4 on page 186. Detailed data on the effect of cold drawing and various annealing treatments are given in Charts 28 to 39 on pages 186 to 189.

TABLE 1
ALUMINUM BRASS
GENERAL DATA—TUBING
Copper, 75.78 %; aluminum, 2.54 %; arsenic, 0.04 %; lead, 0.02 %; zinc, balance

Property	Hard[a]	Soft[b]
Tensile strength, p.s.i. (000 omitted)	83	62
Elongation, % in 2 in.	17	52
Apparent elastic limit, p.s.i. (000 omitted)	76	16
Rockwell hardness F, 1/16-in. ball, 60-kg. load	106	77
Young's modulus of elasticity, p.s.i.	15,000,000	
Melting point, °F.	1770	
Density, lb. per cu. in.	0.301	
Electrical conductivity,(89) % I.A.C.S. at 68°F.	22.50	
Thermal conductivity,(89) B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	58.1	
Specific gravity	8.31	

[a] Extruded, reduced, and cold-drawn to 3/4 by 0.049 in.
[b] Condenser tube anneal for 1 hr. (1050°F.).

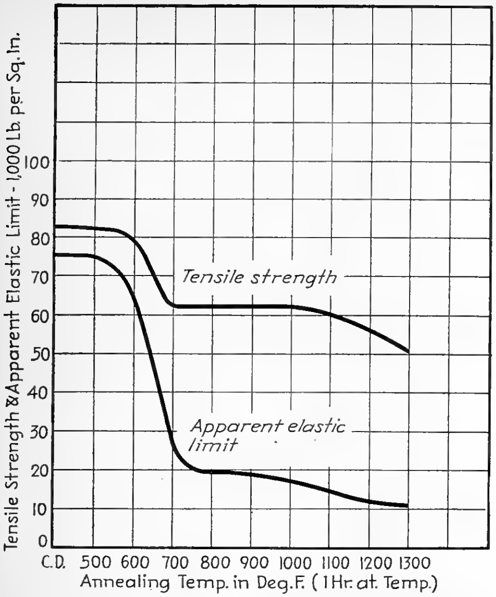


CHART 1.—The effect of annealing on the tensile strength and apparent elastic limit of aluminum-brass condenser tube, previously cold-drawn 50 per cent (reduction of area) from a grain size of 0.045 mm. (75.78 % copper, 2.54 % aluminum, 0.04 % arsenic, balance zinc).

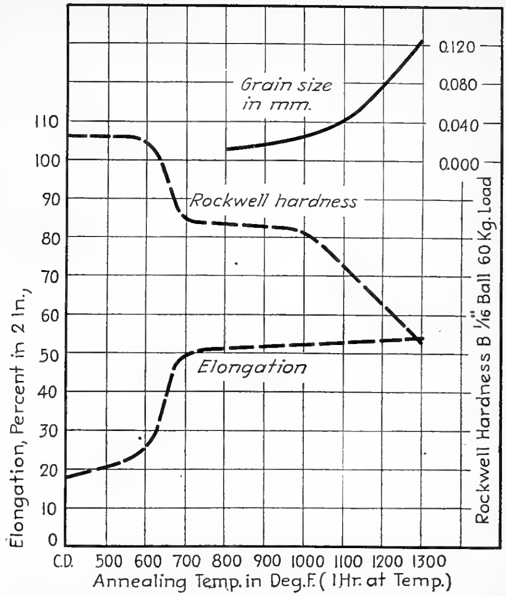


CHART 2.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and grain size of aluminum-brass condenser tube, previously cold-drawn 50 per cent (reduction of area) from a grain size of 0.045 mm. (75.78 % copper, 2.54 % aluminum, 0.04 % arsenic, balance zinc).

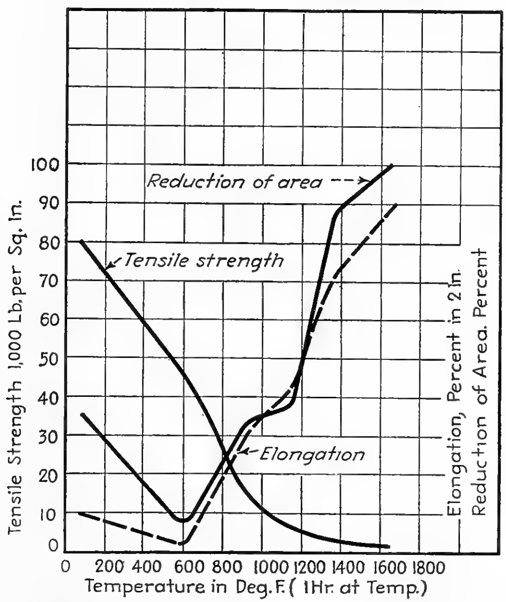


CHART 3.—The effect of elevated temperature on the tensile strength, percentage elongation in 2 in., and percentage reduction of area of aluminum-brass rod (79.00 % copper, 2.52 % aluminum, 0.02 % iron, balance zinc), previously cold-drawn 45 per cent (reduction of area) according to Price[7] (rod under 1 in. in diameter).

TABLE 2
SILICON BRASS NO. 1
GENERAL DATA—STRIP[a]
Copper, 77.74 %; silicon, 1.30 %; lead, nil; zinc, balance

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	99–119	56
Elongation, % in 2 in.	3–4	61
Apparent elastic limit, p.s.i. (000 omitted)	75–91	13
Yield strength, 0.5 % extension, p.s.i. (000 omitted)	70–75	12–15
Yield strength, 0.2 % offset, p.s.i. (000 omitted)	89–104	12–15
Yield strength, 0.1 % offset, p.s.i. (000 omitted)	80–91	12–15
Rockwell hardness F, 1/16-in. ball, 60-kg. load	110–114	67
Rockwell hardness B, 1/16-in. ball, 100-kg. load	93–99	23
Rockwell hardness G, 1/16-in. ball, 150-kg. load	69–81	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	91–93	68
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	78–82	31–30
Young's modulus of elasticity, p.s.i.	15,000,000	
Melting point, °F.	1690	
Density, lb. per cu. in.	0.304	
Coefficient of expansion, per °C. from 25–300°C.[d]	0.0000185	
Electrical conductivity, % I.A.C.S., 68°F.[d]	13.0	
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F.	39	
Specific gravity	8.40	

[a] All tests conducted on 0.040-in. stock.
[b] 6 B. & S. Nos., hard, 0.090–0.015 mm. grain size at ready-to-finish, respectively.
[c] Refer to 1300°F. anneal (1 hr. at temperature).
[d] Approximate values.

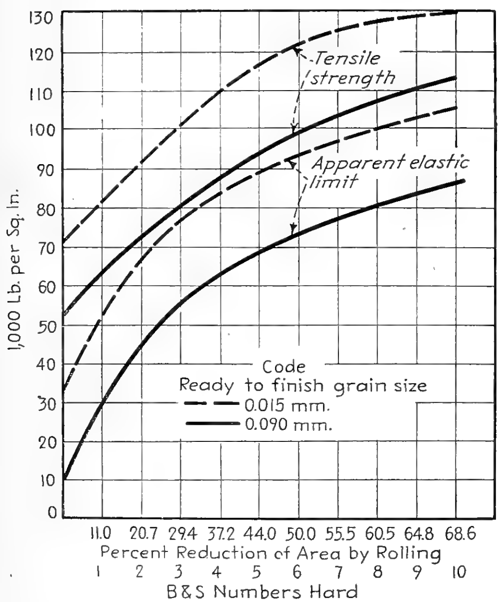


CHART 4.—The effect of cold rolling on the tensile strength and apparent elastic limit of silicon-brass No. 1 strip, previously annealed to two different grain sizes, 0.015 and 0.090 mm. (77.74 % copper, 1.30 % silicon, balance zinc) (0.040-in. stock).

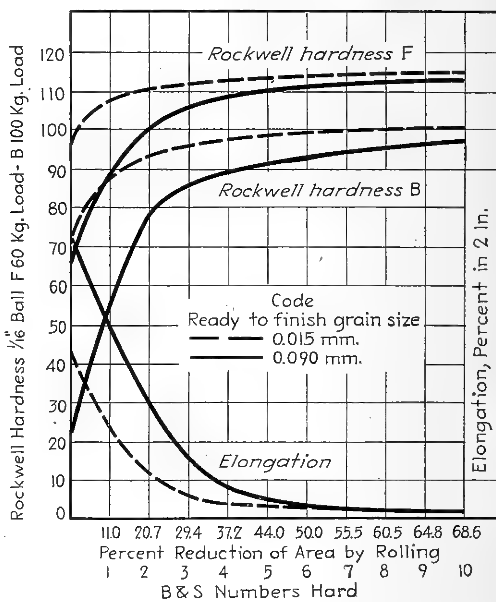


CHART 5.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of silicon-brass No. 1 strip, previously annealed to two different grain sizes, 0.015 and 0.090 mm. (77.74 % copper, 1.30 % silicon, balance zinc) (0.040-in. stock).

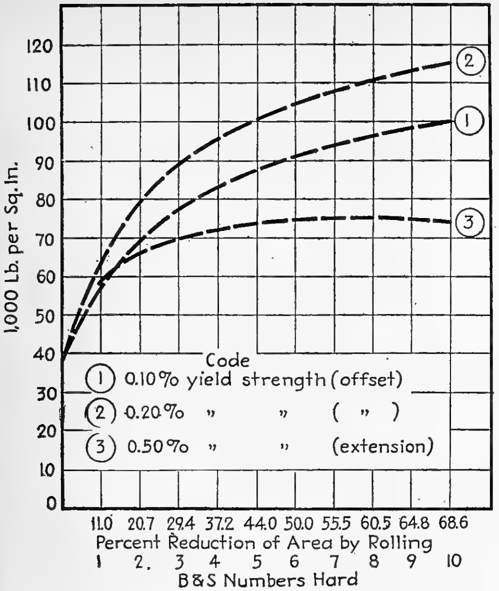


Chart 6.—The effect of cold rolling on the yield strengths of silicon-brass No. 1 strip, previously annealed to a grain size of 0.015 mm. (77.74 % copper, 1.30 % silicon, balance zinc) (0.040-in. stock).

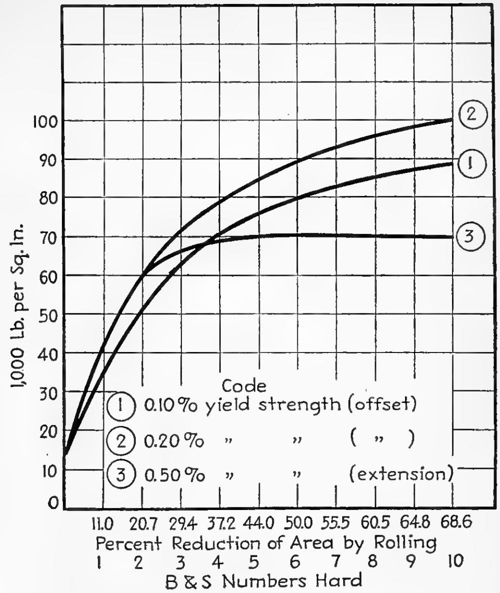


Chart 7.—The effect of cold rolling on the yield strengths of silicon-brass No. 1 strip, previously annealed to a grain size of 0.090 mm. (77.74 % copper, 1.30 % silicon, balance zinc) (0.040-in. stock).

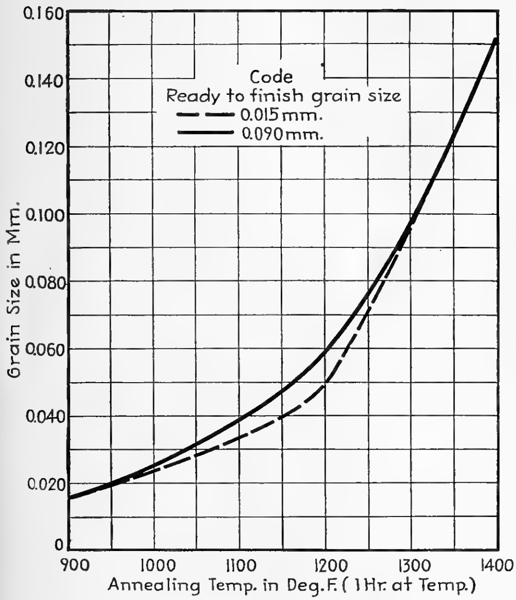


Chart 8.—The effect of annealing on the grain-growing characteristics of silicon-brass No. 1 strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.090 mm. (77.74 % copper, 1.30 % silicon, balance zinc) (0.040-in. stock).

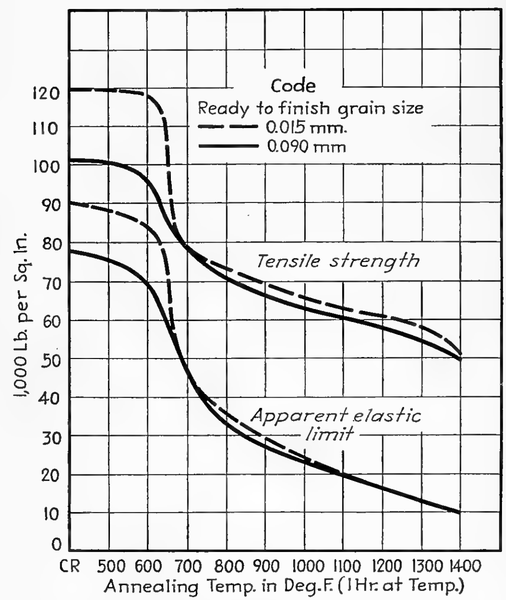


Chart 9.—The effect of annealing on the tensile strength and apparent elastic limit of silicon-brass No. 1 strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.090 mm. (77.74 % copper, 1.30 % silicon, balance zinc) (0.040-in. stock).

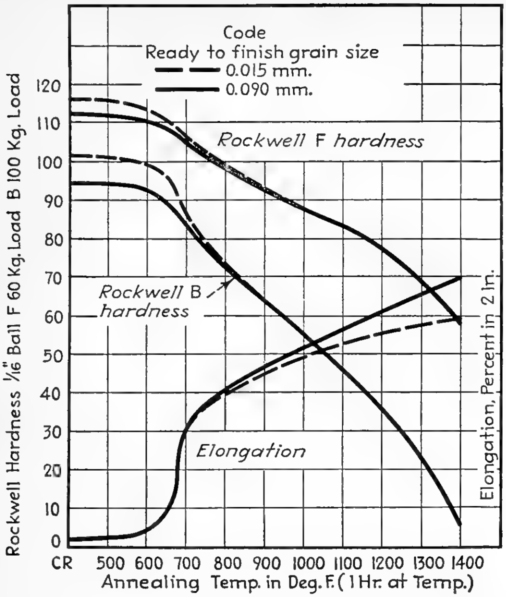


CHART 10.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of silicon-brass No. 1 strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.090 mm. (77.74 % copper, 1.30 % silicon, balance zinc) (0.040-in. stock).

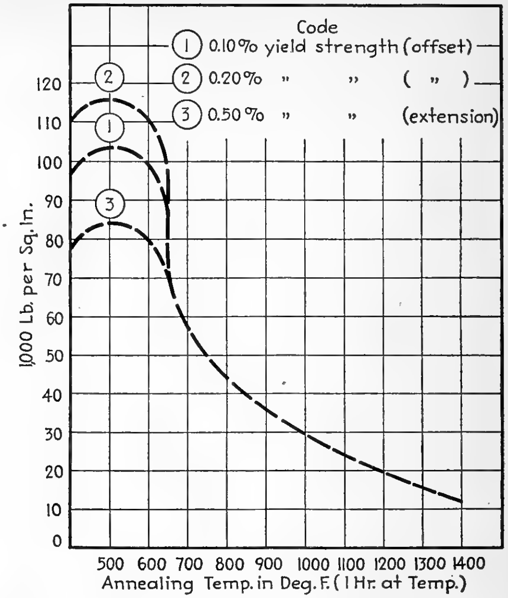


CHART 11.—The effect of annealing on the yield strength of silicon-brass No. 1 strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (77.74 % copper, 1.30 % silicon, balance zinc) (0.040-in. stock).

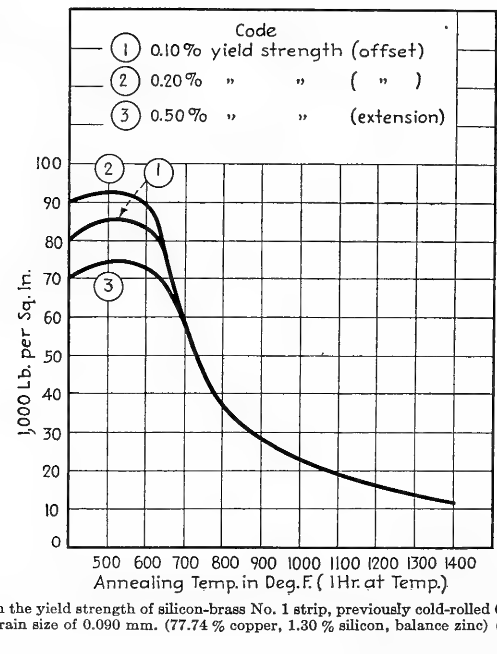


CHART 12.—The effect of annealing on the yield strength of silicon-brass No. 1 strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.090 mm. (77.74 % copper, 1.30 % silicon, balance zinc) (0.040-in. stock).

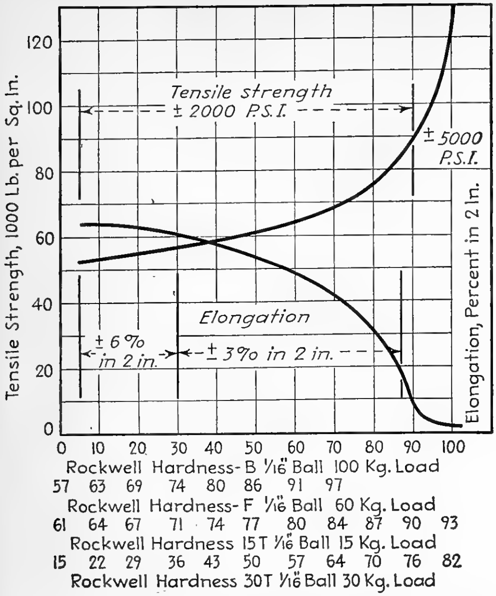


Chart 13.—This chart can be employed to determine the approximate tensile strength and percentage elongation of silicon brass No. 1 strip (77.74 % copper, 1.30 % silicon, balance zinc) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

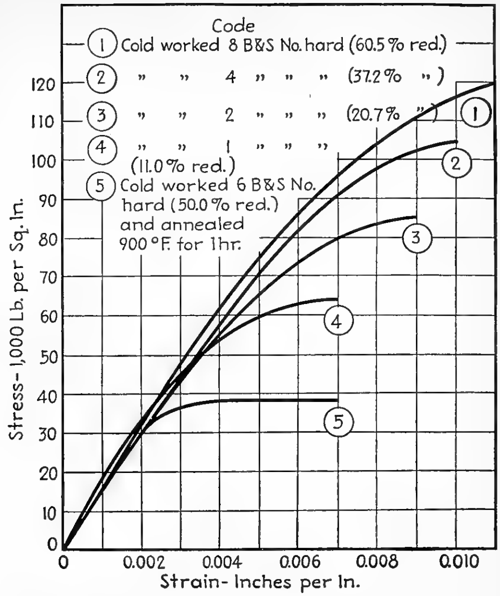


Chart 14.—The effect of cold rolling on the stress-strain characteristics of silicon-brass No. 1 strip (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (77.74 % copper, 1.30 % silicon, balance zinc.)

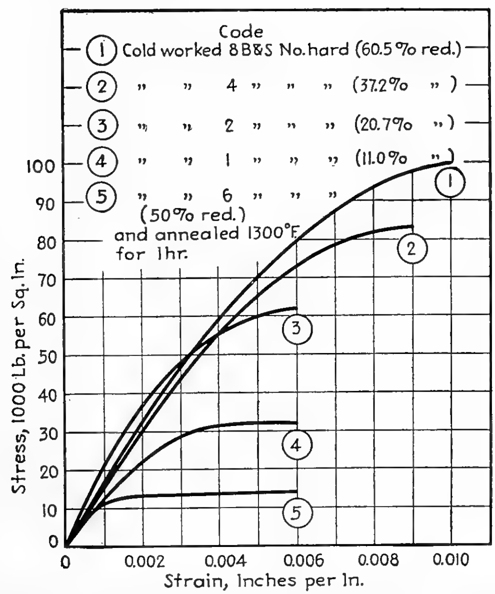


Chart 15.—The effect of cold rolling on the stress-strain characteristics of silicon-brass No. 1 strip (0.040 in. thick) having a ready-to-finish grain size of 0.090 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (77.74 % copper, 1.30 % silicon, balance zinc.)

TABLE 3
SILICON BRASS NO. 2
GENERAL DATA—STRIP[a]
Copper, 72.36 %; silicon, 0.47 %; zinc, balance

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	97–106	49–50
Elongation, % in 2 in.	4	65–62
Apparent elastic limit, p.s.i. (000 omitted)	73–80	8
Yield strength, 0.5 % extension, p.s.i. (000 omitted)	66–68	10–11
Yield strength, 0.2 % offset, p.s.i. (000 omitted)	84–93	10–11
Yield strength, 0.1 % offset, p.s.i. (000 omitted)	73–81	10–11
Rockwell hardness F, 1/16-in. ball, 60-kg. load	111–114	58
Rockwell hardness B, 1/16-in. ball, 100-kg. load	93–98	8
Rockwell hardness G, 1/16-in. ball, 150-kg. load	69–78	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	91–92	71–70
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	78–81	37–36
Young's modulus of elasticity, p.s.i.	15,000,000	
Density, lb. per cu. in.	0.302	
Melting point, °F.	1730	

[a] All tests conducted on 0.040-in. stock.
[b] 6 B. & S. Nos., hard, 0.080–0.015 mm. grain size at ready-to-finish, respectively.
[c] Annealed at 1300°F. for 1 hr.

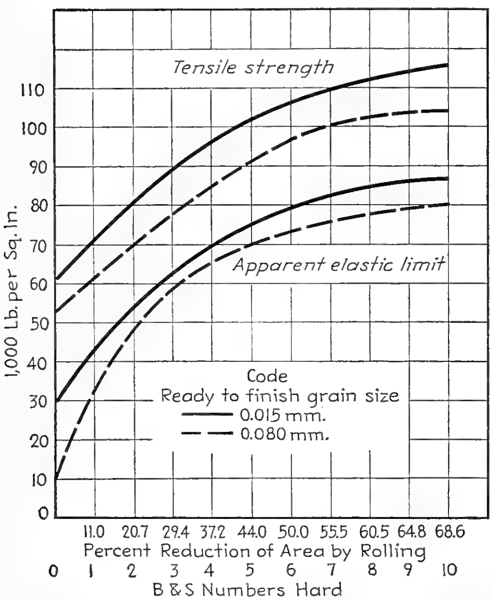


CHART 16.—The effect of cold rolling on the tensile strength and apparent elastic limit of silicon-brass No. 2 strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (72.36 % copper, 0.47 % silicon, balance zinc) (0.040-in. stock).

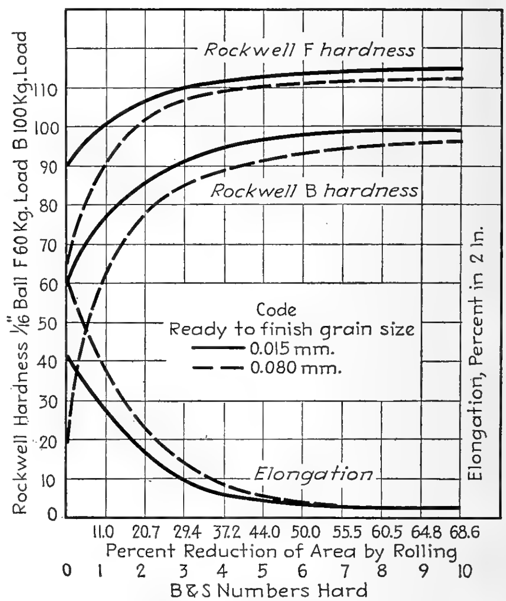


CHART 17.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of silicon-brass No. 2 strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (72.36 % copper, 0.47 % silicon, balance zinc) (0.040-in. stock).

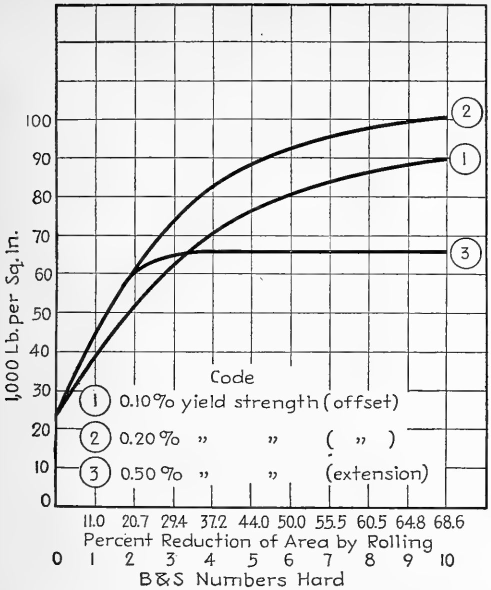


CHART 18.—The effect of cold rolling on the yield strengths of silicon-brass No. 2 strip, previously annealed to a grain size of 0.015 mm. (72.36 % copper, 0.47 % silicon, balance zinc) (0.040-in. stock).

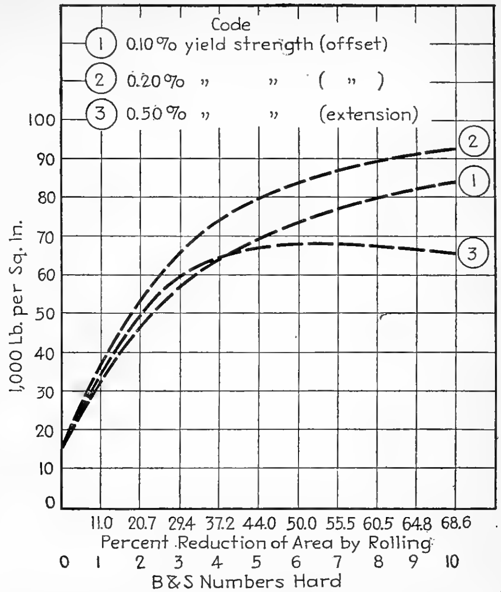


CHART 19.—The effect of cold rolling on this yield strengths of silicon-brass No. 2 strip, previously annealed to a grain size of 0.080 mm. (72.36 % copper, 0.47 % silicon, balance zinc) (0.040-in. stock).

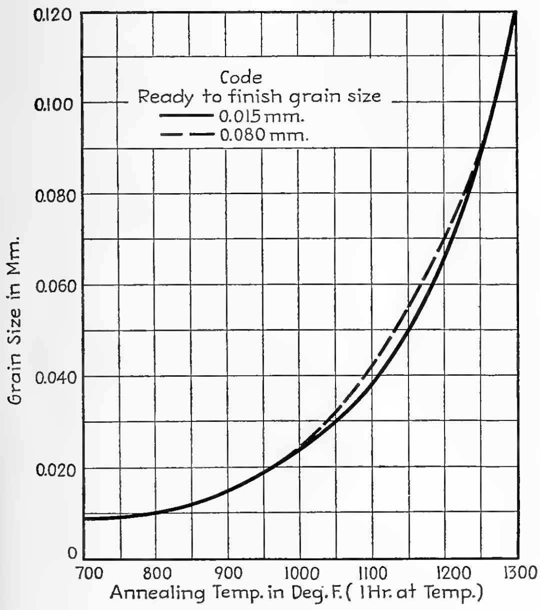


CHART 20.—The effect of annealing on the grain-growing characteristics of silicon-brass No. 2 strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (72.36 % copper, 0.47 % silicon, balance zinc) (0.040-in. stock).

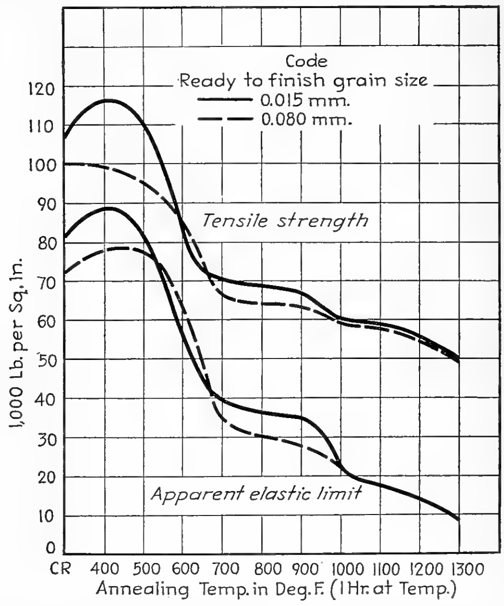


CHART 21.—The effect of annealing on the tensile strength and apparent elastic limit of silicon-brass No. 2 strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (72.36 % copper, 0.47 % silicon, balance zinc) (0.040-in. stock).

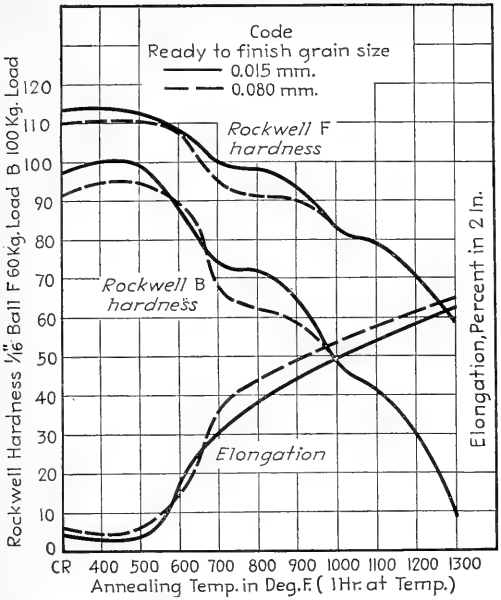


Chart 22.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of silicon-brass No. 2 strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (72.36 % copper, 0.47 % silicon, balance zinc) (0.040-in. stock).

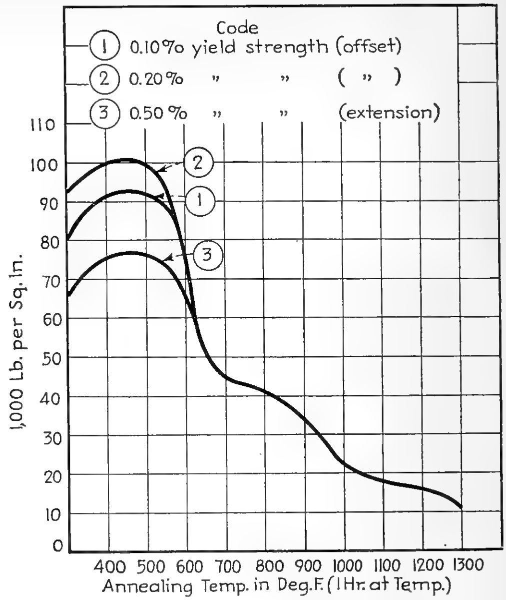


Chart 23.—The effect of annealing on the yield strength of silicon-brass No. 2 strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (72.36 % copper, 0.47 % silicon, balance zinc) (0.040-in. stock).

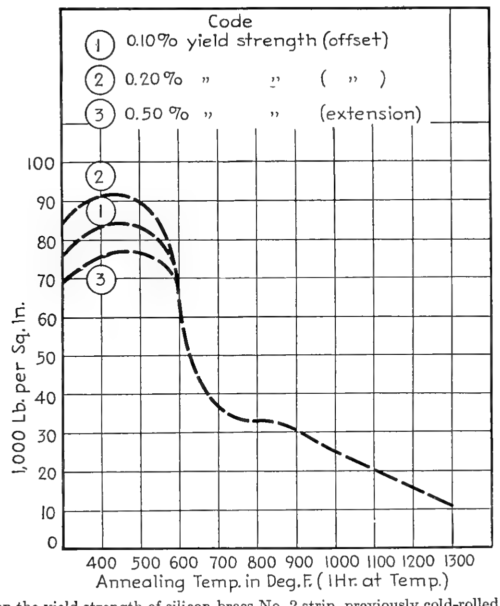


Chart 24.—The effect of annealing on the yield strength of silicon-brass No. 2 strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.080 mm. (72.36 % copper, 0.47 % silicon, balance zinc) (0.040-in. stock).

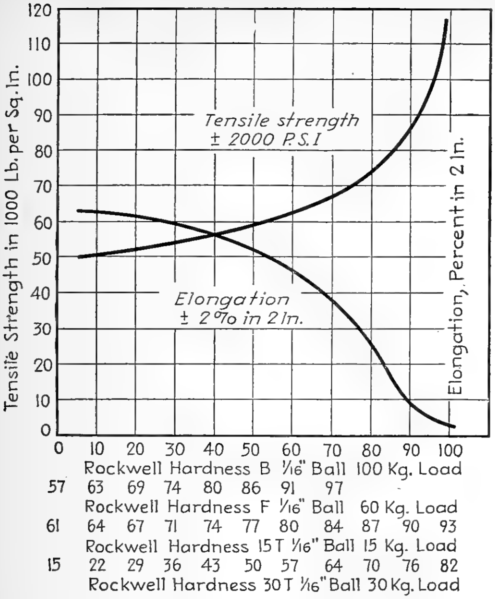


CHART 25.—This chart can be employed to determine the approximate tensile strength and percentage elongation of silicon-brass No. 2 strip (72.36 % copper, 0.47 % silicon, balance zinc) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

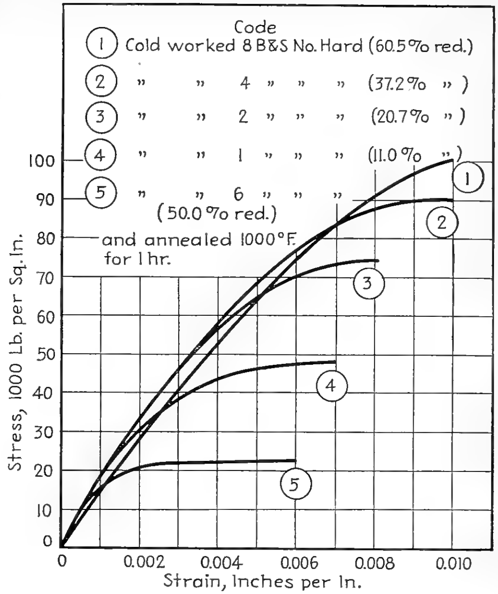


CHART 26.—The effect of cold rolling on the stress-strain characteristics of silicon-brass No. 2 strip (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (72.36 % copper, 0.47 % silicon, balance zinc.)

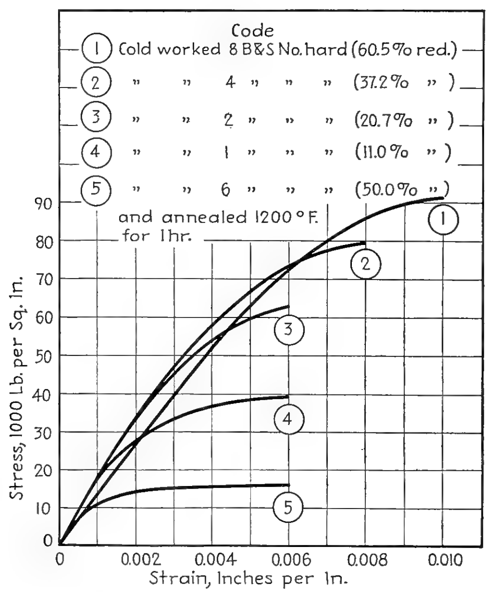


CHART 27.—The effect of cold rolling on the stress-strain characteristics of silicon-brass No. 2 strip (0.040 in. thick) having a ready-to-finish grain size of 0.080 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (72.36 % copper, 0.47 % silicon, balance zinc.)

TABLE 4
ARSENICAL BRASS[a]
General Data—Rod
Copper, 56.28 %; nickel, 1.97 %; iron, 1.34 %; lead, 0.98 %; arsenic, 0.65 %; zinc, balance

Property	Rod		
	Hard[b]	Soft[c]	Hot
Tensile strength, p.s.i. (000 omitted)	85	65	65–70
Apparent elastic limit, p.s.i. (000 omitted)	54	17	17–25
Yield strength, 0.5 % extension, p.s.i. (000 omitted)	62	26	37–22
Yield strength, 0.2 % offset, p.s.i. (000 omitted)	69	26	40–23
Yield strength, 0.1 % offset, p.s.i. (000 omitted)	57	25	34–20
Elongation, % in 2 in.	10	40	40–30
Reduction of area, %	30	35	30–35
Rockwell hardness F, 1/16-in. ball, 60-kg. load	105	85	85–95
Rockwell hardness B, 1/16-in. ball, 100-kg. load	85	55	55–65
Brinell hardness, 10-mm. ball, 500-kg. load	140	89	89–102
Modulus of elasticity, p.s.i.	16,000,000		
Melting point, °F.	1630		
Density, lb. per cu. in.	0.302		
Forging range, °F.	1200–1450		
Forging quality	Excellent		
Type structure	Two phase, alpha-beta		

[a] This alloy has excellent hot-working properties. Because of its structural characteristics it is not recommended for operations involving cold forming, forging, or upsetting. The presence of 0.60 % of lead materially aids machining.
[b] Refers to rod cold-drawn 23 % from extruded condition; rod under 1 in. in diameter with a ready-to-finish grain size of 0.020 mm.
[c] Refers to 1300°F. anneal (1 hr.).

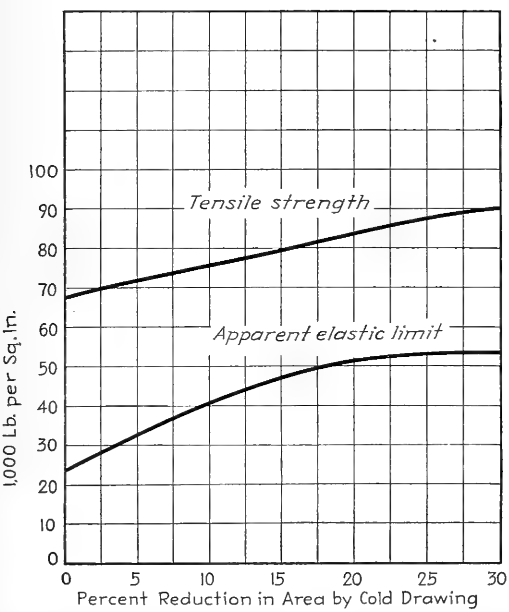


Chart 28.—The effect of cold drawing on the tensile strength and apparent elastic limit of arsenical-brass rod, previously annealed to a grain size of 0.020 mm. (56.28 % copper, 1.97 % nickel, 1.34 % iron, 0.98 % lead, 0.65 % arsenic, balance zinc) (rod under 1 in. in diameter).

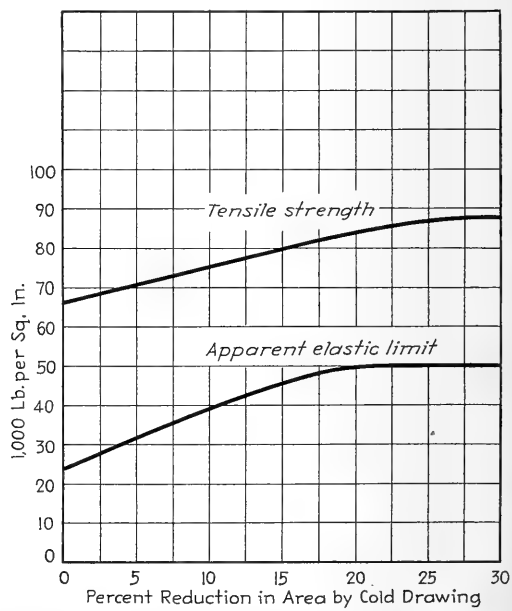


Chart 29.—The effect of cold drawing plus relief annealing at 575°F. for 45 min. on the tensile strength and apparent elastic limit of arsenical-brass rod, previously annealed to a grain size of 0.020 mm. (56.28 % copper, 1.97 % nickel, 1.34 % iron, 0.98 % lead, 0.65 % arsenic, balance zinc) (rod under 1 in. in diameter).

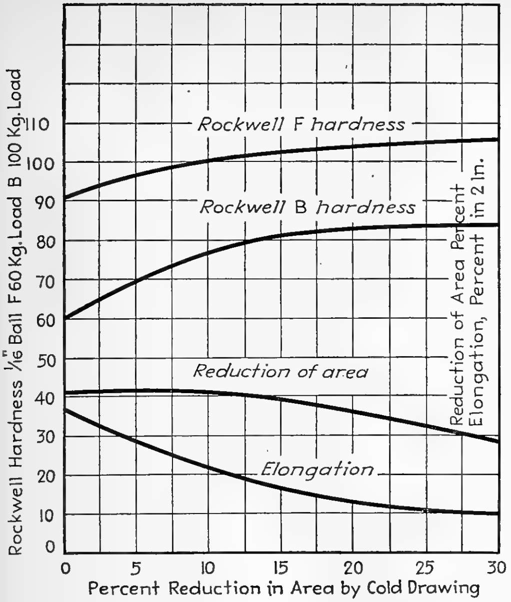


CHART 30.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of arsenical-brass rod, previously annealed to a grain size of 0.020 mm. (56.28 % copper, 1.97 % nickel, 1.34 % iron, 0.98 % lead, 0.65 % arsenic, balance zinc) (rod under 1 in. in diameter).

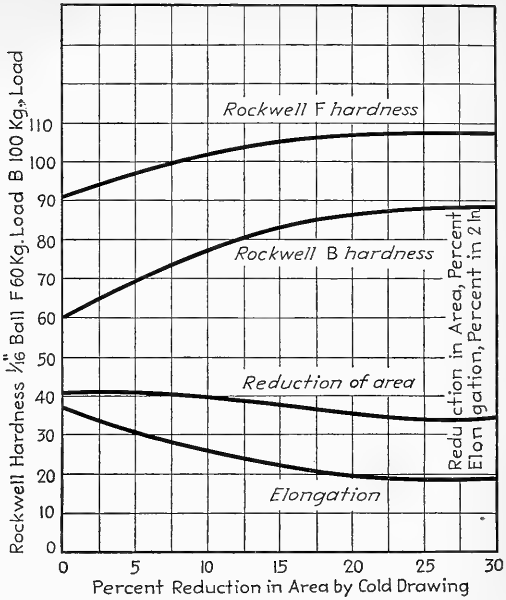


CHART 31.—The effect of cold drawing plus relief annealing at 575°F. for 45 min. on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of arsenical-brass rod, previously annealed to a grain size of 0.020 mm. (56.28 % copper, 1.97 % nickel, 1.34 % iron, 0.98 % lead, 0.65 % arsenic, balance zinc) (rod under 1 in. in diameter).

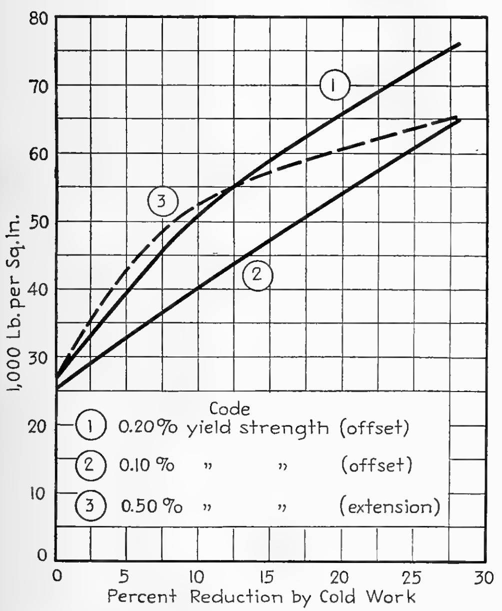


CHART 32.—The effect of cold drawing on the yield strength of arsenical-brass rod, previously annealed to a grain size of 0.020 mm. (56.28 % copper, 1.97 % nickel, 1.34 % iron, 0.98 % lead, 0.65 % arsenic, balance zinc) (rod under 1 in. in diameter).

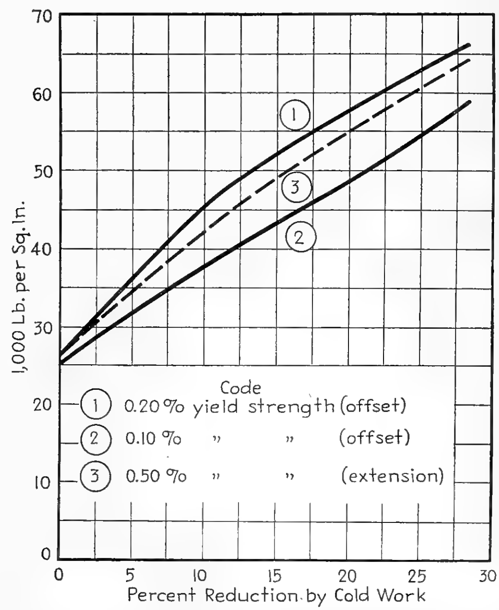


CHART 33.—The effect of cold drawing plus relief annealing at 575°F. for 45 min. on the yield strength of arsenical-brass rod, previously annealed to a grain size of 0.020 mm. (56.28 % copper, 1.97 % nickel, 1.34 % iron, 0.98 % lead, 0.65 % arsenic, balance zinc) (rod under 1 in. in diameter).

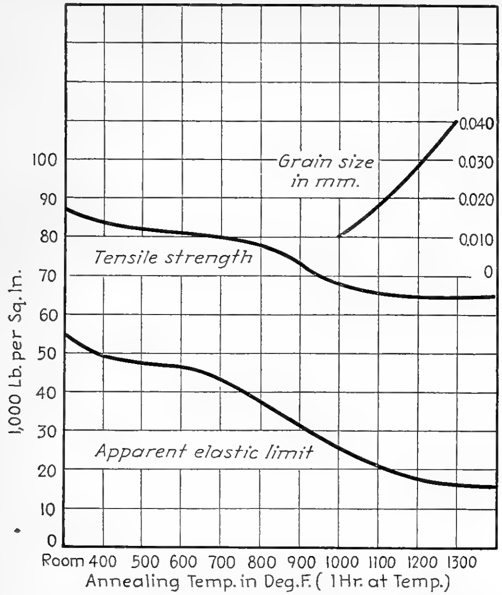


CHART 34.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of arsenical-brass rod, previously cold-drawn 23 per cent (reduction of area) from material having a grain size of 0.020 mm. (56.28 % copper, 1.87 % nickel, 1.34 % iron, 0.98 % lead, 0.65 % arsenic, balance zinc) (rod under 1 in. in diameter).

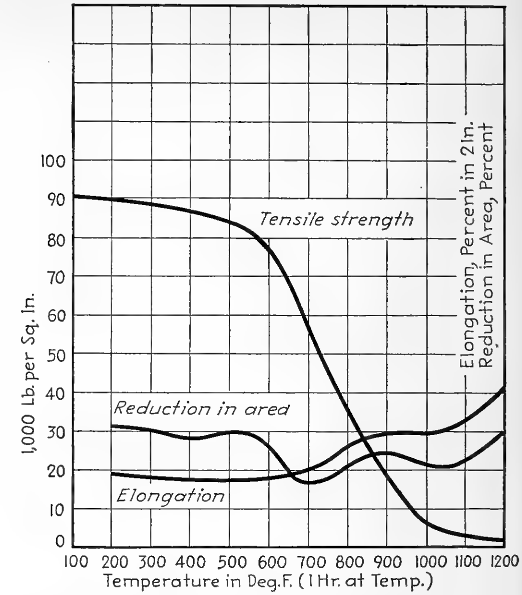


CHART 35.—The effect of elevated temperature on the tensile strength, percentage elongation in 2 in., and percentage reduction of area of arsenical-brass rod (56.28 % copper, 1.87 % nickel, 1.34 % iron, 0.98 % lead, 0.65 % arsenic, balance zinc), previously cold-drawn 27 per cent (reduction of area) from a grain size of 0.025 mm. followed by relief annealing at 570°F. for 45 min. (rod under 1 in. in diameter).

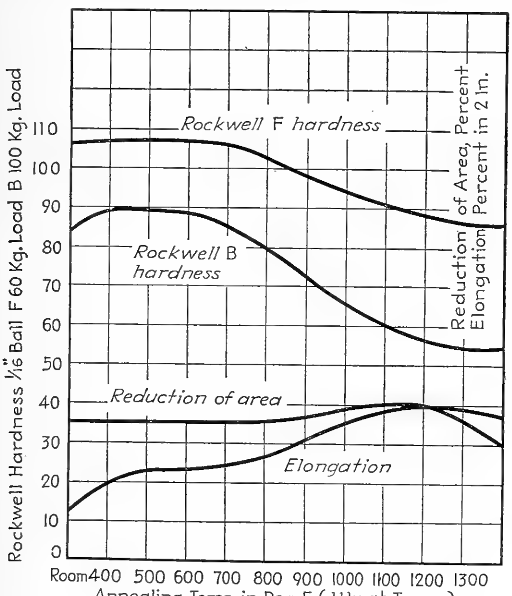


CHART 36.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of arsenical-brass rod, previously cold-drawn 23 per cent (reduction of area) from material having a grain size of 0.020 mm. (56.28 % copper, 1.97 % nickel, 1.34 % iron, 0.98 % lead, 0.65 % arsenic, balance zinc) (rod under 1 in. in diameter).

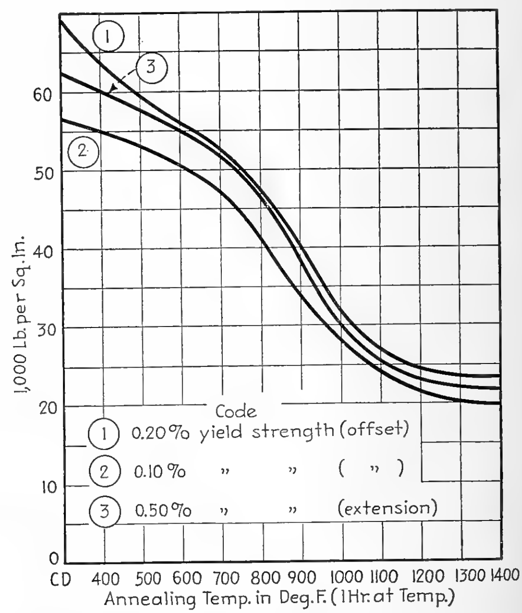


CHART 37.—The effect of annealing on the yield strength of arsenical-brass rod, previously cold-drawn 23 per cent (reduction of area) from material having a grain size of 0.020 mm. (56.28 % copper, 1.97 % nickel, 1.34 % iron, 0.98 % lead, 0.65 % arsenic, balance zinc) (rod under 1 in. in diameter).

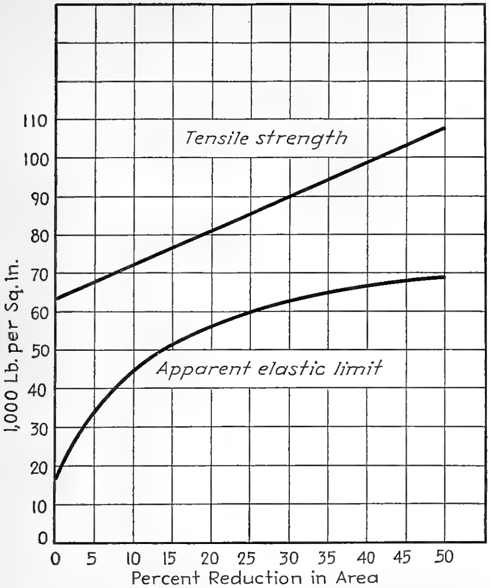


CHART 38.—The effect of cold drawing on the tensile strength and apparent elastic limit of "Weldfast" bronze (modified Muntz metal), previously extruded (57.00 % copper, 1.96 % nickel, 1.46 % iron, 0.21 % manganese, balance zinc) (rod under 1 in. in diameter).

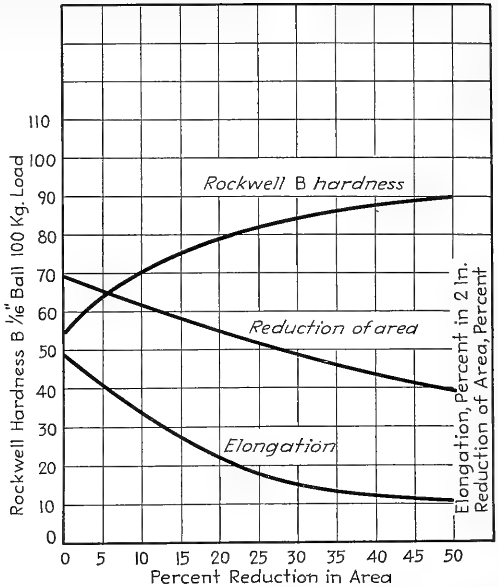


CHART 39.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of "Weldfast" bronze (modified Muntz metal), previously extruded (57.00 % copper, 1.96 % nickel, 1.46 % iron, 0.21 % manganese, balance zinc) (rod under 1 in. in diameter).

CHAPTER VI

NICKEL SILVERS

The copper-nickel-zinc alloys, like the copper-zinc alloys, are of two general types: one containing 65 per cent or more of copper and nickel combined and structurally consisting of a single phase; the other containing 55 to 60 per cent of copper and nickel combined and structurally consisting of two phases. Nickel is added to copper zinc primarily for its influence on color. Figure 1 shows the range of colors that may be secured with nickel additions to copper-zinc alloys.

The single-phase nickel silvers possess excellent cold-working properties and only fair hot-working properties. Accordingly they are most frequently used for those applications requiring ductility in the cold condition.

Figure 2 indicates the range of commercial nickel silvers and their general working characteristics.

Common name	Copper, %	Nickel, %	Zinc, %
30% nickel silver	62	30	8
20% nickel silver	75	20	5
20% nickel silver	66	20	14
18% nickel silver	66	18	16
18% nickel silver	62	18	20
15% nickel silver	66	15	19
12% nickel silver	66	12	22
10% nickel silver	67	10	23
10% nickel silver	62	10	28
5% nickel silver	62	5	33
18% nickel silver (spring stock)	55	18	27
12% nickel silver (leaded)	66	12	2% lead; 20% zinc

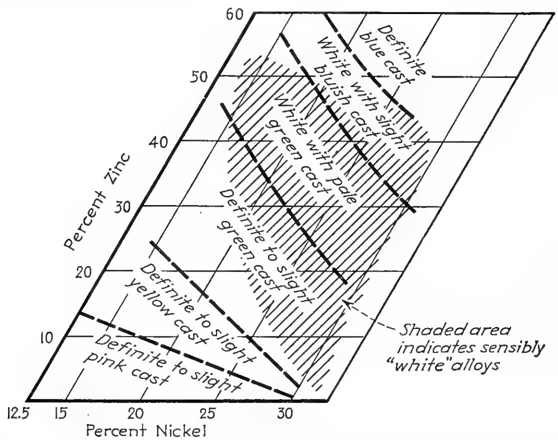


FIG. 1.—Color trends of copper-nickel-zinc alloys, according to Kihlgren.[29]

The single-phase nickel silvers are used almost exclusively for articles that are subsequently to be plated such as tableware and hollow ware. However, the alloy containing 55 per cent of copper and either 15 or 18 per cent of nickel is used extensively as spring material, because it possesses higher tensile properties in combination with higher modulus of elasticity than any of the copper-zinc or copper-nickel-zinc alloys.

Lead is frequently added to these nickel silvers to improve machining, blanking, and shearing operations.

The nominal composition of the more important of the nickel silvers is given in the table on this page.

The more important physical properties and a summarization of mechanical properties of these alloys may be found in Tables 1 to 13 on pages 191 to 222. Charts 1 to 108 on pages 192 to 225 give in detail the influence of cold working and the effect of various annealing treatments on the mechanical properties.

The alpha-beta nickel silvers can be readily hot-worked by any of the commercial processes. Because of their hot plasticity over a wide temperature range they can be fabricated into difficult and intricate shapes, such as plumbing fixtures, stair rails, architectural shapes, and escalator parts.

Occasionally lead is added to these alloys to improve machining. The addition of lead does not interfere with the hot-extrusion properties of these alloys but it does make them unsuitable for hot-rolling and forging operations. The mechanical properties of the more important of these alloys have been developed by Cook[28] and are contained in Table 12 on page 221.

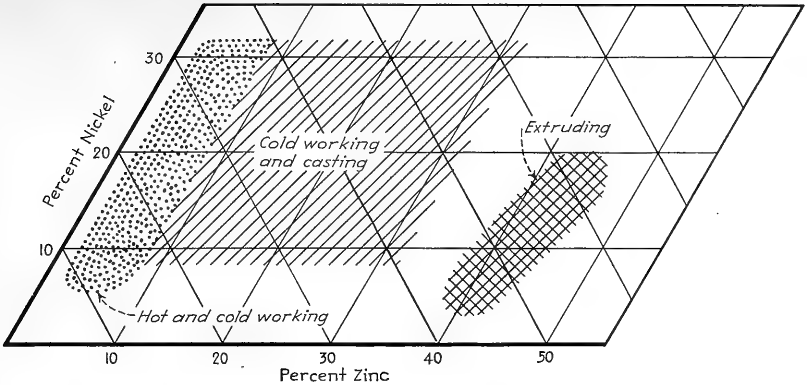


Fig. 2.—Composition ranges of nickel silvers, according to Kihlgren, Pilling, and Wise.[27]

TABLE 1
30 PER CENT NICKEL SILVER
General Data[a]—Strip

Copper, 62.02 %; nickel, 29.77 %; zinc, 7.93 %; manganese, 0.14 %; lead, 0.003 %; iron, 0.09 %

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	94	59
0.10 % proof strength, p.s.i. (000 omitted)	86.5	
Limit of proportionality, p.s.i. (000 omitted)	46	
Elongation, % in 2 in.	5.5	35
Reduction of area, %	8	
Rockwell hardness B, 1/16-in. ball, 100-kg. load	91	
Rockwell hardness E, 1/8-in. ball, 100-kg. load	111	
Diamond pyramid hardness, 10-kg. load	199	94
Erichsen value, mm	...	60
Brinell hardness, 10 kg., 1-mm. ball	174	
Shore Scleroscope M. H.	54	
S. & S., Shore Scleroscope U. H. and self-recorder	38	
Specific gravity	8.868	8.872
Density, lb. per cu. in.	0.320	
Coefficient of thermal expansion, $\times 10^{-6}$:		
At 0–100°C.	16.2	
At 0–200°C.	16.6	
At 0–300°C.	17.0	
At 0–400°C.	17.8	
Thermal conductivity:		
At 70°F., B.t.u. per sq. ft. per ft. per hr. per °F	11.13	
At 400°F., B.t.u. per sq. ft. per ft. per hr. per °F	13.55	
Temperature coefficient of thermal conductivity	0.00120	
Specific resistance, microhm-cm.[3] at 20°C.	37.89	
Melting point, °F.	2190	
Modulus of elasticity, p.s.i.	18,000,000	

[a] Based on data by Cook.[26]
[b] Refers to strip cold-rolled 60 % (reduction in thickness) from a ready-to-finish anneal at 1450°F. for 2 hr.
[c] Refers to a 1450°F. anneal for 2 hr.

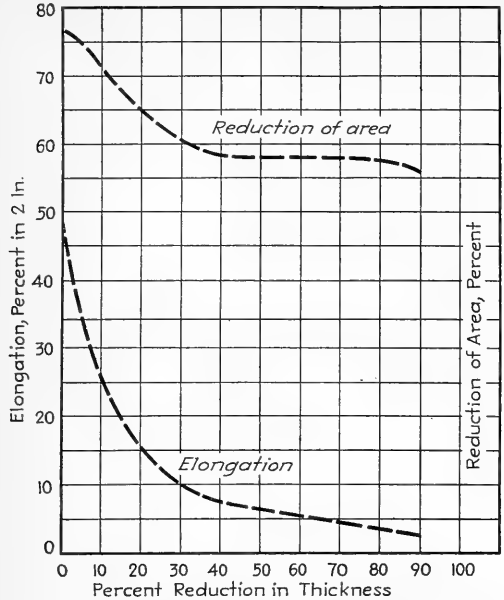


CHART 1.—The effect of cold rolling on the percentage reduction of area and percentage elongation in 2 in. of 30 per cent nickel-silver strip (29.77 % nickel, 62.02 % copper, balance zinc), previously annealed at 1450°F. according to Cook.[26]

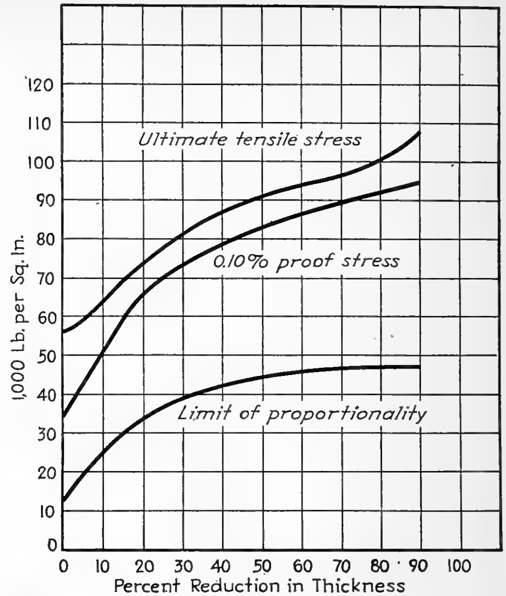


CHART 2.—The effect of cold rolling on tensile strength, proof strength, and proportional limit of 30 per cent nickel-silver strip (29.77 % nickel, 62.02 % copper, balance zinc), previously annealed at 1450°F. according to Cook.[26]

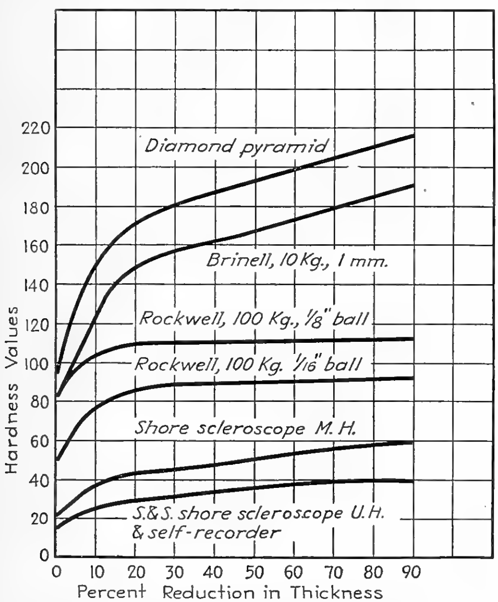


CHART 3.—The effect of cold rolling on the hardness of 30 per cent nickel-silver strip (29.77 % nickel, 62.02 % copper, balance zinc) previously annealed at 1450°F. according to Cook.[26]

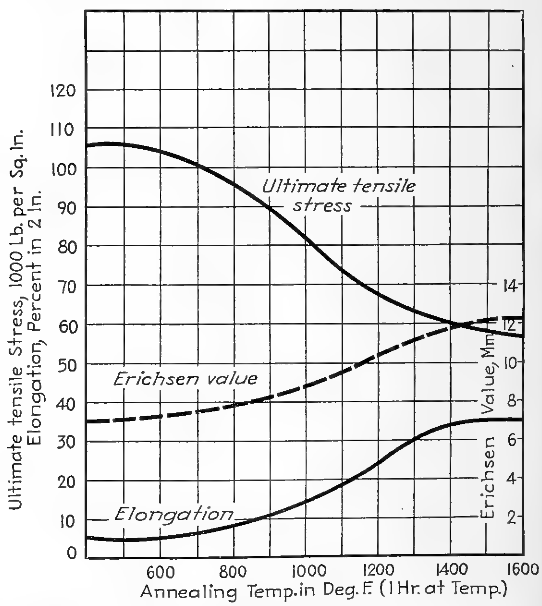


CHART 4.—The effect of annealing on the tensile strength, Erichsen value, and percentage elongation in 2 in. of 30 per cent nickel-silver strip (29.77 % nickel, 62.02 % copper, balance zinc), previously cold-rolled 60 per cent according to Cook.[26]

TABLE 2
20 PER CENT NICKEL SILVER
GENERAL DATA—STRIP[a]
Copper, 66.11 %; nickel, 21.13 %; manganese, 0.09 %; zinc, balance

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	82–90	51–54
Elongation, % in 2 in.	3	35–40
Apparent elastic limit, p.s.i. (000 omitted)	62–68	13–16
Yield strength, 0.5 % extension, p.s.i. (000 omitted)	76–81	17–18
Yield strength, 0.2 % offset, p.s.i. (000 omitted)	78–86	17–18
Yield strength, 0.1 % offset, p.s.i. (000 omitted)	76–83	17–18
Rockwell hardness F, 1/16-in. ball, 60-kg. load	108–110	72–75
Rockwell hardness B, 1/16-in. ball, 100-kg. load	85–90	32–33
Rockwell hardness G, 1/16-in. ball, 150-kg. load	58–66	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	88–90	71
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	74–76	38
Young's modulus of elasticity, p.s.i.	17,500,000	
Melting point, °F.	2055	
Density, lb. per cu. in.	0.318	
Coefficient of expansion, per °C. from 25–300°C.	0.0000146	
Electrical conductivity, % I.A.C.S., 68°F.	5.6	
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	19	
Specific gravity	8.81	

[a] All tests conducted on 0.040-in. stock.
[b] 6 B. & S. Nos., hard, 0.070–0.015 mm. grain size at ready-to-finish.
[c] 1400°F. anneal (1 hr. at temperature) of material described in footnote *b*.

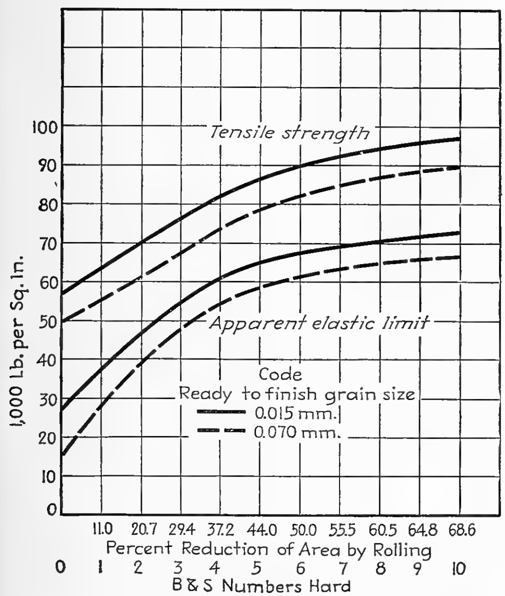


CHART 5.—The effect of cold rolling on the tensile strength and apparent elastic limit of 20 per cent nickel-silver strip, previously annealed to two different grain sizes, 0.015 and 0.070 mm. (66.11 % copper, 21.13 % nickel, balance zinc) (0.040-in. stock).

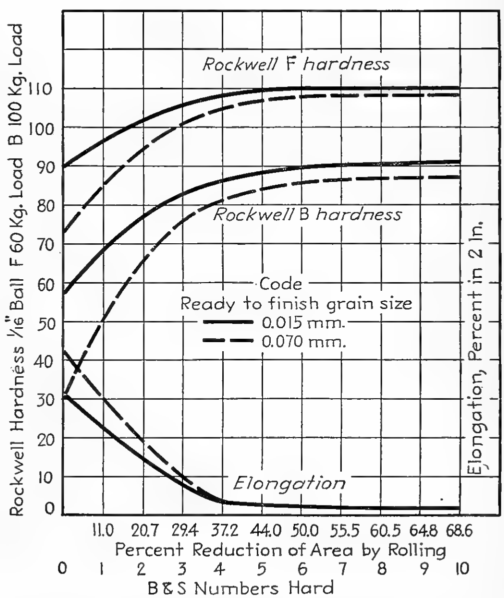


CHART 6.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of 20 per cent nickel-silver strip, previously annealed to two different grain sizes, 0.015 and 0.070 mm. (66.11 % copper, 21.13 % nickel, balance zinc) (0.040-in. stock).

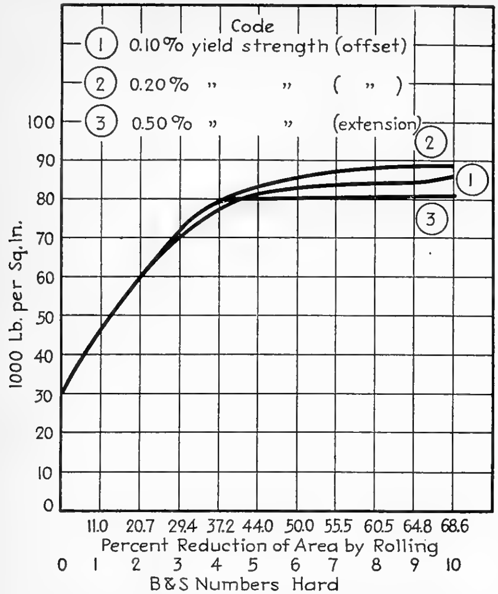


CHART 7.—The effect of cold rolling on the yield strengths of 20 per cent nickel-silver strip, previously annealed to a grain size of 0.015 mm. (66.11 % copper, 21.13 % nickel, balance zinc) (0.040-in. stock)

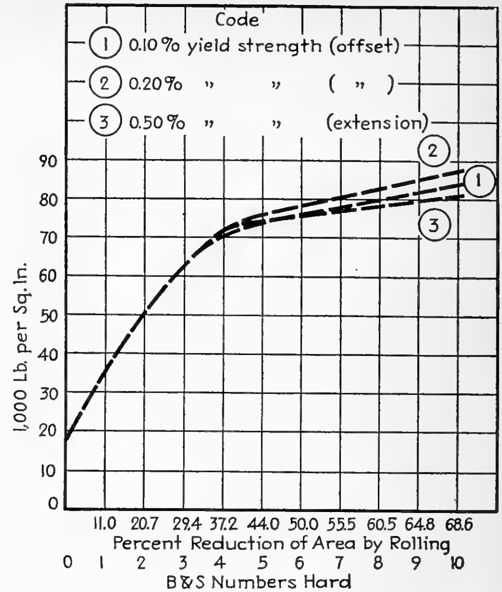


CHART 8.—The effect of cold rolling on the yield strengths of 20 per cent nickel-silver strip, previously annealed to a grain size of 0.070 mm. (66.11 % copper, 21.13 % nickel, balance zinc) (0.040-in. stock).

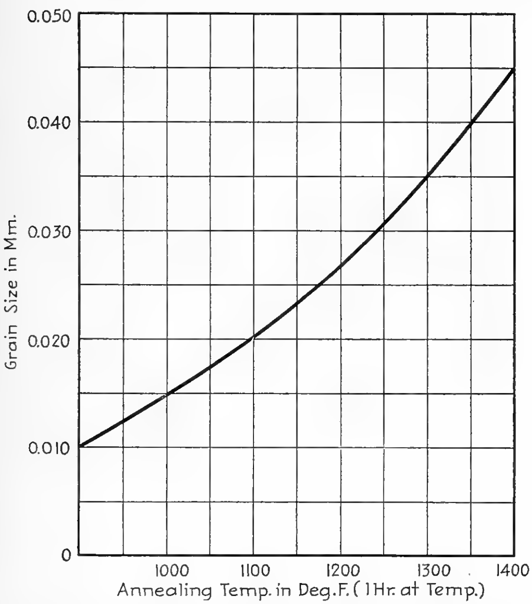


CHART 9.—The effect of annealing on the grain-growing characteristics of 20 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (66.11 % copper, 21.13 % nickel, balance zinc) (0.040-in. stock).

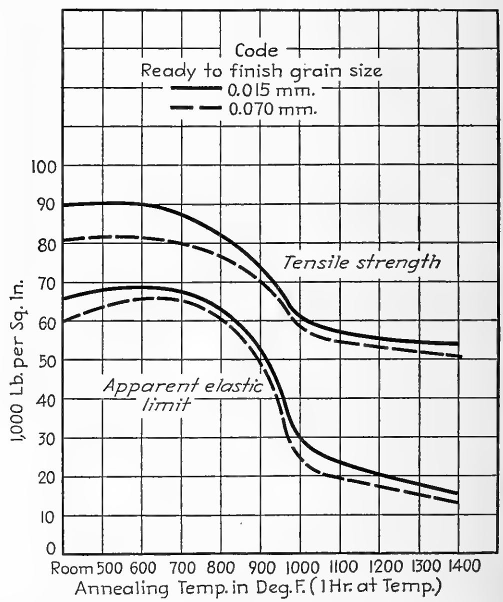


CHART 10.—The effect of annealing on the tensile strength and apparent elastic limit of 20 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 mm. and 0.070 mm. (66.11 % copper, 21.13 % nickel, balance zinc) (0.040-in. stock).

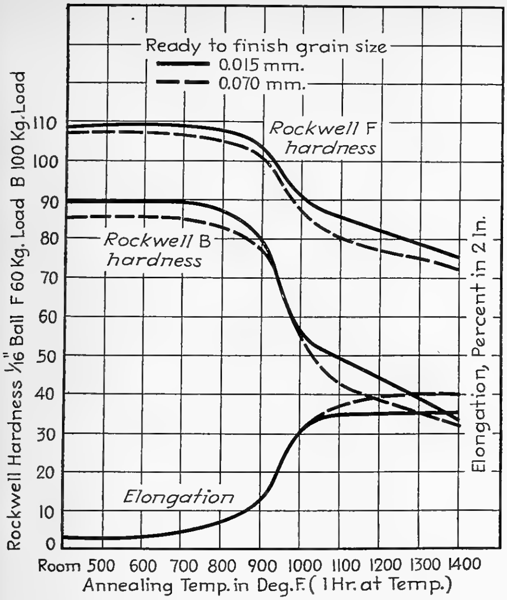


CHART 11.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of 20 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (66.11 % copper, 21.13 % nickel, balance zinc) (0.040-in. stock).

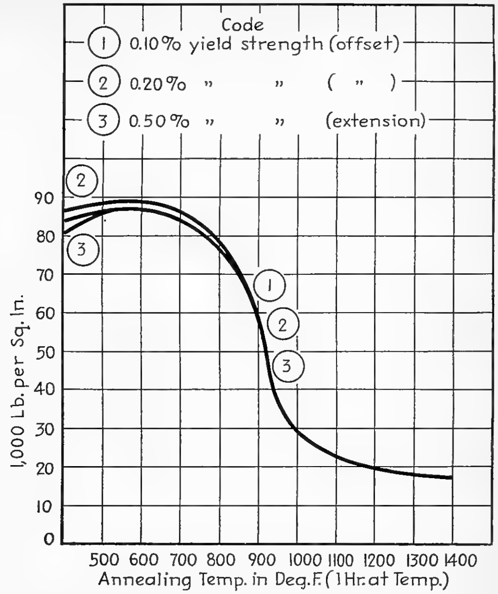


CHART 12.—The effect of annealing on the yield strength of 20 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (66.11 % copper, 21.13 % nickel, balance zinc) (0.040-in. stock).

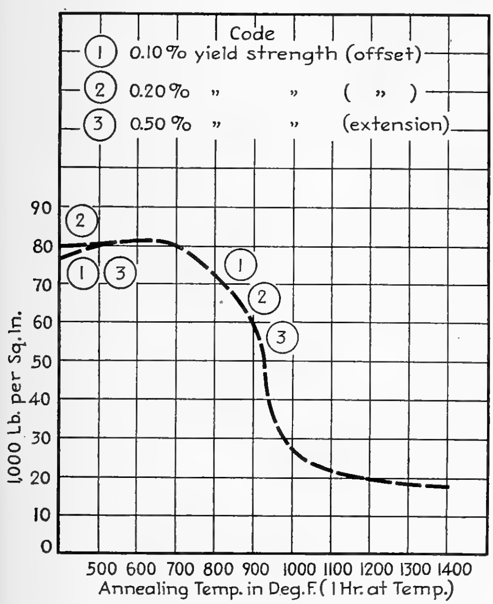


CHART 13.—The effect of annealing on the yield strength of 20 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.070 mm. (66.11 % copper, 21.13 % nickel, balance zinc) (0.040-in. stock).

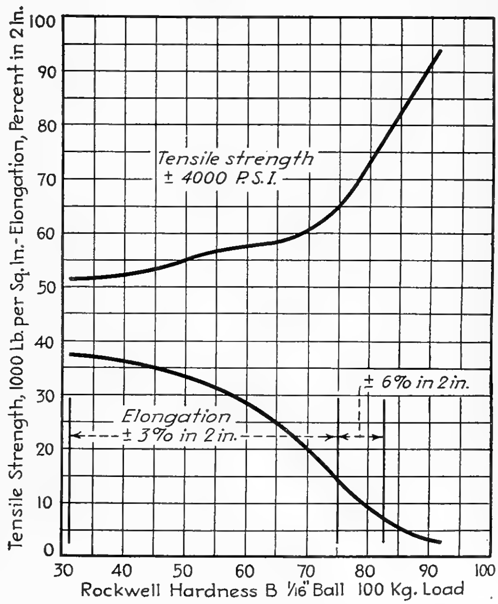


CHART 14.—This chart can be employed to determine the approximate tensile strength and percentage elongation of 20 per cent nickel-silver strip (66.11 % copper, 21.13 % nickel, balance zinc) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

TABLE 3
20 PER CENT NICKEL SILVER
General Data for Tube
Copper, 75.00 %; nickel, 20.00 %; zinc, 5.00 %

Property	Hard[a]	Soft[b]
Tensile strength, p.s.i. (000 omitted)	81	49
Elongation, % in 2 in.	5	46
Apparent elastic limit, p.s.i. (000 omitted)	78	16
Rockwell hardness F, 1/16-in. ball, 60-kg. load	106	66
Young's modulus of elasticity, p.s.i	17,500,000	
Melting point, °F.	2100	
Specific gravity	8.84	
Electrical conductivity, % I.A.C.S., 68°F.	6.20	
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	22.3	
Coefficient of expansion, per °C. from 25–300°C.	0.0000164	
Density, lb. per cu. in.	0.319	

Available Creep Data[(3)]

Previous history: cold-drawn rod 0.750 in.; annealed 1202°F.; tensile strength, 50,400 p.s.i.; % elongation in 2 in., 51; % reduction of area, 75.

Temperature, °F.	Stress, p.s.i., required to produce designated rate of creep per 1,000 hr.	
	0.01 %	0.10 %
600	13,800	27,800
750	8,400	13,500

[a] Extruded, reduced, drawn to 3/4 by 0.049 in.
[b] Annealed at 1300°F. for 1 hr.

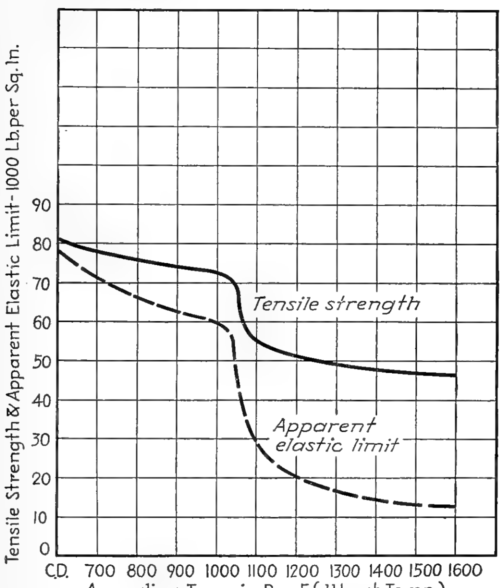


Chart 15.—The effect of annealing on the tensile strength and apparent elastic limit of 20 per cent nickel-silver tube, previously cold-drawn 40 per cent (reduction of area) (75.00 % copper, 20.00 % nickel, 5.00 % zinc).

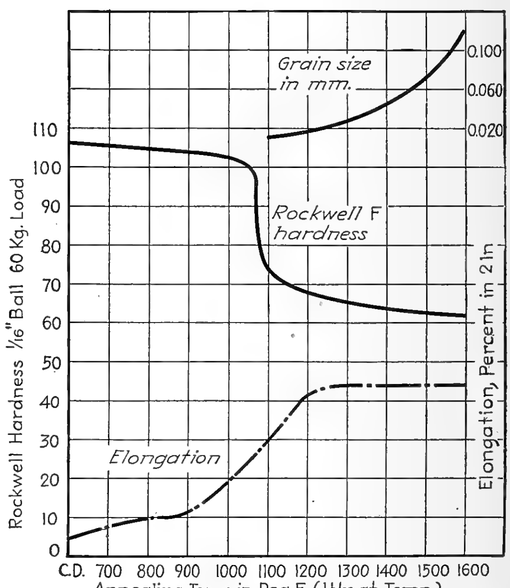


Chart 16.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and grain size of 20 per cent nickel-silver tube, previously cold-drawn 40 per cent (reduction of area) (75.00 % copper, 20.00 % nickel, 5.00 % zinc).

TABLE 4
18 PER CENT NICKEL SILVER (DEEP DRAWING)
GENERAL DATA—STRIP[a]
Copper, 66.00 %; nickel, 18.00 %; zinc, 17.00 %

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	84–98	61
Elongation, % in 2 in.	3	32–36
Apparent elastic limit, p.s.i. (000 omitted)	68–78	26
Yield strength, 0.5 % extension, p.s.i. (000 omitted)	82–85	24–30
Yield strength, 0.2 % offset, p.s.i. (000 omitted)	84–94	24–30
Yield strength, 0.1 % offset, p.s.i. (000 omitted)	82–90	24–30
Rockwell hardness F, 1/16-in. ball, 60-kg. load	110–111	85
Rockwell hardness B, 1/16-in. ball, 100-kg. load	88–94	54
Rockwell hardness G, 1/16-in. ball, 150-kg. load	63–73	3–16
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	89–91	77–80
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	75–79	50–56
Young's modulus of elasticity, p.s.i.	18,500,000	
Melting point, °F.	2030	
Density, lb. per cu. in.	0.316	
Coefficient of expansion, per °C. from 25–300°C.	0.0000148	
Electrical conductivity, % I.A.C.S., 68°F.	5.91	
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	19.30	
Specific gravity	8.76	

[a] All tests conducted on 0.040-in. stock.
[b] 6 B. & S. Nos., hard, 0.070–0.015 mm. grain size at ready-to-finish, respectively.
[c] Refer to 1100°F. anneal (1 hr. at temperature).

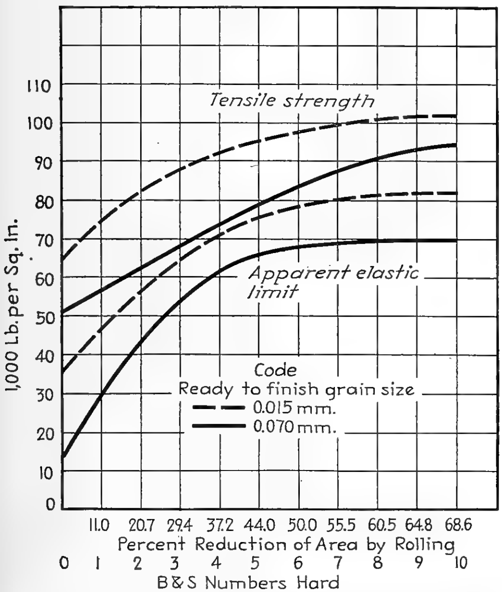


CHART 17.—The effect of cold rolling on the tensile strength and apparent elastic limit of 18 per cent nickel-silver strip, previously annealed to two different grain sizes, 0.015 and 0.070 mm. (66.00 % copper, 18.00 % nickel, balance zinc) (0.040-in.stock).

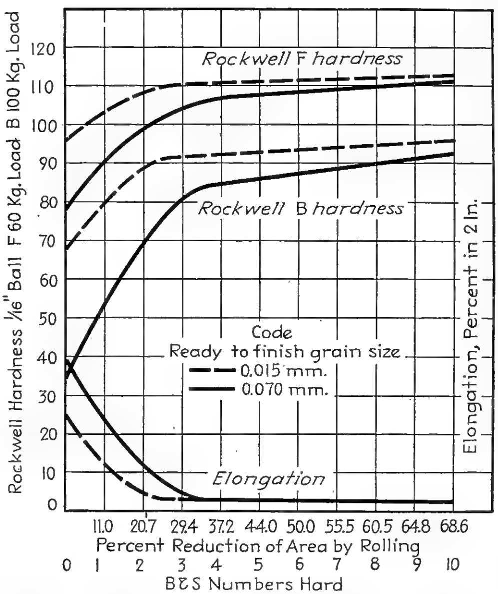


CHART 18.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of 18 per cent nickel-silver strip, previously annealed to two different grain sizes, 0.015 and 0.070 mm. (66.00 % copper, 18 % nickel, balance zinc) (0.040-in. stock).

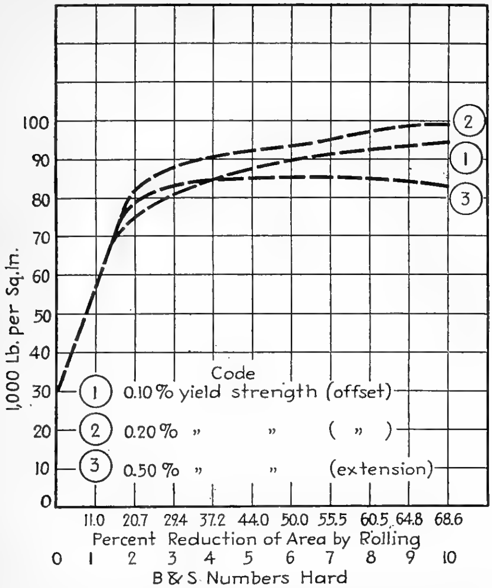


Chart 19.—The effect of cold rolling on the yield strengths of 18 per cent nickel-silver strip, previously annealed to a grain size of 0.015 mm. (66.00 % copper, 18.00 % nickel, balance zinc) (0.040-in. stock).

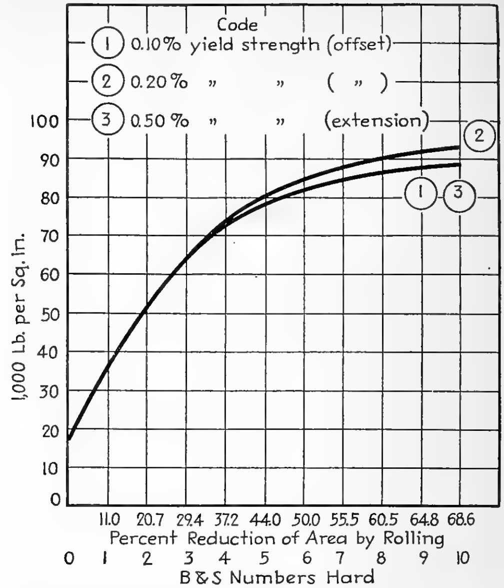


Chart 20.—The effect of cold rolling on the yield strengths of 18 per cent nickel-silver strip, previously annealed to a grain size of 0.070 mm. (66.00 % copper, 18.00 % nickel, balance zinc) (0.040-in. stock).

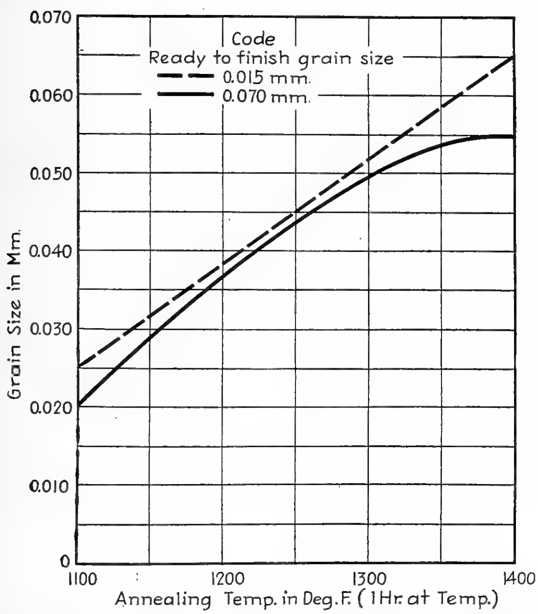


Chart 21.—The effect of annealing on the grain-growing characteristics of 18 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (66.00 % copper, 18.00 % nickel, balance zinc) (0.040-in. stock).

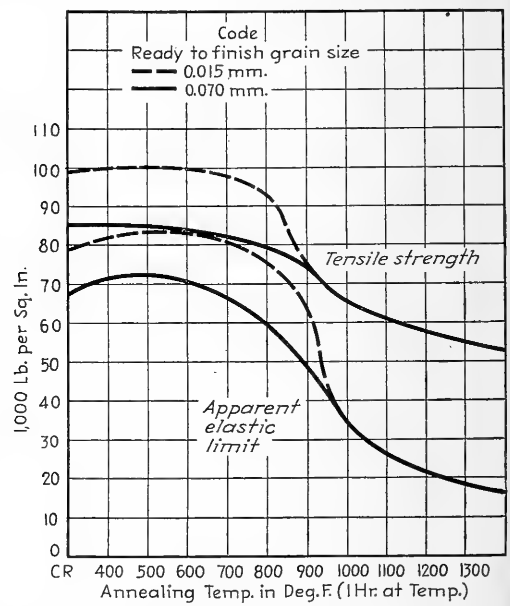


Chart 22.—The effect of annealing on the tensile strength and apparent elastic limit of 18 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (66.00 % copper, 18.00 % nickel, balance zinc) (0.040-in. stock).

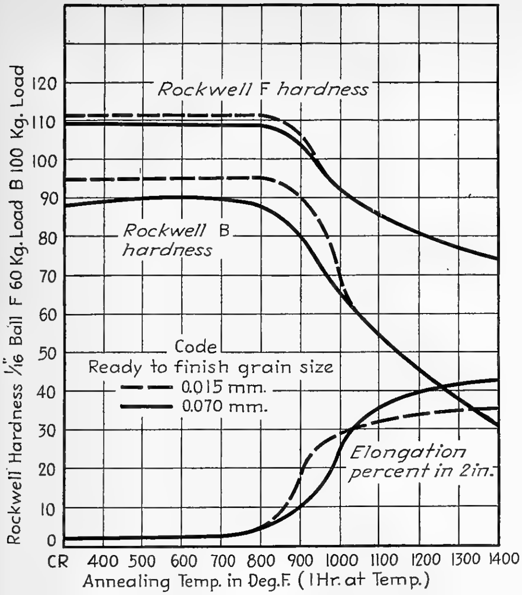


CHART 23.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of 18 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (66.00 % copper, 18.00 % nickel, balance zinc) (0.040-in. stock).

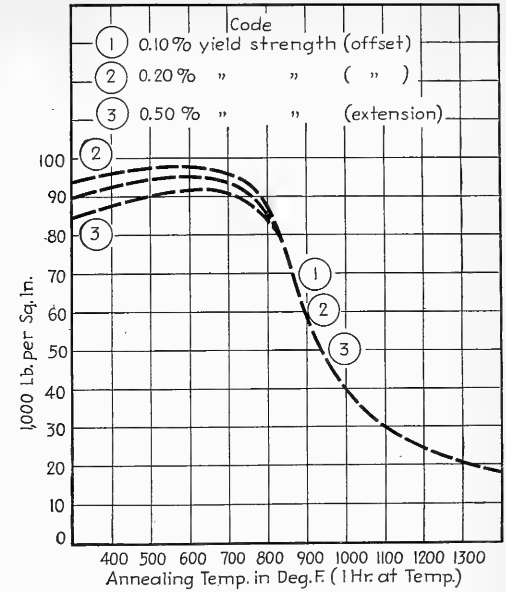


CHART 24.—The effect of annealing on the yield strength of 18 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (66.00 % copper, 18.00 % nickel, balance zinc) (0.040-in. stock).

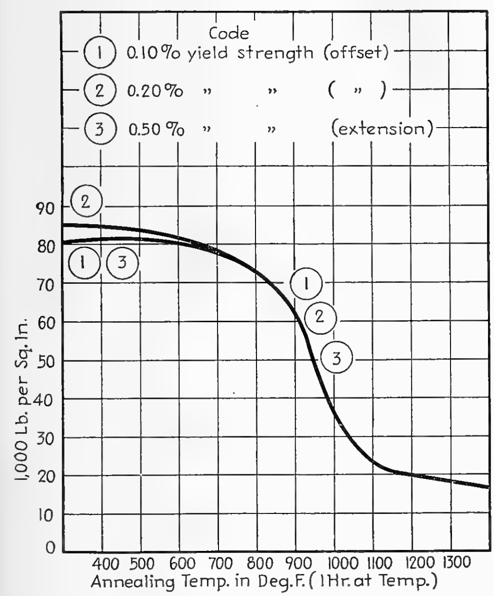


CHART 25.—The effect of annealing on the yield strength of 18 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.070 mm. (66.00 % copper, 18.00 % nickel, balance zinc) (0.040-in. stock).

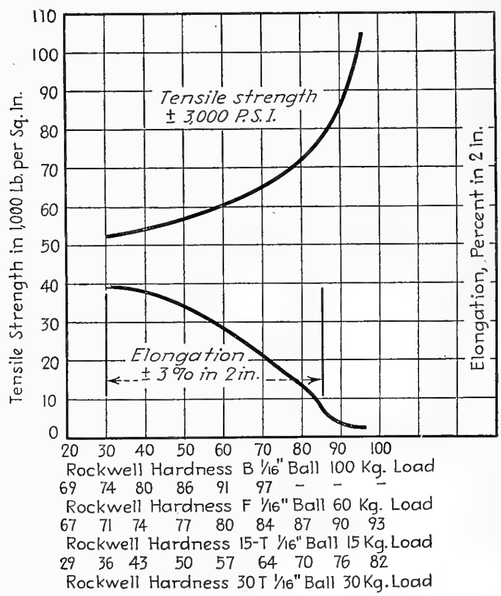


CHART 26.—This chart can be employed to determine the approximate tensile strength and percentage elongation of 18 per cent nickel-silver strip (66.00 % copper, 18.00 % silver, balance zinc) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

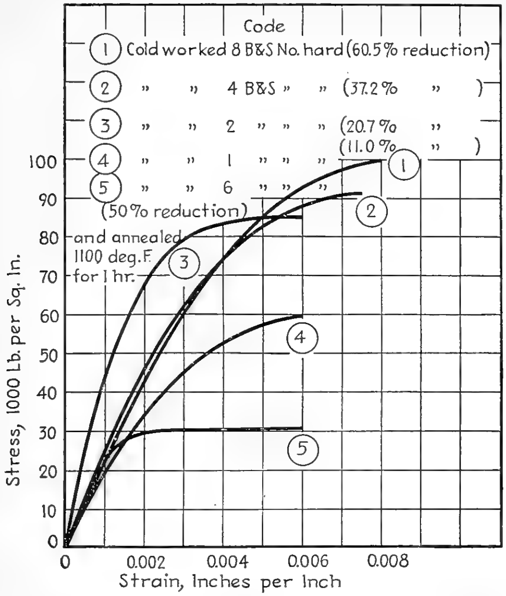


Chart 27.—The effect of cold rolling on the stress-strain characteristics of 18 per cent deep-drawing nickel-silver strip (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (66.00 % copper, 18.00 % nickel, balance zinc.)

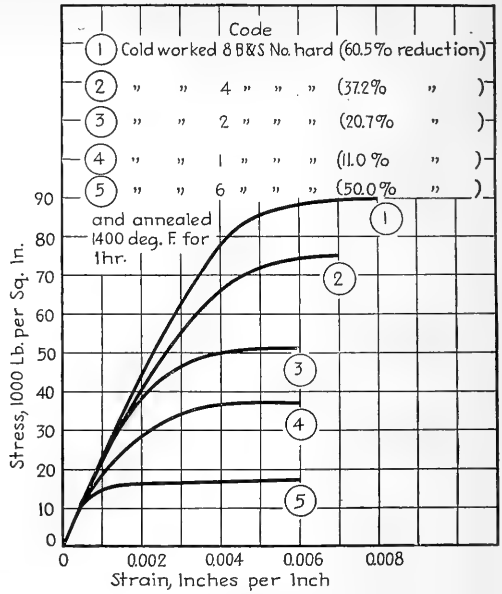


Chart 28.—The effect of cold rolling on the stress-strain characteristics of 18 per cent deep-drawing nickel-silver strip (0.040 in. thick) having a ready-to-finish grain size of 0.070 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (66.00 % copper, 18.00 % nickel, balance zinc.)

TABLE 5
18 PER CENT NICKEL SILVER (SPRING STOCK)

General Data—Strip[a]

Copper, 56.56 %; nickel, 17.77 %; zinc, balance

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	100–125	49–61
Elongation, % in 2 in.	2–3	47–48
Apparent elastic limit, p.s.i. (000 omitted)	78–99	17
Yield strength, 0.5 % extension, p.s.i. (000 omitted)	91–92	20–22
Yield strength, 0.2 % offset, p.s.i. (000 omitted)	101–119	20–22
Yield strength, 0.1 % offset, p.s.i. (000 omitted)	93–109	20–22
Rockwell hardness F, 1⁄16-in. ball, 60-kg. load	112–115	81
Rockwell hardness B, 1⁄16-in. ball, 100-kg. load	95–101	44
Rockwell hardness G, 1⁄16-in. ball, 150-kg. load	72–84	
Rockwell hardness 15-T, 1⁄16-in. ball, 15-kg. load	92–	75
Rockwell hardness 30-T, 1⁄16-in. ball, 30-kg. load	79–	46
Young's modulus of elasticity, p.s.i.	18,000,000	
Endurance limit (at 10^8 reversals):(1,6)		
Soft, p.s.i. (000 omitted)	17.5	
4 B. & S. Nos., hard, p.s.i. (000 omitted)	21.5	
10 B. & S. Nos., hard, p.s.i. (000 omitted)	21.5	
Melting point, °F.	1930	
Density, lb. per cu. in.	0.314	
Coefficient of expansion, per °C. from 25–300°C.	0.0000150	
Electrical conductivity, % I.A.C.S., 68°F.	5.56	
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F	18	
Specific gravity	8.70	

[a] All tests conducted on 0.040-in. stock.

[b] 6 B. & S. Nos., hard, 0.080–0.015 mm. grain size at ready-to-finish, respectively.

[c] Refer to 1400°F. anneal (1 hr. at temperature).

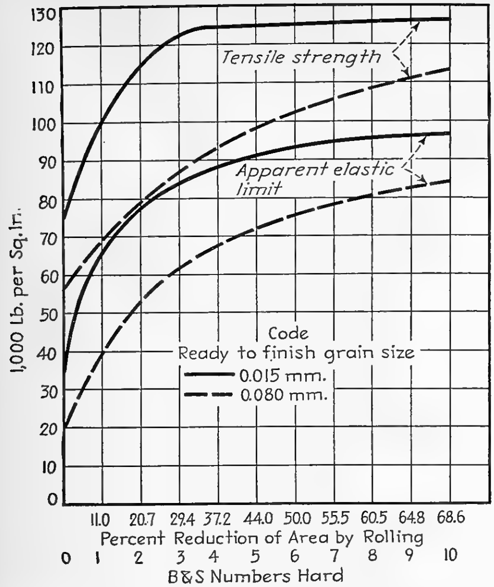


Chart 29.—The effect of cold rolling on the tensile strength and apparent elastic limit of 18 per cent nickel-silver (spring) strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. 56.56 % copper, 17.77 % nickel, balance zinc) (0.040-in. stock).

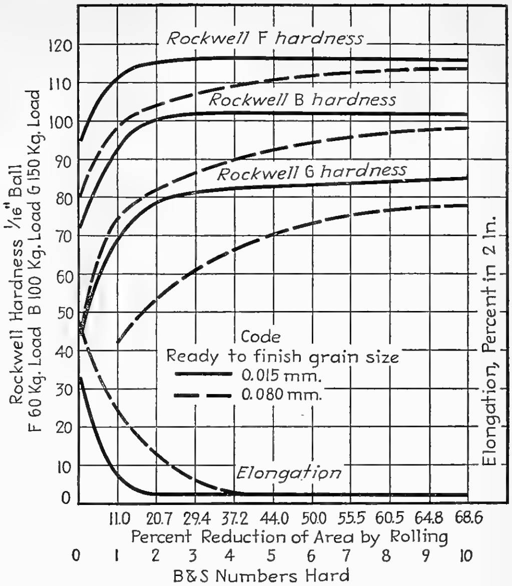


Chart 30.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of 18 per cent nickel-silver (spring) strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (56.56 % copper, 17.77 % nickel, balance zinc) (0.040-in. stock).

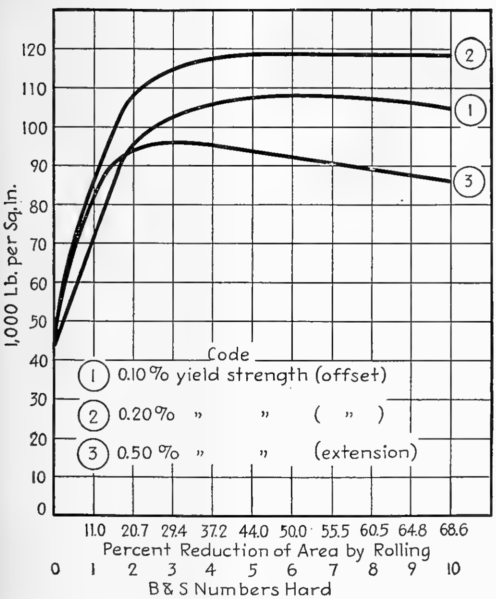


Chart 31.—The effect of cold rolling on the yield strengths of 18 per cent nickel-silver (spring) strip, previously annealed to a grain size of 0.015 mm. (56.56 % copper, 17.77 % nickel, balance zinc) (0.040-in. stock).

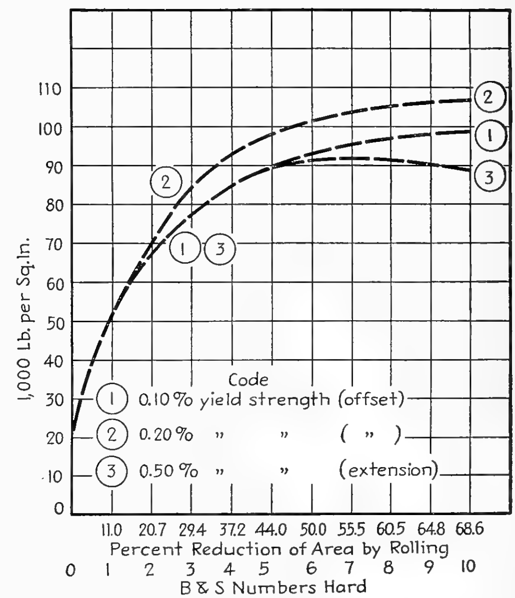


Chart 32.—The effect of cold rolling on the yield strengths of 18 per cent nickel-silver (spring) strip, previously annealed to a grain size of 0.080 mm. (56.56 % copper, 17.77 % nickel, balance zinc) (0.040-in. stock).

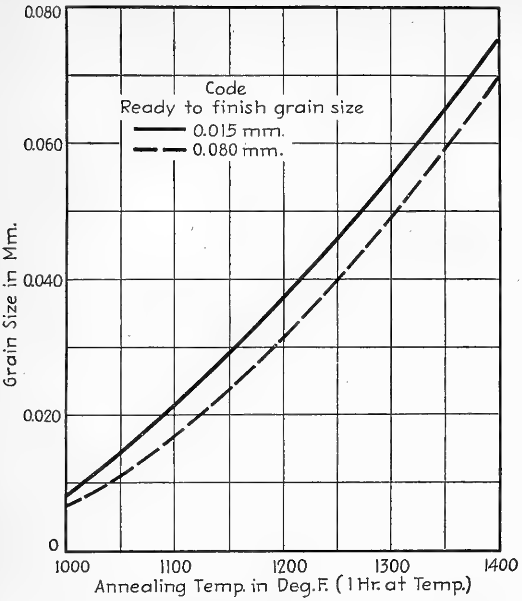


CHART 33.—The effect of annealing on the grain-growing characteristics of 18 per cent nickel-silver (spring) strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (56.56 % copper, 17.77 % nickel, balance zinc) (0.040-in. stock).

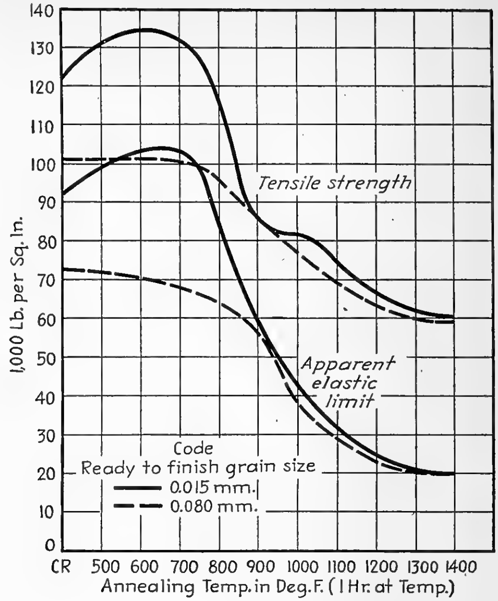


CHART 34.—The effect of annealing on the tensile strength and apparent elastic limit of 18 per cent nickel-silver (spring) strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (56.56 % copper, 17.77 % nickel, balance zinc) (0.040-in. stock).

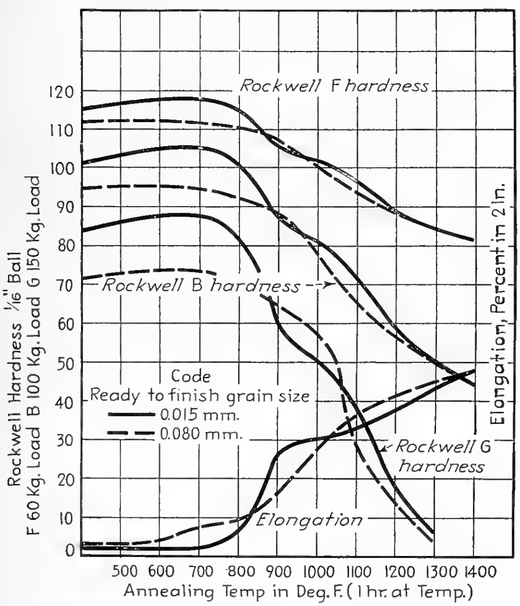


CHART 35.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of 18 per cent nickel-silver (spring) strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (56.56 % copper, 17.77 % nickel, balance zinc) (0.040-in. stock).

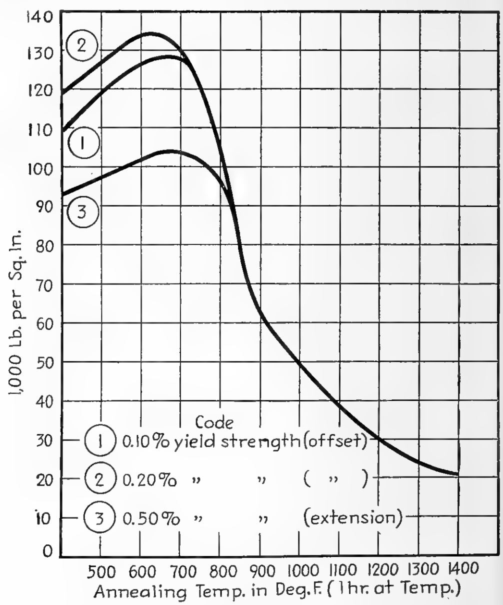


CHART 36.—The effect of annealing on the yield strength of 18 per cent nickel-silver (spring) strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (56.56 % copper, 17.77 % nickel, balance zinc) (0.040-in. stock).

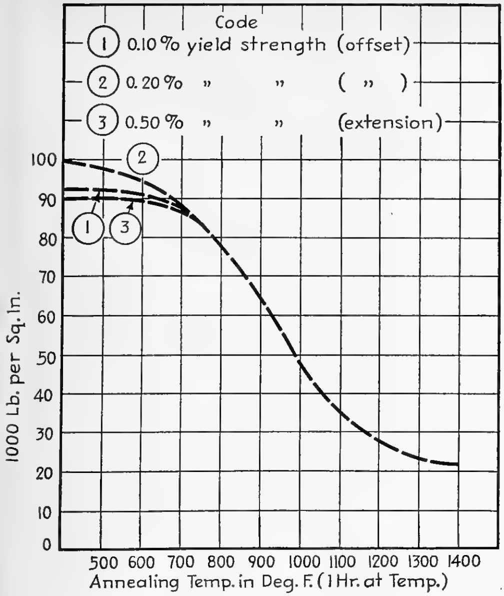


CHART 37.—The effect of annealing on the yield strength of 18 per cent nickel-silver (spring) strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.080 mm. (56.56 % copper, 17.77 % nickel, balance zinc) (0.040-in. stock).

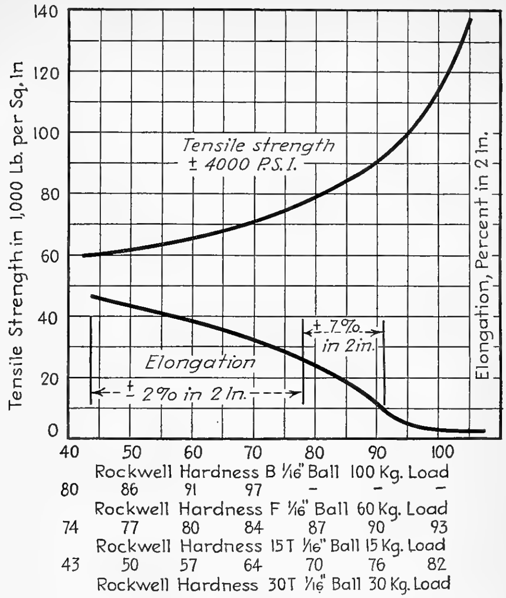


CHART 38.—This chart can be employed to determine the approximate tensile strength and percentage elongation of 18 per cent nickel-silver (spring) strip (56.56 % copper, 17.77 % nickel, balance zinc) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

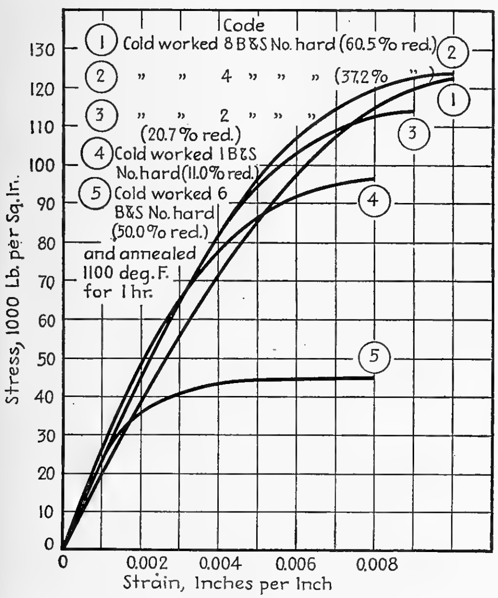


CHART 39.—The effect of cold rolling on the stress-strain characteristics of 18 per cent spring-stock nickel-silver strip (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (56.56 % copper, 17.77 % nickel, balance zinc.)

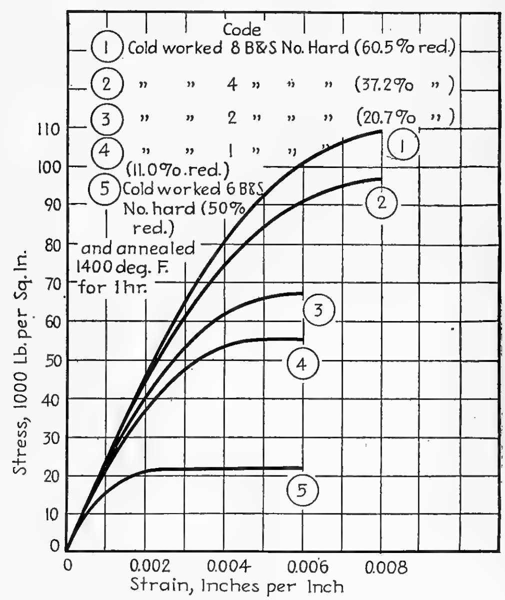


CHART 40.—The effect of cold rolling on the stress-strain characteristics of 18 per cent spring-stock nickel-silver strip (0.040 in. thick) having a ready-to-finish grain size of 0.080 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (56.56 % copper, 17.77 % nickel, balance zinc.)

TABLE 6
18 PER CENT NICKEL SILVER
GENERAL DATA[a]—STRIP

Copper, 62.05%; nickel, 18.40%; zinc, 19.36%; manganese, 0.12%; lead, 0.004%; iron, 0.07%

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	100	61
0.10% proof strength, p.s.i. (000 omitted)	91	
Limit of proportionality, p.s.i. (000 omitted)	49	
Elongation, % in 2 in	4	43
Reduction of area, %	8	
Rockwell hardness B, 1/16-in. ball, 100-kg. load	94	
Rockwell hardness E, 1/8-in. ball, 100-kg. load	112	
Diamond pyramid hardness, 10-kg. load	209	89
Erichsen value, mm		64
Brinell hardness, 10-kg., 1-mm. ball	184	
Shore Scleroscope M. H	58	
S. & S., Shore Scleroscope U. H. & self-recorder	39	
Specific gravity	8.719	8.724
Density, lb. per cu. in.	0.315	
Coefficient of thermal expansion, $\times 10^{-6}$:		
At 0–100°C	14.8	
At 0–200°C	15.4	
At 0–300°C	16.0	
At 0–400°C	16.8	
Thermal conductivity:		
At 70°F., B.t.u. per sq. ft. per ft. per hr. per °F.	13.07	
At 400°F., B.t.u. per sq. ft. per ft. per hr. per °F.	15.73	
Temperature coefficient of thermal conductivity	0.00114	
Specific resistance, microhms-cm.³ at 20°C	27.55	
Melting point, °F.	2010	
Modulus of elasticity, p.s.i.	18,000,000	

[a] Based on data by Cook.(26)
[b] Refers to strip cold-rolled 60% (reduction in thickness) from a ready-to-finish anneal at 1450°F. for 2 hr.
[c] Refers to a 1450°F. anneal for 2 hr.

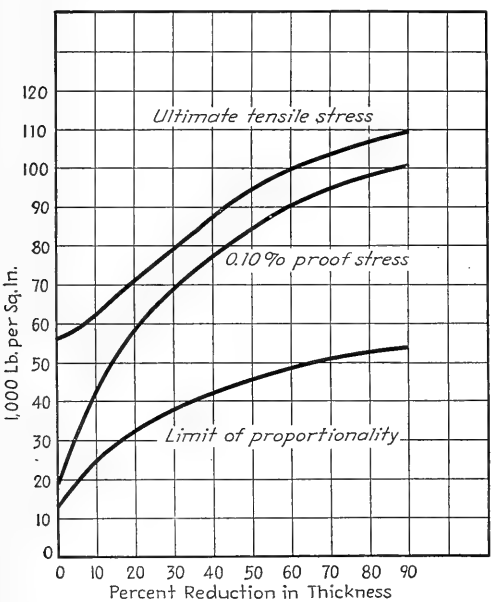


CHART 41.—The effect of cold rolling on the tensile strength, proof strength, and proportional limit of 18 per cent nickel-silver strip (18.40% nickel, 62.05% copper, balance zinc) previously annealed at 1450°F. according to Cook.(26)

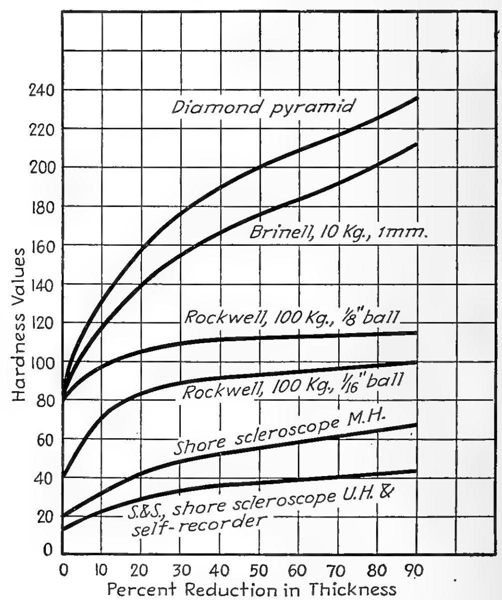


CHART 42.—The effect of cold rolling on the hardness of 18 per cent nickel-silver strip (18.40% nickel, 62.05% copper, balance zinc) previously annealed at 1450°F. according to Cook.(26)

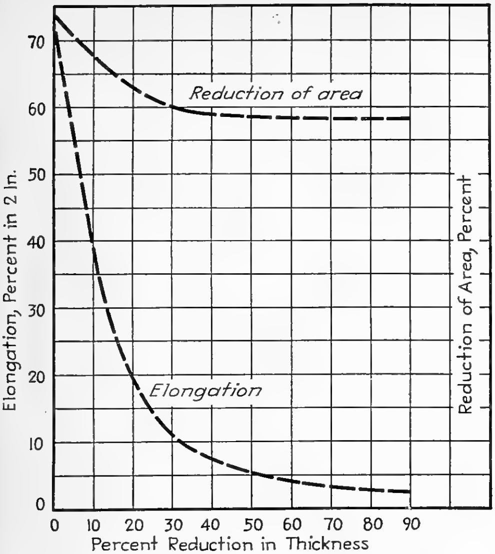


CHART 43.—The effect of cold rolling on the percentage reduction of area and percentage elongation in 2 in. of 18 per cent nickel-silver strip (18.40 % nickel, 62.05 % copper, balance zinc), previously annealed at 1450°F. according to Cook.(26)

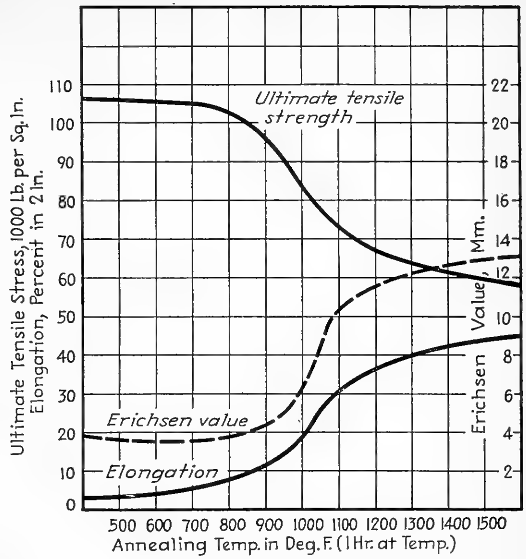


CHART 44.—The effect of annealing on the tensile strength, Erichsen value, and percentage elongation in 2 in. of 18 per cent nickel-silver strip (18.40 % nickel, 62.05 % copper, balance zinc), previously cold-rolled 60 per cent (reduction of area) according to Cook.(26)

TABLE 7
15 PER CENT NICKEL SILVER
GENERAL DATA—STRIP[a]

Copper, 66.18 %; nickel, 15.02 %; zinc, balance

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	85–96	54–55
Elongation, % in 2 in	2	40–45
Apparent elastic limit, p.s.i. (000 omitted)	66–75	15–16
Yield strength, 0.5 % extension, p.s.i. (000 omitted)	79–81	17–19
Yield strength, 0.2 % offset, p.s.i. (000 omitted)	81–90	17–19
Yield strength, 0.1 % offset, p.s.i. (000 omitted)	79–85	17–19
Rockwell hardness F, 1/16-in. ball, 60-kg. load	108–111	70–71
Rockwell hardness B, 1/16-in. ball, 100-kg. load	88–91	24–25
Rockwell hardness G, 1/16-in. ball, 150-kg. load	63–68	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	89–90	69–69
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	75–77	32–33
Young's modulus of elasticity, p.s.i	18,000,000	
Melting point, °F	1965	
Density, lb. per cu. in	0.314	
Coefficient of expansion, per °C. from 25–300°C	0.0000150	
Electrical conductivity, % I.A.C.S., 20°C	6.3	
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F	20	
Specific gravity	8.70	

[a] All tests conducted on 0.040-in. stock.

[b] 6 B. & S. Nos., hard, 0.100–0.015 mm. grain size at ready-to-finish, respectively.

[c] Same as footnote b after 1400°F. anneal (1 hr.).

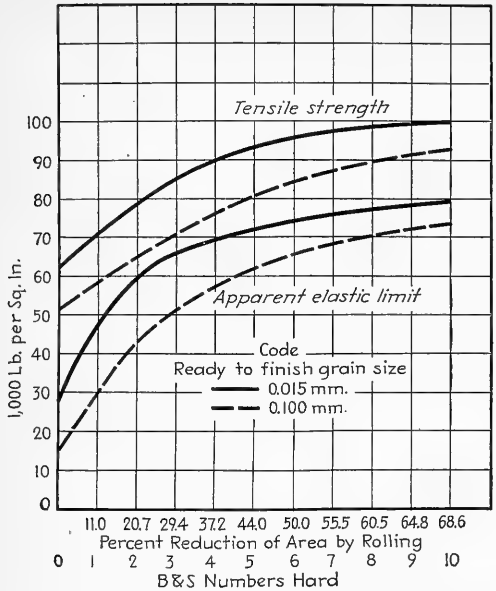


CHART 45.—The effect of cold rolling on the tensile strength and apparent elastic limit of 15 per cent nickel-silver strip, previously annealed to two different grain sizes, 0.015 and 0.100 mm. (66.18 % copper, 15.02 % nickel, balance zinc) (0.040-in. stock).

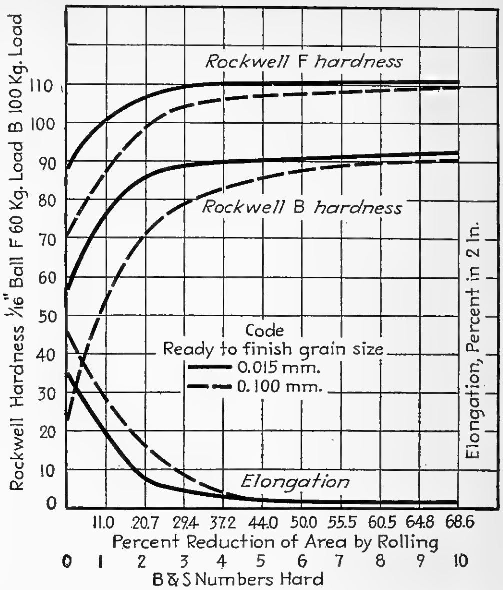


CHART 46.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of 15 per cent nickel-silver strip, previously annealed to two different grain sizes, 0.015 and 0.100 mm. (66.18 % copper, 15.02 % nickel, balance zinc) (0.040-in. stock).

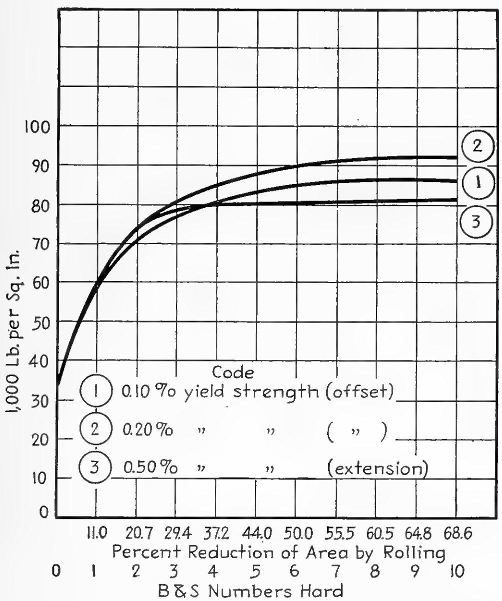


CHART 47.—The effect of cold rolling on the yield strengths of 15 per cent nickel-silver strip, previously annealed to a grain size of 0.015 mm. (66.18 % copper, 15.02 % nickel, balance zinc) (0.040-in. stock).

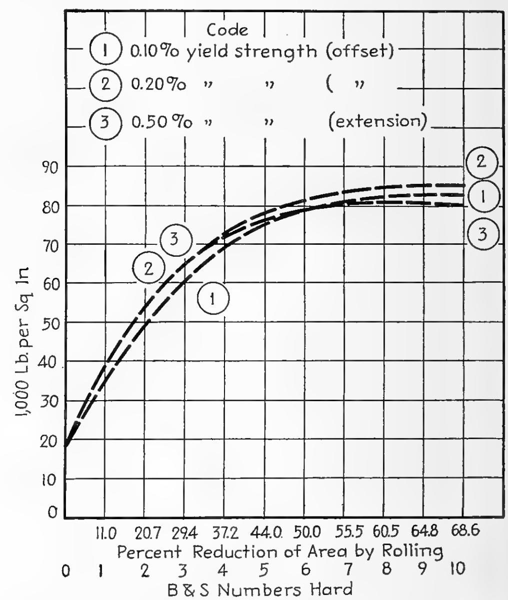


CHART 48.—The effect of cold rolling on the yield strengths of 15 per cent nickel-silver strip, previously annealed to a grain size of 0.100 mm. (66.18 % copper, 15.02 % nickel, balance zinc) (0.040-in. stock).

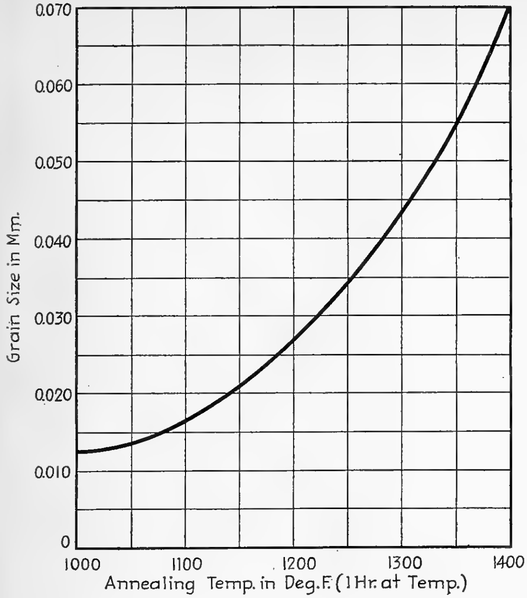


CHART 49.—The effect of annealing on the grain-growing characteristics of 15 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.100 mm. (66.18 % copper, 15.02 % nickel, balance zinc) (0.040-in. stock).

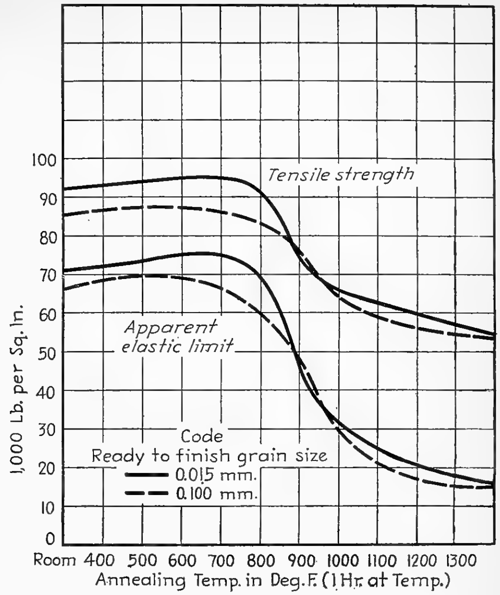


CHART 50.—The effect of annealing on the tensile strength and apparent elastic limit of 15 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.100 mm. (66.18 % copper, 15.02 % nickel, balance zinc) (0.040-in. stock).

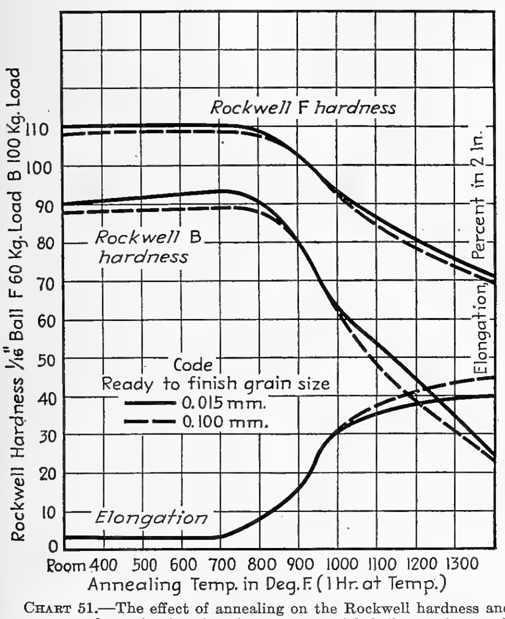


CHART 51.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of 15 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.100 mm. (66.18 % copper, 15.02 % nickel, balance zinc) (0.040-in. stock).

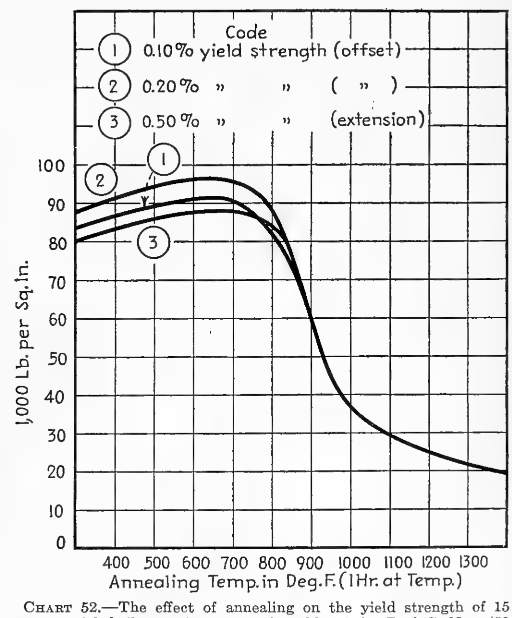


CHART 52.—The effect of annealing on the yield strength of 15 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (66.18 % copper, 15.02 % nickel, balance zinc) (0.040-in. stock).

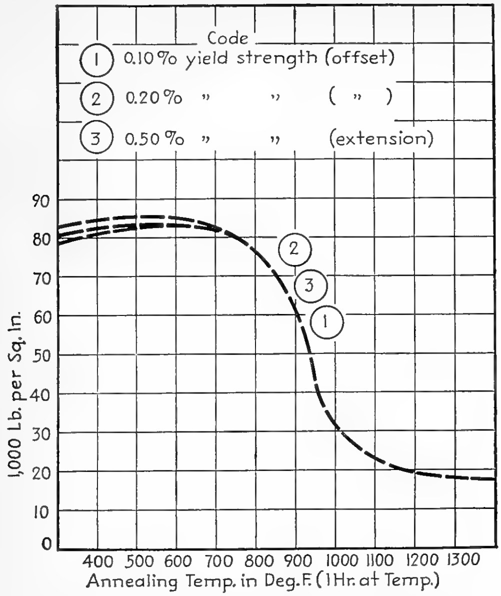


Chart 53.—The effect of annealing on the yield strength of 15 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.100 mm. (66.18 % copper, 15.02 % nickel, balance zinc) (0.040-in. stock).

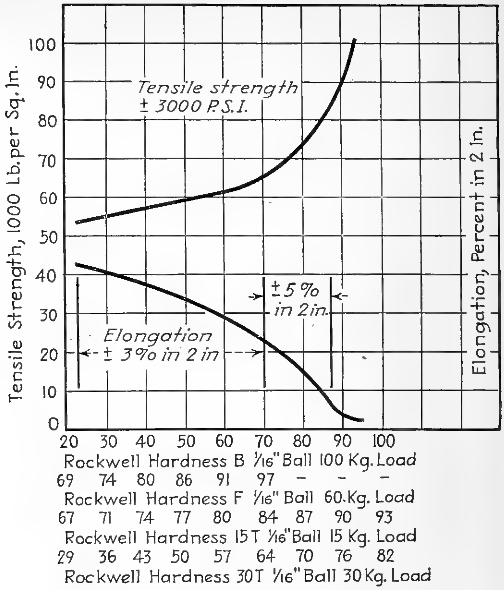


Chart 54.—This chart can be employed to determine the approximate tensile strength and percentage elongation of 15 per cent nickel-silver strip (66.18 % copper, 15.02 % nickel, balance zinc) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

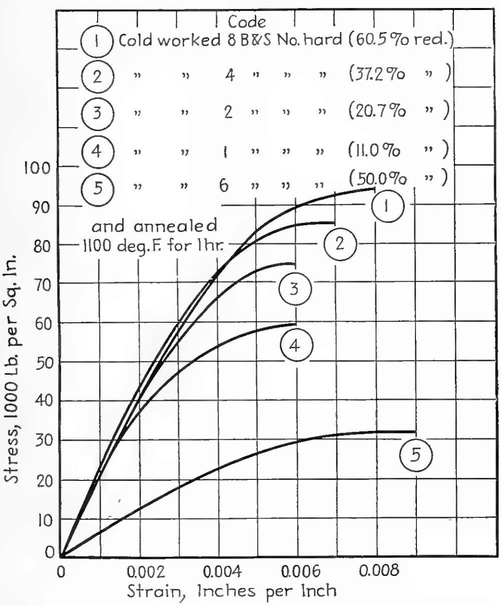


Chart 55.—The effect of cold rolling on the stress-strain characteristics of 15 per cent nickel-silver strip (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (66.18 % copper, 15.05 % nickel, balance zinc.)

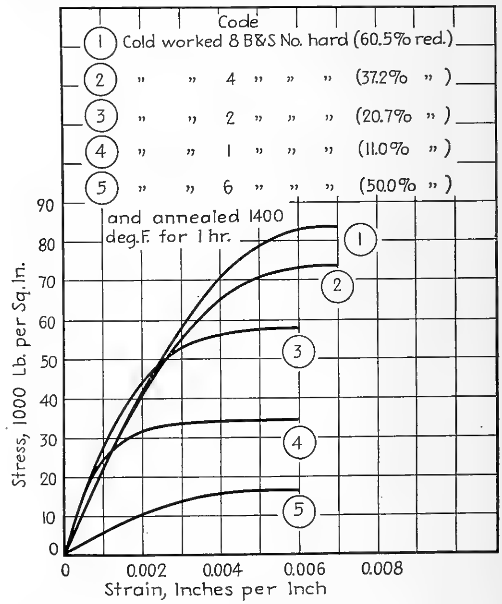


Chart 56.—The effect of cold rolling on the stress-strain characteristics of 15 per cent nickel-silver strip (0.040 in. thick) having a ready-to-finish grain size of 0.100 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (66.18 % copper, 15.05 % nickel, balance zinc.)

TABLE 8

12 PER CENT NICKEL SILVER

General Data—Strip[a]

Copper, 66.24%; nickel, 11.57%; zinc, balance

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	88–102	52–54
Elongation, % in 2 in	3	43–49
Apparent elastic limit, p.s.i. (000 omitted)	69–82	16
Yield strength, 0.5% extension, p.s.i. (000 omitted)	77–82	17–18
Yield strength, 0.2% offset, p.s.i. (000 omitted)	84–96	17–18
Yield strength, 0.1% offset, p.s.i. (000 omitted)	80–90	17–18
Rockwell hardness F, 1/16-in. ball, 60-kg. load	110–113	69
Rockwell hardness B, 1/16-in. ball, 100-kg. load	90–94	22
Rockwell hardness G, 1/16-in. ball, 150-kg. load	64–71	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	90–91	68
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	76–78	31
Young's modulus of elasticity, p.s.i	18,000,000	
Melting point, °F	1900	
Density, lb. per cu. in	0.314	
Coefficient of expansion, per °C. from 25–300°C	0.0000150	
Electrical conductivity, % I.A.C.S., 68°F	7.3	
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F	23	
Specific gravity	8.70	

[a] All tests conducted on 0.040-in. stock.

[b] 6 B. & S. Nos., hard, 0.080–0.015 mm. grain size at ready-to-finish, respectively.

[c] Same as footnote b after 1400°F. anneal for 1 hr.

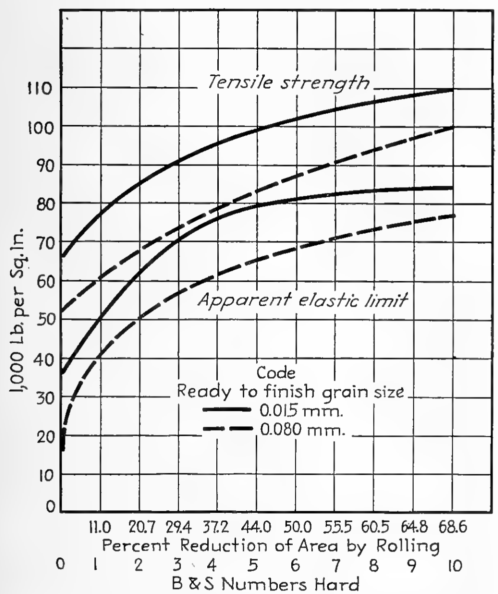


Chart 57.—The effect of cold rolling on the tensile strength and apparent elastic limit of 12 per cent nickel-silver strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (66.24% copper, 11.57% nickel, balance zinc) (0.040-in. stock).

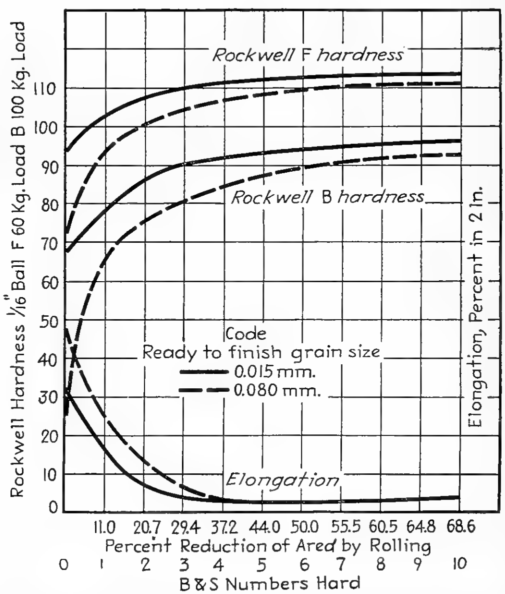


Chart 58.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of 12 per cent nickel-silver strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (66.24% copper, 11.57% nickel, balance zinc) (0.040-in. stock).

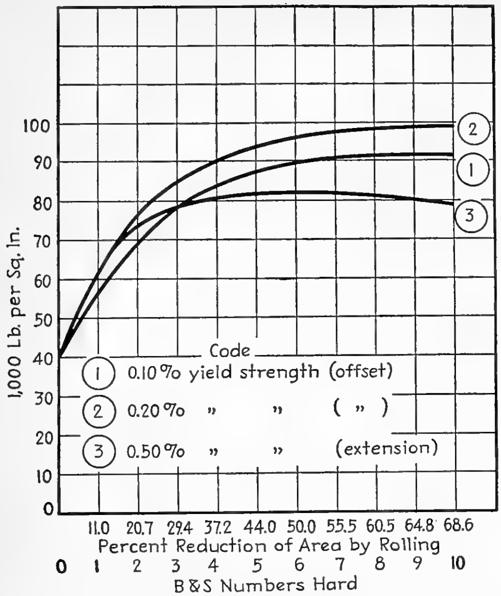


CHART 59.—The effect of cold rolling on the yield strengths of 12 per cent nickel-silver strip, previously annealed to a grain size of 0.015 mm. (66.24 % copper, 11.57 % nickel, balance zinc) (0.040-in. stock).

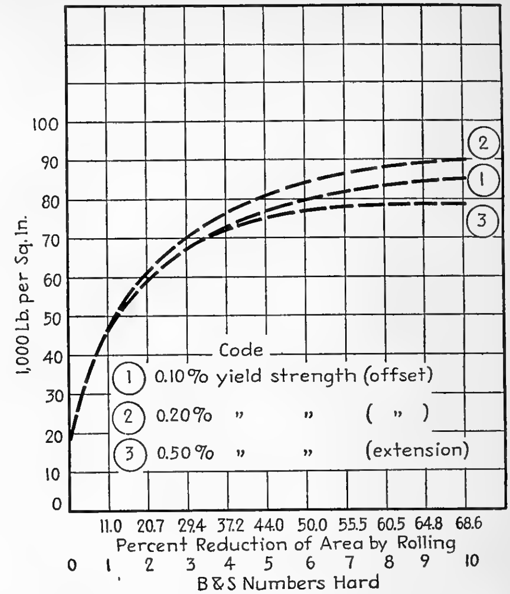


CHART 60.—The effect of cold rolling on the yield strengths of 12 per cent nickel-silver strip, previously annealed to a grain size of 0.080 mm. (66.24 % copper, 11.57 % nickel, balance zinc) (0.040-in. stock).

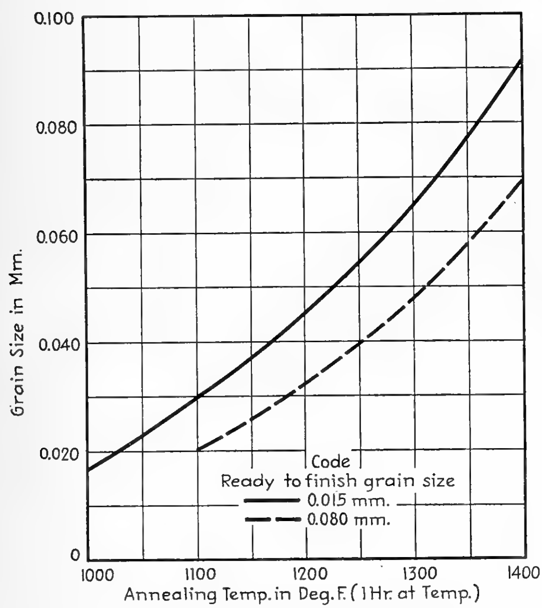


CHART 61.—The effect of annealing on the grain-growing characteristics of 12 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (66.24 % copper, 11.57 % nickel, balance zinc) (0.040-in. stock).

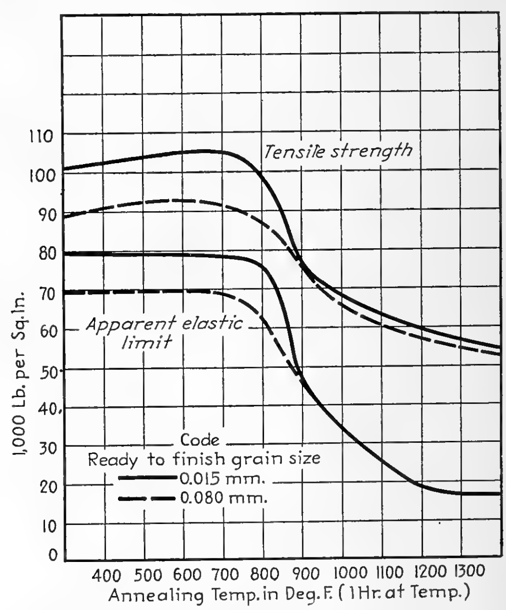


CHART 62.—The effect of annealing on the tensile strength and apparent elastic limit of 12 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (66.24 % copper, 11.57 % nickel, balance zinc) (0.040-in. stock).

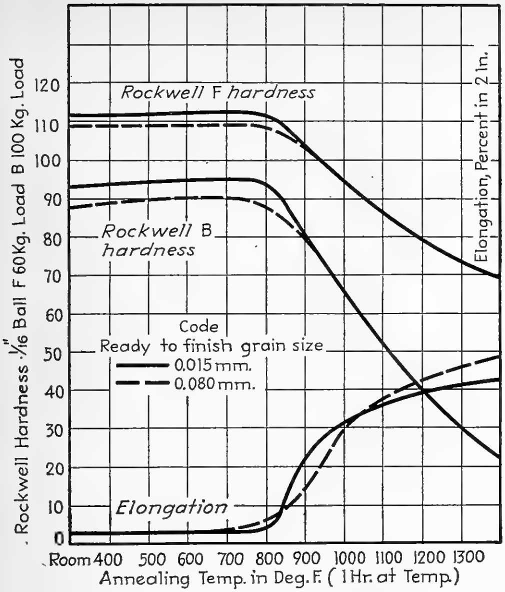


CHART 63.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of 12 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (66.24 % copper, 11.57 % nickel, balance zinc) (0.040-in. stock).

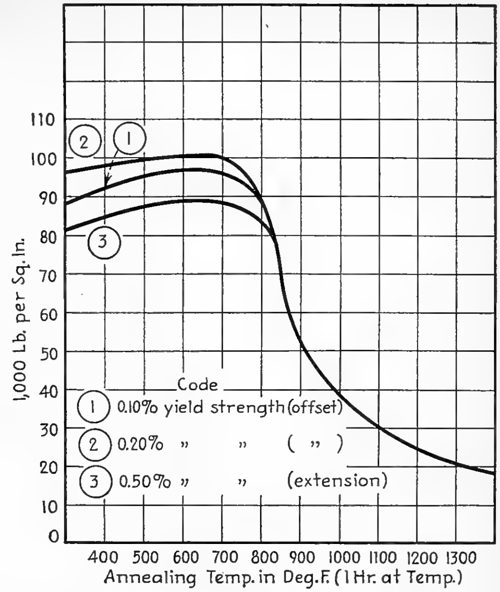


CHART 64.—The effect of annealing on the yield strength of 12 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (66.24 % copper, 11.57 % nickel, balance zinc) (0.040-in. stock).

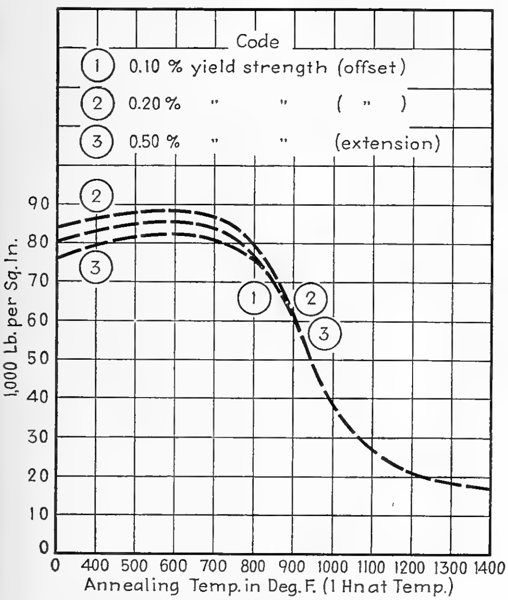


CHART 65.—The effect of annealing on the yield strength of 12 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.080 mm. (66.24 % copper, 11.57 % nickel, balance zinc) (0.040-in. stock).

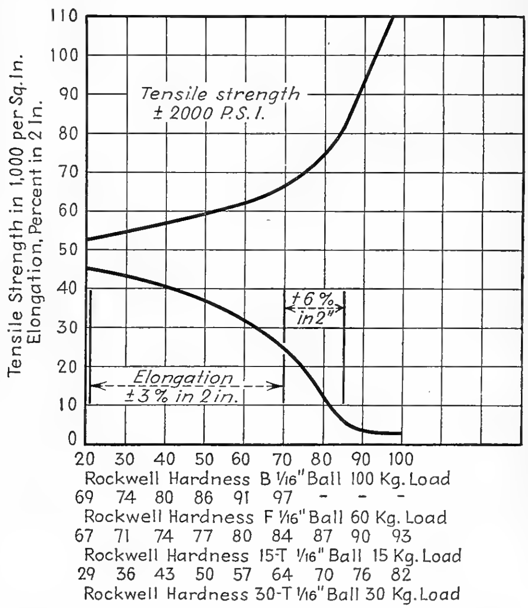


CHART 66.—This chart can be employed to determine the approximate tensile strength and percentage elongation of 12 per cent nickel-silver strip (66.24 % copper, 11.57 % nickel, balance zinc) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

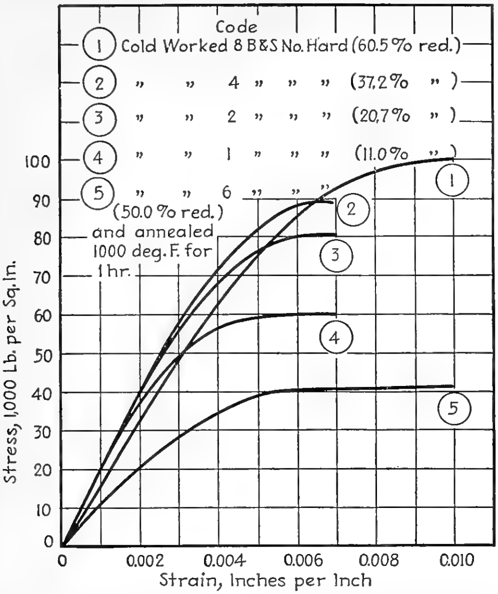


CHART 67.—The effect of cold rolling on the stress-strain characteristics of 12 per cent nickel-silver strip (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used (66.24 % copper, 11.57 % nickel, balance zinc).

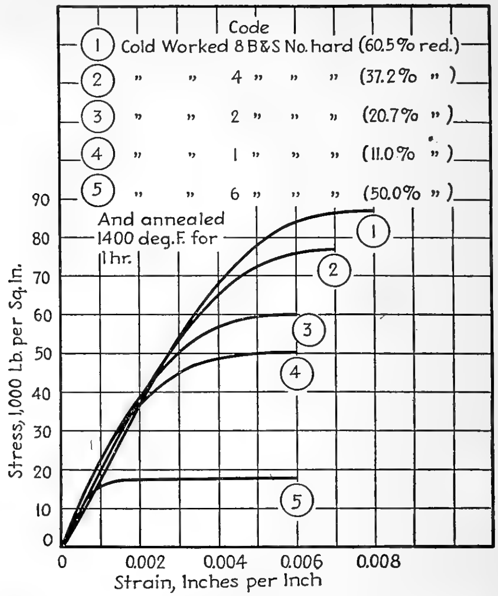


CHART 68.—The effect of cold rolling on the stress-strain characteristics of 12 per cent nickel-silver strip (0.040 in. thick) having a ready-to-finish grain size of 0.080 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used (66.24 % copper, 11.57 % nickel, balance zinc).

TABLE 9
10 PER CENT NICKEL SILVER
GENERAL DATA—STRIP[a]

Copper, 66.02 %; nickel, 10.73 %; manganese, 0.15 %; zinc, balance

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	87–103	50
Elongation, % in 2 in.	2	51–42
Apparent elastic limit, p.s.i. (000 omitted)	71–81	13
Yield strength, 0.5 % extension, p.s.i. (000 omitted)	81–82	15–16
Yield strength, 0.2 % offset, p.s.i. (000 omitted)	84–98	15–16
Yield strength, 0.1 % offset, p.s.i. (000 omitted)	81–92	15–16
Rockwell hardness F, 1/16-in. ball, 60-kg. load	108–112	68–69
Rockwell hardness B, 1/16-in. ball, 100-kg. load	88–96	21–23
Rockwell hardness G, 1/16-in. ball, 150-kg. load	63–76	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	89–92	68
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	75–80	30–31
Young's modulus of elasticity, p.s.i.	17,500,000	
Melting point, °F.	1850	
Density, lb. per cu. in.	0.313	
Coefficient of expansion, per °C. from 25–300°C.	0.0000150	
Electrical conductivity, % I.A.C.S., 68°F.	8.27	
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	26.6	
Specific gravity	8.67	

[a] All tests conducted on 0.040-in. stock.

[b] 6 B. & S. Nos., hard, 0.080–0.015 mm. grain size at ready-to-finish, respectively.

[c] Refer to 1300°F. anneal (1 hr. at temperature).

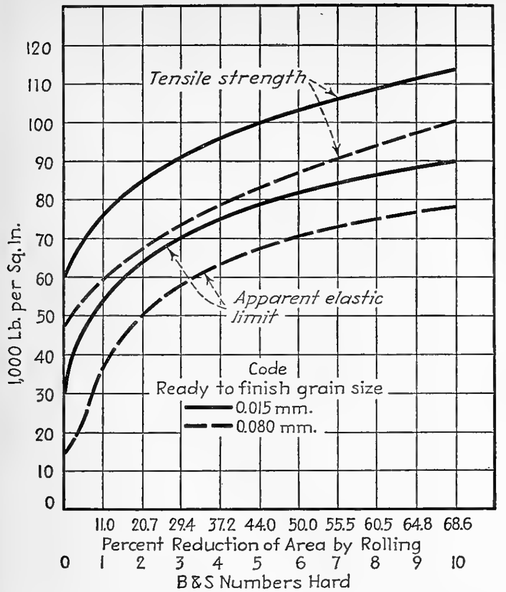


CHART 69.—The effect of cold rolling on the tensile strength and apparent elastic limit of 10 per cent nickel-silver strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (66.02 % copper, 10.73 % nickel, balance zinc) (0.040-in. stock).

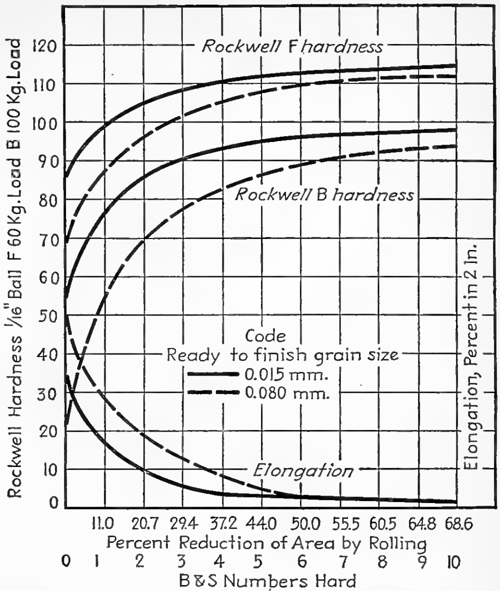


CHART 70.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of 10 per cent nickel-silver strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. 66.02 % copper, 10.73 % nickel, balance zinc) (0.040-in. stock).

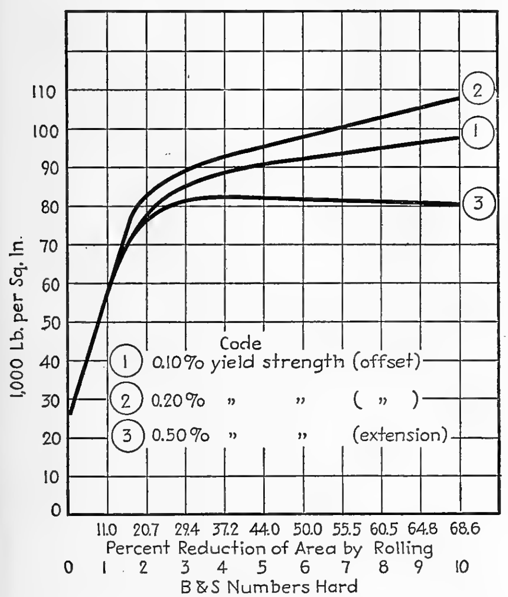


CHART 71.—The effect of cold rolling on the yield strengths of 10 per cent nickel-silver strip, previously annealed to a grain size of 0.015 mm. (66.02 % copper, 10.73 % nickel, balance zinc) (0.040-in. stock).

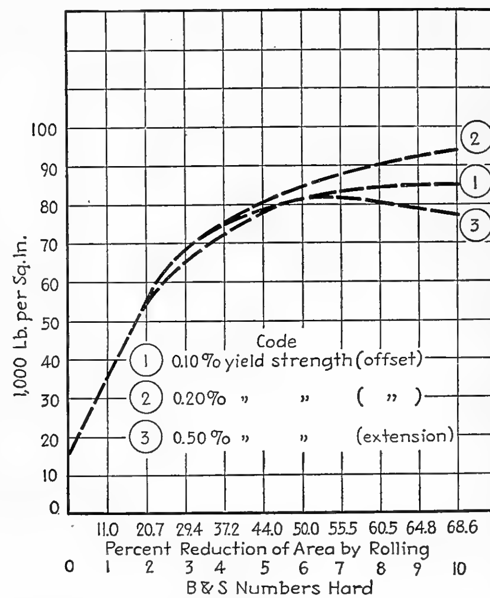


CHART 72.—The effect of cold rolling on the yield strengths of 10 per cent nickel-silver strip, previously annealed to a grain size of 0.080 mm. (66.02 % copper, 10.73 % nickel, balance zinc) (0.040-in. stock).

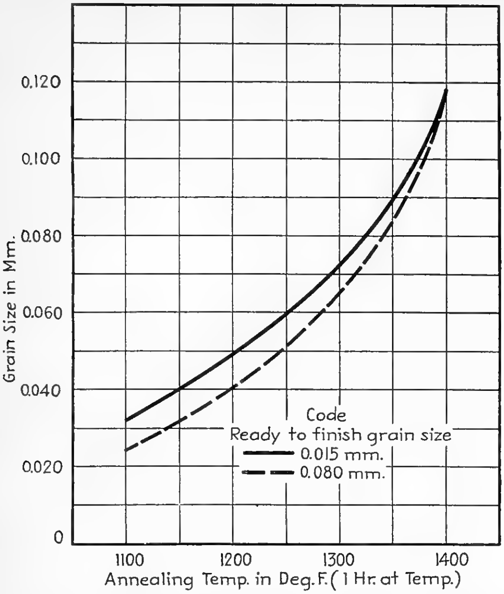


CHART 73.—The effect of annealing on the grain-growing characteristics of 10 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (66.02 % copper, 10.73 % nickel, balance zinc) (0.040-in. stock).

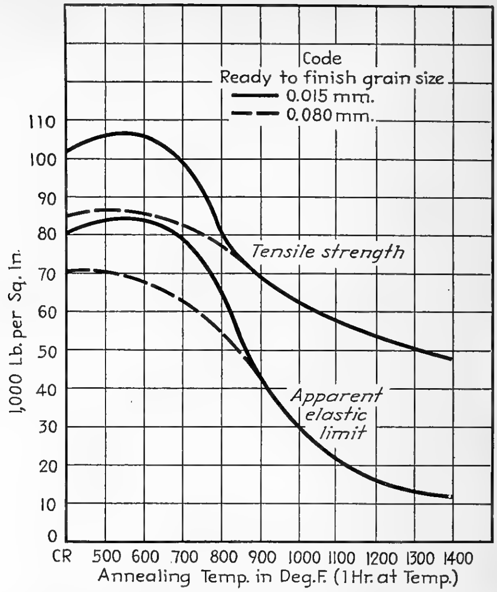


CHART 74.—The effect of annealing on the tensile strength and apparent elastic limit of 10 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (66.02 % copper, 10.73 % nickel, balance zinc) (0.040-in. stock).

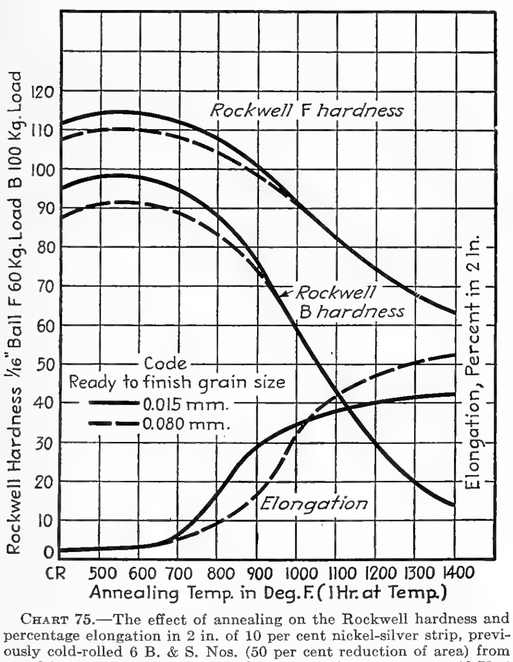


CHART 75.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of 10 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (66.02 % copper, 10.73 % nickel, balance zinc) (0.040-in. stock).

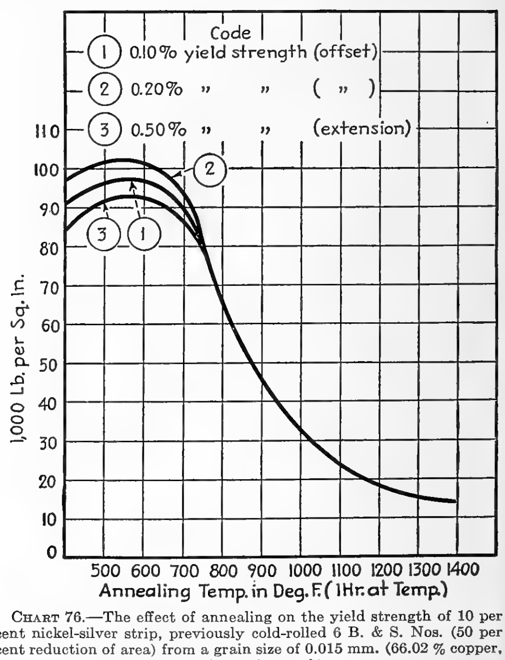


CHART 76.—The effect of annealing on the yield strength of 10 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (66.02 % copper, 10.73 % nickel, balance zinc) (0.040-in. stock).

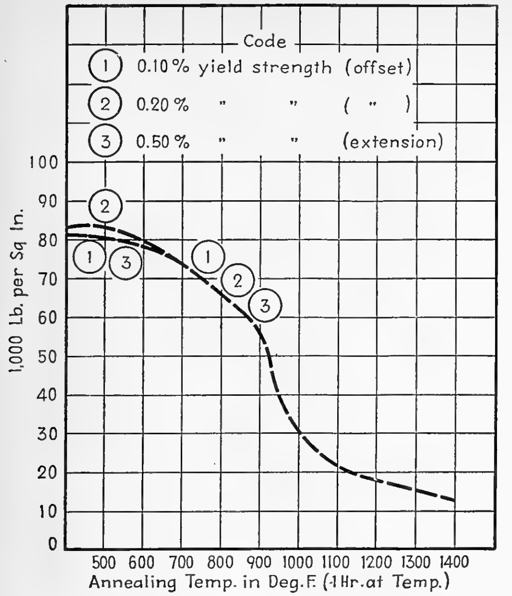


CHART 77.—The effect of annealing on the yield strength of 10 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.080 mm. (66.02 % copper, 10.73 % nickel, balance zinc) (0.040-in. stock).

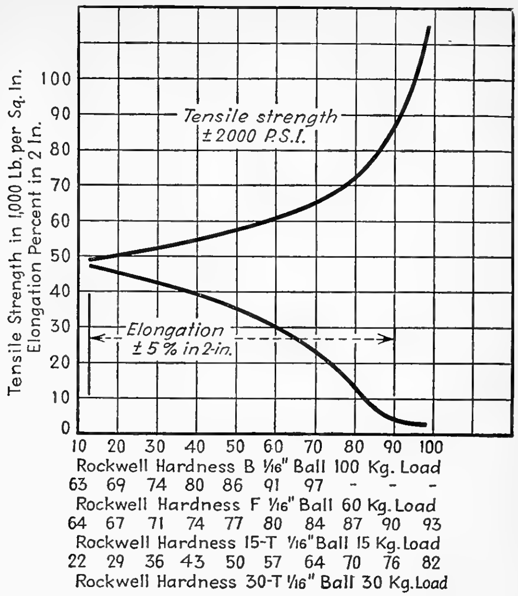


CHART 78.—This chart can be employed to determine the approximate tensile strength and percentage elongation of 10 per cent nickel-silver strip (66.02 % copper, 10.73 % nickel, balance zinc) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

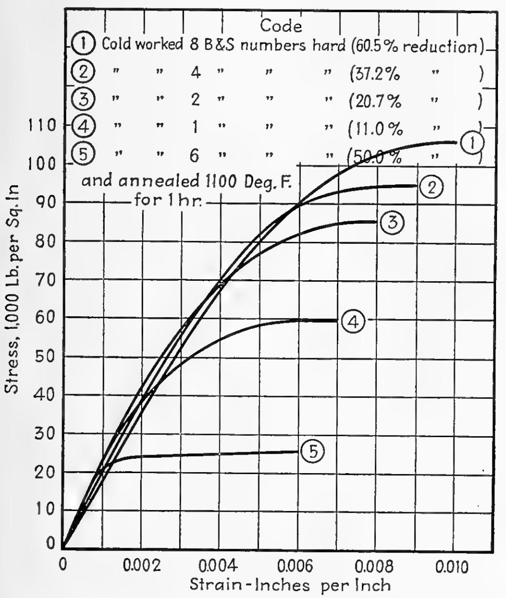


CHART 79.—The effect of cold rolling on the stress-strain characteristics of 10 per cent nickel-silver strip (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (66.02 % copper, 10.73 % nickel, balance zinc.)

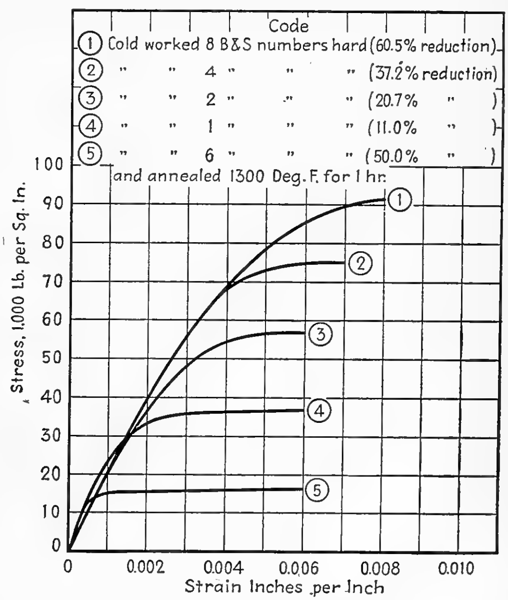


CHART 80.—The effect of cold rolling on the stress-strain characteristics of 10 per cent nickel-silver strip (0.040 in. thick) having a ready-to-finish grain size of 0.080 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (66.02 % copper, 10.73 % nickel, balance zinc.)

TABLE 10

10 PER CENT NICKEL SILVER

General Data[a]—Strip

Copper, 62.62%; nickel, 10.05%; zinc, 27.14%; manganese, 0.13%; lead, 0.005%; iron, 0.04%

Property	Hard[b]	Soft[c]
Tensile, strength, p.s.i. (000 omitted)	101	52
0.10% proof strength, p.s.i. (000 omitted)	86	
Limit of proportionality, p.s.i. (000 omitted)	47	
Elongation, p.s.i. (000 omitted)	5	56
Reduction of area, % in 2 in	52.5	
Rockwell hardness B, 1/16-in. ball, 100-kg. load	95	
Rockwell hardness E, 1/8-in. ball, 100-kg. load	114	
Diamond pyramid hardness, 10-kg. load	207	72
Erichsen value, mm	.....	139.5
Brinell hardness, 10 kg., 1-mm. ball	184	
Shore Scleroscope M.H	58	
S. & S., Shore Scleroscope U. H. and self-recorder	39	
Specific gravity	8.602	8.608
Density, lb. per cu. in	0.310	
Coefficient of thermal expansion, $\times 10^{-6}$:		
At 0–100°C	15.0	
At 0–200°C	15.8	
At 0–300°C	16.4	
At 0–400°C	17.0	
Thermal conductivity,		
At 70°F., B.t.u. per sq. ft. per ft. per hr. per °F	21.54	
At 400°F., B.t.u. per sq. ft. per ft. per hr. per °F	26.14	
Temperature coefficient of thermal conductivity	0.00123	
Specific resistance, microhms-cm.[3] at 20°C	20.71	
Melting point, °F	1790	
Modulus of elasticity, p.s.i	18,000,000	

[a] Based on data by Cook.[26]

[b] Refers to strip cold-rolled 60% (reduction in thickness) from a ready-to-finish anneal for 2 hr.

[c] Refers to a 1450°F. anneal for 2 hr.

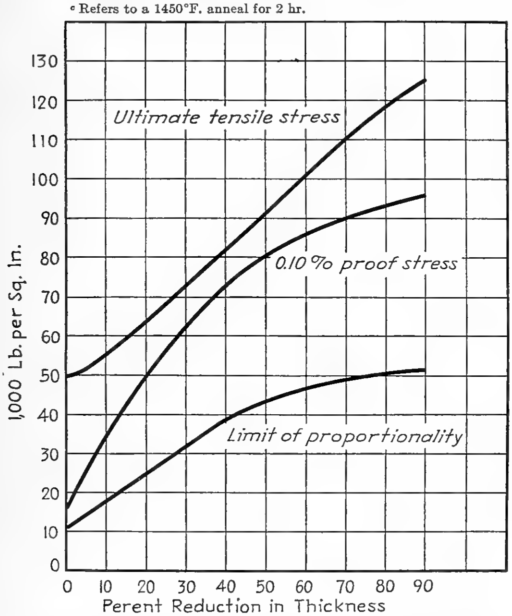


Chart 81.—The effect of cold rolling on the tensile strength, proof strength, and proportional limit of 10 per cent nickel-silver strip (62.62% copper, 10.05% nickel, balance zinc), previously annealed at 1450°F. for 2 hr. according to Cook.[26]

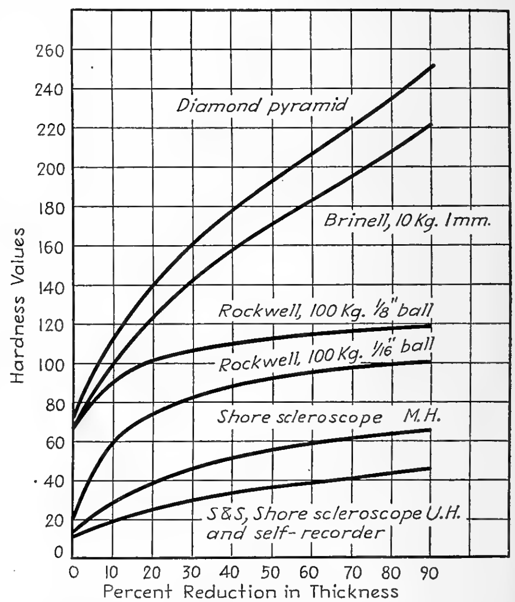


Chart 82.—The effect of cold rolling on the hardness of 10 per cent nickel-silver strip (62.62% copper, 10.05% nickel, balance zinc), previously annealed at 1450°F. for 2 hr. according to Cook.[26]

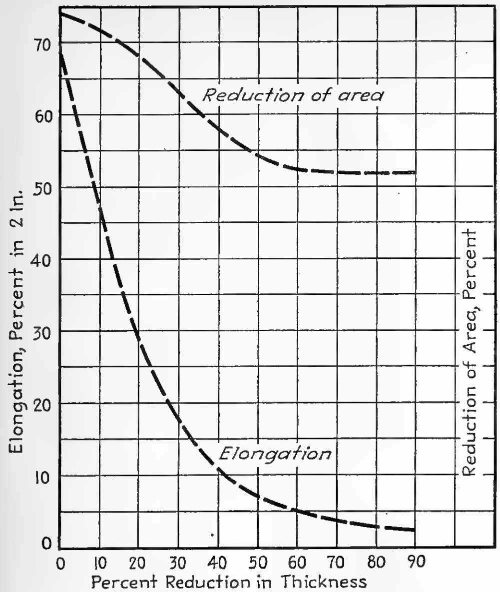


CHART 83.—The effect of cold rolling on the percentage reduction of area and percentage elongation in 2 in. of 10 per cent nickel-silver strip (62.62 % copper, 10.05 % nickel, balance zinc), previously annealed at 1450°F. for 2 hr. according to Cook.(26)

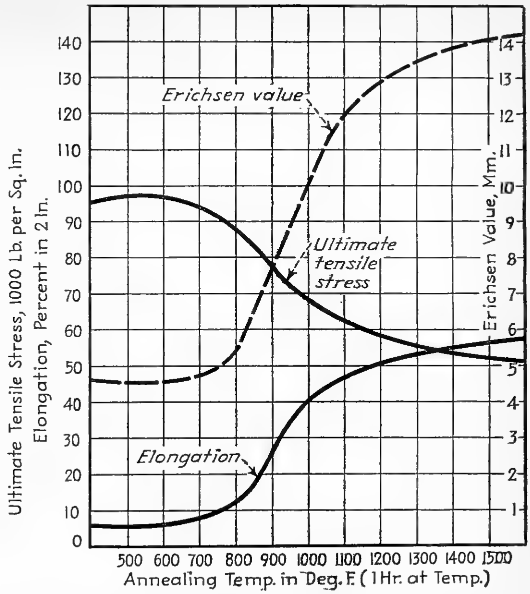
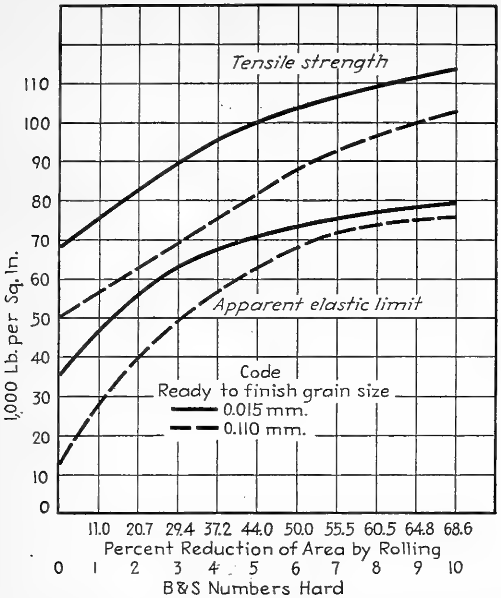


CHART 84.—The effect of annealing on the tensile strength, Erichsen value, and percentage elongation in 2 in. of 10 per cent nickel-silver strip (62.62 % copper, 10.05 % nickel, balance zinc), previously cold-rolled 60 per cent (reduction of area) according to Cook.(26)

TABLE 11
5 PER CENT NICKEL SILVER
GENERAL DATA—STRIP[a]
Copper, 63.55 %; nickel, 5.14 %; zinc, balance

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	90–104	51–53
Elongation, % in 2 in.	4	67–75
Apparent elastic limit, p.s.i. (000 omitted)	69–74	12
Yield strength, 0.5 % extension, p.s.i. (000 omitted)	72–75	17–20
Yield strength, 0.2 % offset, p.s.i. (000 omitted)	84–93	17–20
Yield strength, 0.1 % offset, p.s.i. (000 omitted)	77–84	17–20
Rockwell hardness F, 1/16-in. ball, 60-kg. load	107–112	64
Rockwell hardness B, 1/16-in. ball, 100-kg. load	88–95	14
Rockwell hardness G, 1/16-in. ball, 150-kg. load	63–74	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	89–92	65
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	75–79	25
Young's modulus of elasticity, p.s.i.	16,000,000	
Melting point, °F.	1760	
Density, lb. per cu. in.	0.308	
Electrical conductivity, % I.A.C.S., 68°F.	12.0	
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	34	
Specific gravity	8.50	

[a] All tests conducted on 0.040-in. stock.
[b] 6 B. & S. Nos., hard, 0.110–0.015 mm. grain size at ready-to-finish.
[c] 1300°F. anneal (1 hr. at temperature) of material described in footnote b.



· CHART 85.—The effect of cold rolling on the tensile strength and apparent elastic limit of 5 per cent nickel-silver strip, previously annealed to two different grain sizes, 0.015 and 0.110 mm. (63.55 % copper, 5.14 % nickel, balance zinc) (0.040-in. stock).

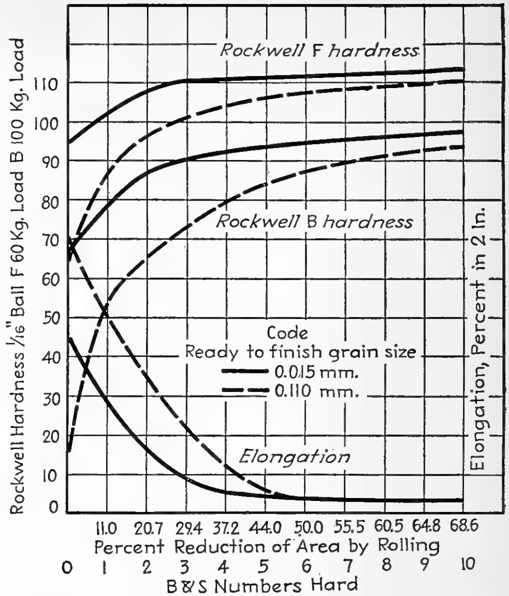


CHART 86.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of 5 per cent nickel-silver strip, previously annealed to two different grain sizes, 0.015 and 0.110 mm. (63.55 % copper, 5.14 % nickel, balance zinc) (0.040-in. stock).

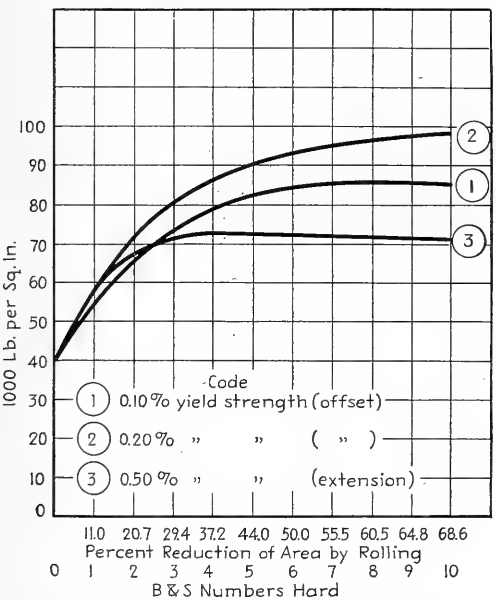


CHART 87.—The effect of cold rolling on the yield strengths of 5 per cent nickel-silver strip, previously annealed to a grain size of 0.015 mm. (63.55 % copper, 5.14 % nickel, balance zinc) (0.040-in. stock).

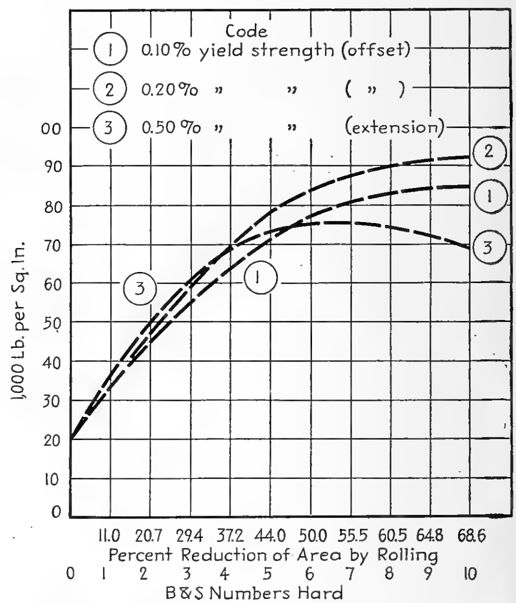


CHART 88.—The effect of cold rolling on the yield strengths of 5 per cent nickel-silver strip, previously annealed to a grain size of 0.110 mm. (63.55 % copper, 5.14 % nickel, balance zinc) (0.040-in. stock).

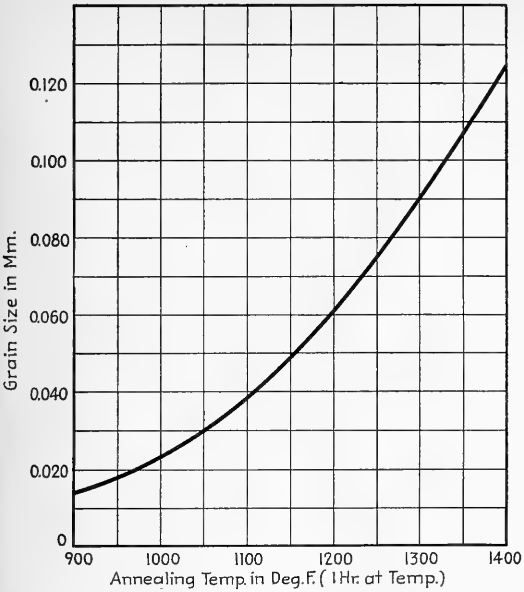


CHART 90.—The effect of annealing on the grain-growing characteristics of 5 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0,110 mm. (63.55 % copper, 5.14 % nickel, balance zinc) (0.040-in. stock).

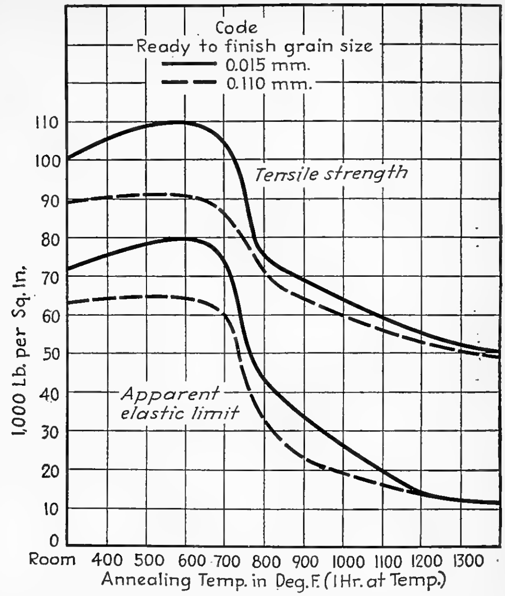


CHART 89.—The effect of annealing on the tensile strength and apparent elastic limit of 5 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.110 mm. (63.55 % copper, 5.14 % nickel, balance zinc) (0.040-in. stock).

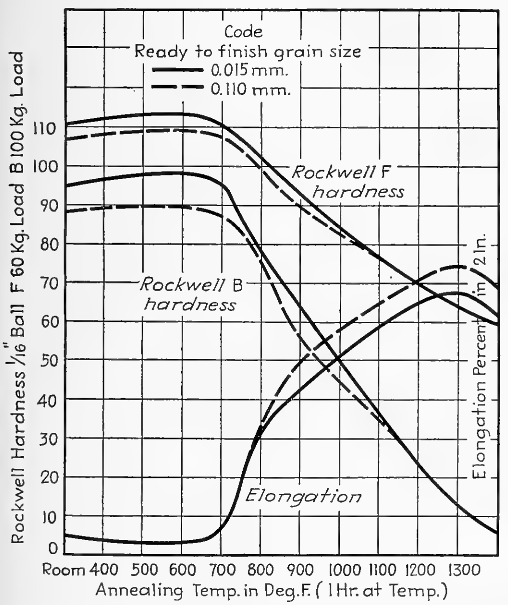


CHART 91.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of 5 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.110 mm. (63.55 % copper, 5.14 % nickel, balance zinc) (0.040-in. stock).

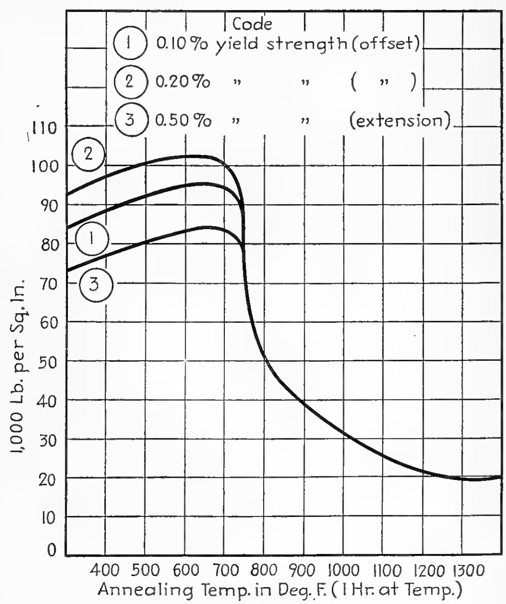


CHART 92.—The effect of annealing on the yield strength of 5 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (63.55 % copper, 5.14 % nickel, balance zinc) (0.040-in. stock).

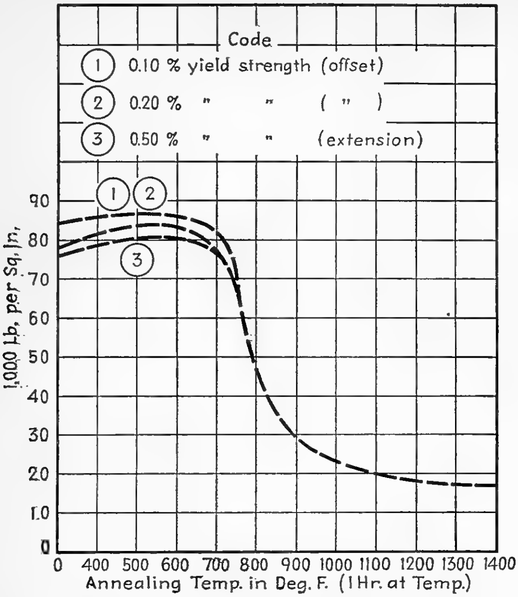


CHART 93.—The effect of annealing on the yield strength of 5 per cent nickel-silver strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.110 mm. (63.55 % copper, 5.14 % nickel, balance zinc) (0.040-in. stock).

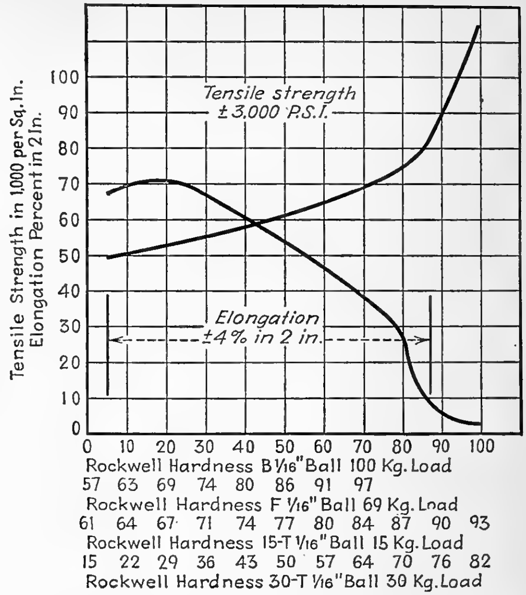


CHART 94.—This chart can be employed to determine the approximate tensile strength and percentage elongation of 5 per cent nickel-silver strip (63.55 % copper, 5.14 % nickel, balance zinc) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

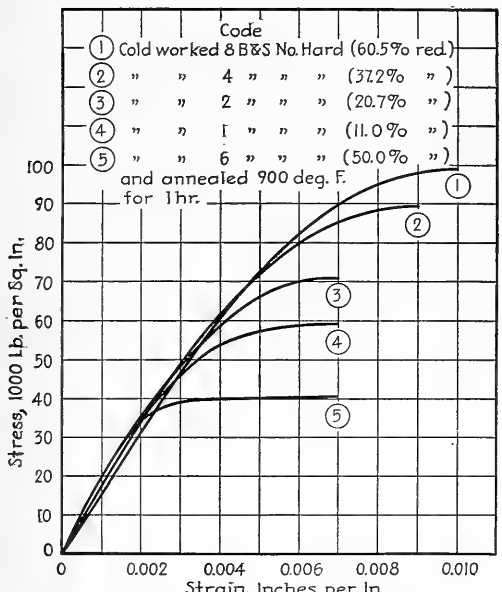


CHART 95.—The effect of cold rolling on the stress-strain characteristics of 5 per cent nickel-silver strip (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (63.55 % copper, 5.14 % nickel, balance zinc.)

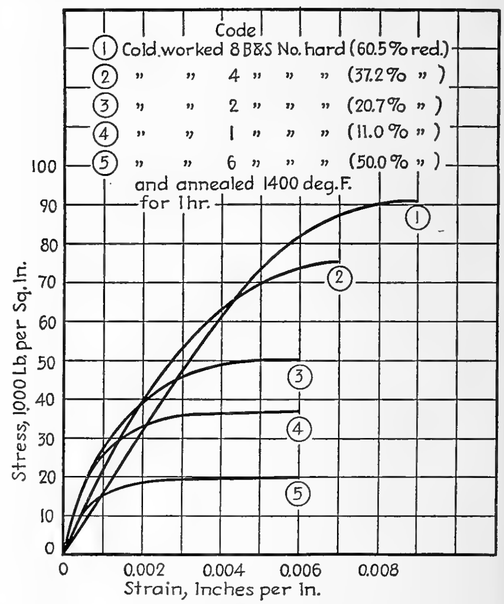


CHART 96.—The effect of cold rolling on the stress-strain characteristics of 5 per cent nickel-silver strip (0.040 in. thick) having a ready-to-finish grain size of 0.110 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (63.55 % copper, 5.14 % nickel, balance zinc.)

TABLE 12
MECHANICAL PROPERTIES OF EXTRUDED NICKEL SILVERS[a]

Chemical composition, %				Physical properties						
Copper	Nickel	Zinc	Other additions	Tensile strength p.s.i. (000 omitted)	Elongation, % in 2 in.	Diamond pyramid hardness No. (10-kg. load)	Izod value, ft.-lb.	Machinability[b]	Micro structure	Forging range, °F.
44.8	10.1	Balance		F90[c] B95[c]	28.0 26.0	155 166	27 29	60	*B* (and *a*) *B* (and *a*)	1100–1550
44.6	12.6	Balance	Deoxidized with Cu-Mn	F77 B87	41.9 37.0	132 144	47 54	52	*a* (and *B*) *a* (and *B*)	
43.8	16.1	Balance		F79 B83	40.5 34.0	168 171	20 48	40	*a* (and *B*)	
44.5	10.2	Balance	No deoxidant	F84 B86	.... 28.5	157 161	29 32	56	*B* (and *a*) *B* (and *a*)	1200–1550
44.8	9.9	Balance	0.02% P	F92 B100	25.3	157 175	27 28	55	*B* (and *a*) *B* (and *a*)	1200–1550
44.9	10.2	Balance	0.08% P	F97 B100	21.0 15.5	162 166	22 25	60	*B* (trace *a*) *B* (and *a*)	
44.7	10.5	Balance	0.11% So	F84 B86	10.5 9.5	172 170	20 28	63	*B* (trace *a*) *B* (trace *a*)	1100–1550
44.6	10.1	Balance	0.26% Si	F100 B102	14.0 12.5	198 196	19 14	53	*B* *B*	1100–1550
44.8	10.1	Balance	} Deoxidized with Cu-Mn	F90 B96	28.0 26.0	155 166	27 29	60	*B* (and *a*) *B* (and *a*)	
44.9	9.7	Balance	0.56% Pb	F93 B93	28.7 18.5	177 164	28 23	57	*B* (and *a*) *B* (and *a*)	
44.6	9.4	Balance	1.55% Pb	F89 B89	27.2 17.0	150 151	28 20	77	*B* (and *a*) *B* (and *a*)	
44.1	9.1	Balance	2.88% Pb	F89 B79	25.0 12.0	154 161	22 16	80	*B* (and *a*) *B* (and *a*)	

[a] Based on data by Cook.[28]
[b] Assuming free-cutting brass (60% copper; 3% lead; balance, zinc) as 100%.
[c] F and B refer to front and back ends of extruded rod.

TABLE 13
LEADED 12 PER CENT NICKEL SILVER
GENERAL DATA—STRIP[a]
Copper, 65.49%; nickel, 12.11%; lead, 1.96%; zinc, balance

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	83–96	51–53
Apparent elastic limit, p.s.i. (000 omitted)	60–73	13
Yield strength, 0.5% extension, p.s.i. (000 omitted)	77–88	17–19
Yield strength, 0.2% offset, p.s.i. (000 omitted)	76–85	16–18
Yield strength, 0.1% offset, p.s.i. (000 omitted)	74–80	16–18
Elongation, % in 2 in.	3	44–38
Rockwell hardness F, 1/16-in. ball, 60-kg. load	106–110	73
Rockwell hardness B, 1/16-in. ball, 100-kg. load	81–91	27
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	74–44	71
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	80–56	37
Young's modulus of elasticity, p.s.i.	17,000,000	
Melting point, °F.	1900	
Density, lb. per cu. in.	0.314	
Coefficient of expansion, per °C. from 25–300°C.	0.0000150	
Electrical conductivity, % I.A.C.S., 68°F.	7.3	
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	23	
Specific gravity	8.70	

[a] Apply to strip only (all tests conducted on 0.040-in. stock).
[b] 6 B. & S. Nos., hard, 0.060–0.015 mm. grain size at ready-to-finish.
[c] Refers to 1400°F. anneal (1 hr. at temperature).

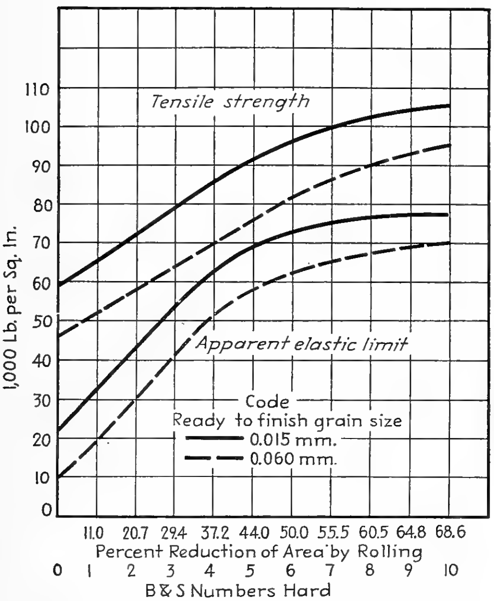


CHART 97.—The effect of cold rolling on the tensile strength and apparent elastic limit of 12 per cent nickel-silver-leaded strip, previously annealed to two different grain sizes, 0.015 and 0.060 mm. (65.49% copper, 12.11% nickel, 1.96% lead, balance zinc) (0.040-in. stock).

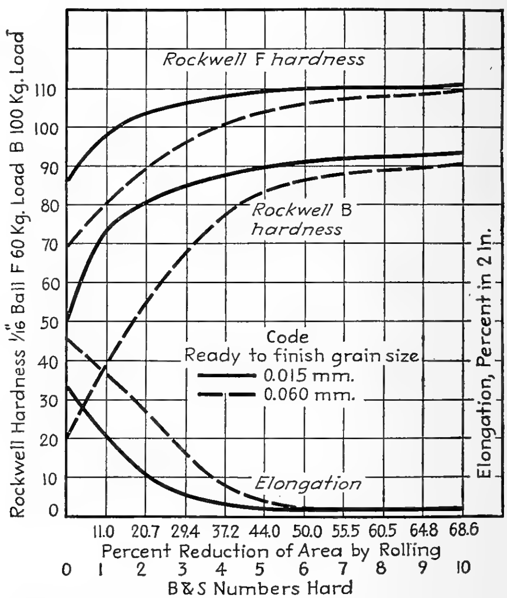


CHART 98.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of 12 per cent nickel-silver–leaded strip, previously annealed to two different grain sizes, 0.015 and 0.060 mm. (65.49% copper, 12.11% nickel, 1.96% lead, balance zinc) (0.040-in. stock).

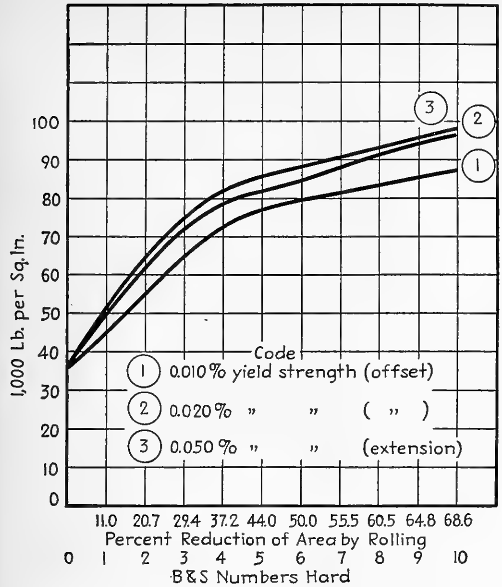


CHART 99.—The effect of cold rolling on the yield strengths of 12 per cent nickel-silver–leaded strip, previously annealed to a grain size of 0.015 mm. (65.49 % copper, 12.11 % nickel, 1.96 % lead, balance zinc) (0.040-in. stock).

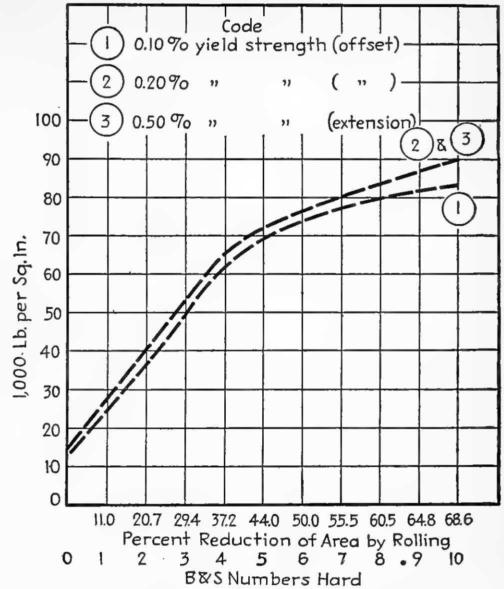


CHART 100.—The effect of cold rolling on the yield strengths of 12 per cent nickel-silver–leaded strip, previously annealed to a grain size of 0.060 mm. (65.49 % copper, 12.11 % nickel, 1.96 % lead, balance zinc) (0.040-in. stock).

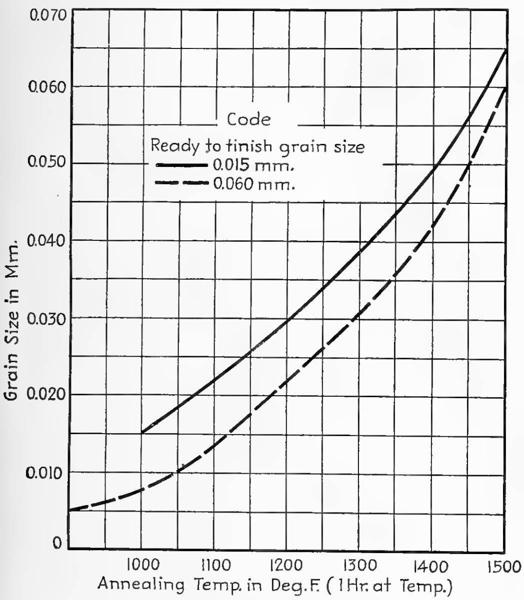


CHART 101.—The effect of annealing on the grain-growing characteristics of 12 per cent nickel-silver–leaded strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.060 mm. (65.49 % copper, 12.11 % nickel, 1.96 % lead, balance zinc) (0.040-in. stock).

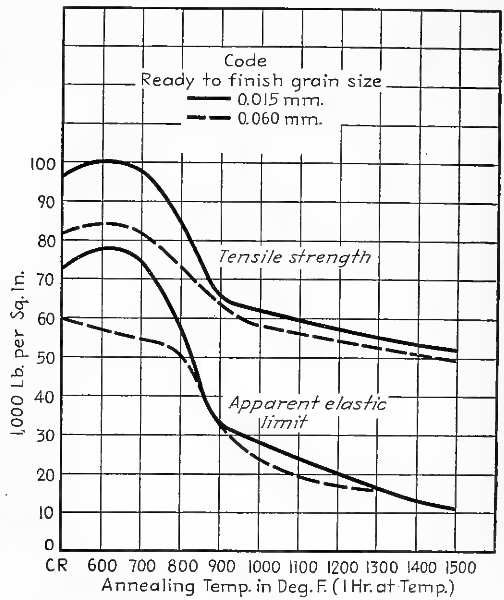


CHART 102.—The effect of annealing on the tensile strength and apparent elastic limit of 12 per cent nickel-silver–leaded strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.060 mm. (65.49 % copper, 12.11 % nickel, 1.96 % lead, balance zinc) (0.040-in. stock).

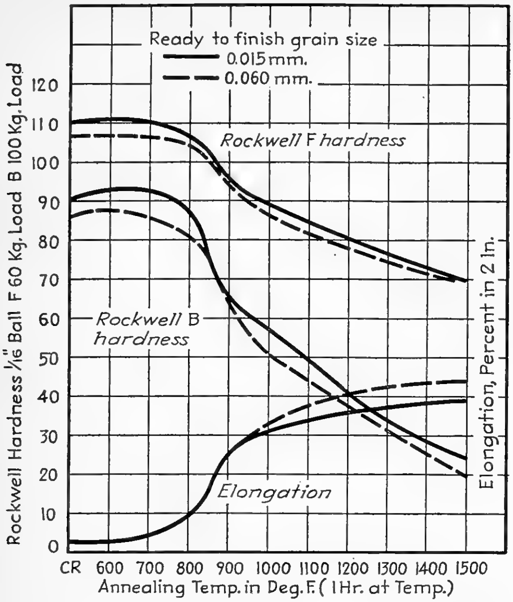


CHART 103.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of 12 per cent nickel-silver–leaded strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.060 mm. (65.49 % copper, (12 11 % nickel, 1.96 % lead, balance zinc) (0.040-in. stock).

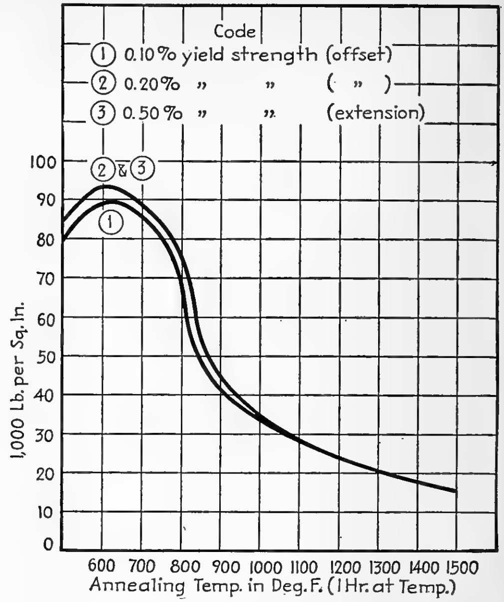


CHART 104.—The effect of annealing on the yield strength of 12 per cent nickel-silver–leaded strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (65.49 % copper, 12.11 % nickel, 1.96 % lead, balance zinc) (0.040-in. stock).

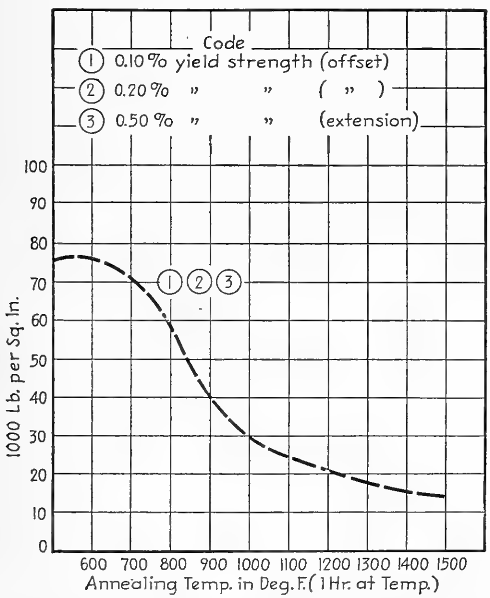


CHART 105.—The effect of annealing on the yield strength of 12 per cent nickel-silver–leaded strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.060 mm. (65.49 % copper, 12.11 % nickel, 1.96 % lead, balance zinc) (0.040-in. stock).

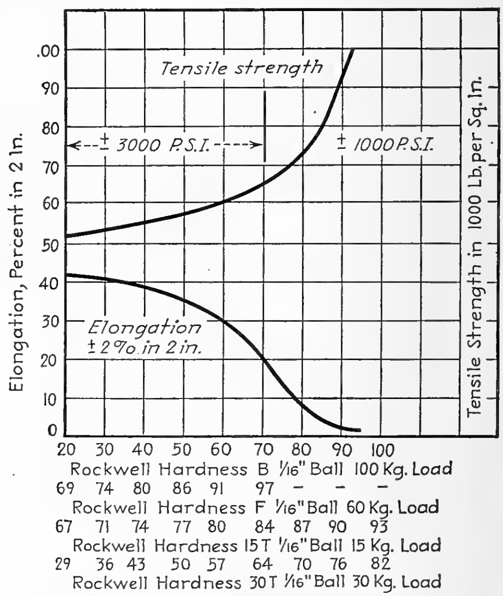


CHART 106.—This chart can be employed to determine the approximate tensile strength and percentage elongation of 12 per cent nickel-silver–leaded strip (65.49 % copper, 12.11 % nickel, 1.96 % lead, balance zinc) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

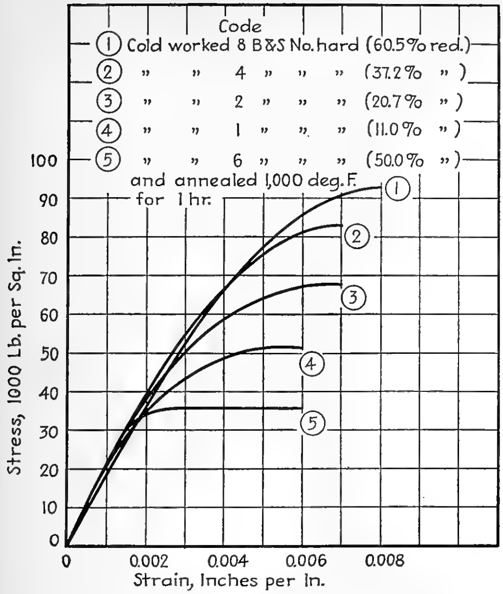


Chart 107.—The effect of cold working on the stress-strain characteristics of leaded 12 per cent nickel-silver strip (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 inches used. (65.49 % copper, 12.11 % nickel, 1.96 % lead, balance zinc.)

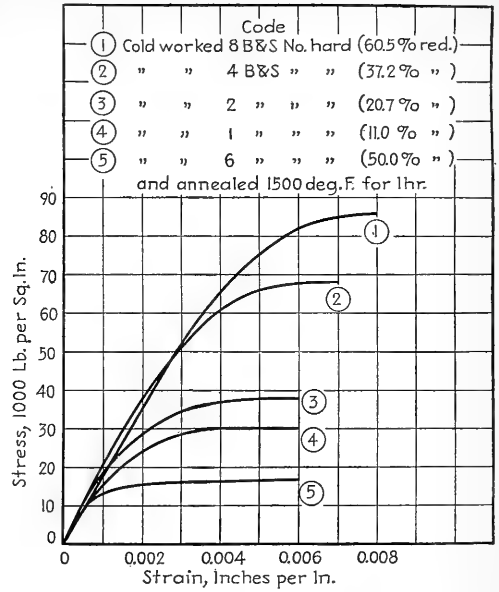


Chart 108.—The effect of cold working on the stress-strain characteristics of leaded 12 per cent nickel-silver strip (0.040 in. thick) having a ready-to-finish grain size of 0.060 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used (65.49 % copper, 12.11 % nickel, 1.96 % lead, balance zinc).

CHAPTER VII

THE CUPRO-NICKELS

The copper-base alloys of nickel, *i.e.*, those in which copper is the predominant alloy constituent, are commercially available in two types: one containing 80 per cent of copper and 20 per cent of nickel, and the other containing 70 per cent of copper and 30 per cent of nickel. Both of these alloys are single-phase solid solutions of copper and nickel and are known as the "cupro-nickels."

Although these alloys have been known for many years, they did not assume commercial importance until about 1925. At that time the demand for condenser tubes capable of resisting the erosive-corrosive attack of high-velocity salt water used as the coolant in Navy surface condensers led to their commercial development.

Since that time 70-30 cupro-nickel has shown a marked superiority as a condenser-tube alloy to the 80-20 alloy. The 80-20 cupro-nickel tube continues to find some use as a condenser-tube material in less severe applications.

Both of these alloys, in addition to their excellent corrosion-resisting properties, possess tensile properties similar to those of 70-30 brass and, in addition, are the most resistant of the copper-base alloys to failure by stress corrosion and corrosion fatigue. Both cupro-nickels have been used in strip form for the manufacture of ammunition component parts. Bolts, nuts, screws, and similar parts are manufactured by cold-heading operations. Because of their generally valuable properties, it is probable that their use will be extended.

The physical and general mechanical properties of the two cupro-nickels are given in Tables 1 and 2 on pages 227 and 234. More detailed data are given in Charts 1 to 39 on pages 228 to 238.

FOOTNOTES TO TABLE 1

[a] Refers to rod cold-drawn 50 %; rod under 1 in. in diameter, ready-to-finish grain size, 0.035 mm.
[b] Refers to a 1400°F. anneal (1 hr.).
[c] Material cold-forged from soft rod (5–40 % reduction of area).
[d] Material cold-forged from cold-worked condition (40 %).
[e] Extruded, reduced, and drawn to 3/4 by 0.049 in.
[f] Footnote *e* after 1300°F. anneal (1 hr.).
[g] All tests conducted on 0.040-in. stock.
[h] 6 B. & S. Nos., hard, 0.070–0.015 mm. grain size at ready-to-finish, respectively
[i] Material described in footnote *h* after 1300°F. anneal (1 hr.).

TABLE 1
70-30 CUPRO-NICKEL
GENERAL DATA—ROD
Copper, 68.56%; nickel, 30.48%; iron, 0.39%; manganese, 0.57%

Property	Rod		Forgings		
	Hard[a]	Soft[b]	Hot	Cold[c]	Cold[d]
Tensile strength, p.s.i. (000 omitted)	85	55	55–60	60–80	85
Apparent elastic limit, p.s.i. (000 omitted)	69	16	16–20	33–67	67
Yield strength, 0.5% extension, p.s.i. (000 omitted)	78	20	14–25	44–76	78
Yield strength, 0.2% offset, p.s.i. (000 omitted)	78	20	14–25	38–75	78
Yield strength, 0.1% offset, p.s.i. (000 omitted)	70	18	14–25	37–66	68
Elongation, % in 2 in.	15	45	45	40–15	15
Reduction of area, %	75	85	85–80	83–76	75
Endurance limit, p.s.i. (000 omitted)	32	22	22–24	22–27	32
Rockwell hardness F, 1/16-in. ball, 60-kg. load	103	79	79–85	90–103	103
Rockwell hardness B, 1/16-in. ball, 100-kg. load	81	37	37–50	58–80	80
Brinell hardness, 10-mm. ball, 500-kg. load	133	72	72–83	92–130	130
Modulus of elasticity, p.s.i.	22,000,000				
Forging range, °F.	1600–1900				
Forging quality	Fair				
Type structure	Single phase, alpha				

GENERAL DATA—TUBE
Copper, 68.94%; iron, 0.26%; nickel, 30.15%; manganese, 0.60%; carbon, 0.049%

Property	Hard[e]	Soft[f]
Tensile strength, p.s.i. (000 omitted)	84	49
Elongation, % in 2 in.	4	50
Apparent elastic limit, p.s.i. (000 omitted)	83	18
Rockwell hardness F, 1/16-in. ball, 60-kg. load	107	68
Young's modulus of elasticity, p.s.i.	22,000,000	

GENERAL DATA—STRIP[g]
Copper, 68.94%; nickel, 29.61%

Property	Hard[h]	Soft[i]
Tensile strength, p.s.i. (000 omitted)	82–87	54–57
Elongation, % in 2 in.	3	38–35
Apparent elastic limit, p.s.i. (000 omitted)	64–69	14–18
Yield strength:		
0.5% extension, p.s.i. (000 omitted)	79–80	18–19
0 2% offset, p.s.i. (000 omitted)	81–84	18–19
0.1% offset, p.s.i. (000 omitted)	77–80	18–19
Rockwell hardness F, 1/16-in. ball, 60-kg. load	106–108	78–81
Rockwell hardness B, 1/16-in. ball, 100-kg. load	85–87	36–44
Rockwell hardness G, 1/16-in. ball, 150-kg. load	57–61	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	88–89	73–75
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	74–75	40–46

PHYSICAL DATA

Melting point, °F.	2250
Coefficient of expansion, per °C. from 25–300°C.	0.0000162
Electrical conductivity, % I.A.C.S.	4.7
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	16.7
Density, lb. per cu. in.	0.323
Specific gravity	8.96
Stress relief anneal, °F.	555
Annealing range, °F.	1250–1600

AVAILABLE CREEP DATA[(3)]

Previous history: cold-drawn to 0.750 in. in diameter, annealed 1022°F., Rockwell B, 72, tensile strength, 64,700 p.s.i.; 0.50% yield strength, 48,300 p.s.i.; % elongation in 2 in., 37; % reduction of area, 65.

At 750°F. a stress of 9,100 p.s.i. is required to produce a rate of creep per 1,000 hr. of 0.01%

At 750°F. a stress of 18,800 p.s.i. is required to produce a rate of creep per 1,000 hr. of 0.10%

See page 226 for footnotes to table.

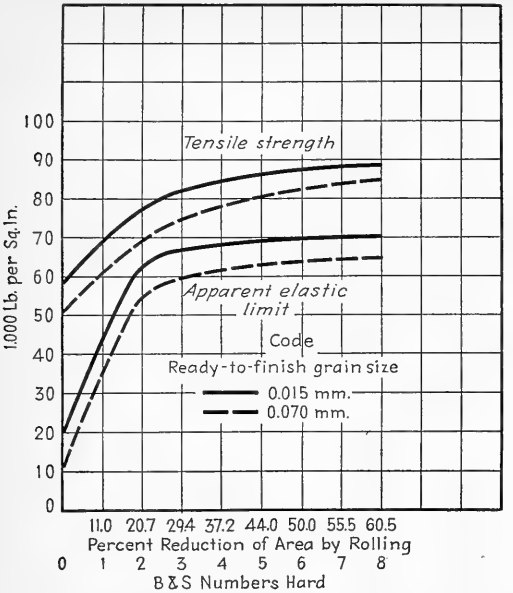


CHART 1.—The effect of cold rolling on the tensile strength and apparent elastic limit of 70-30 cupro-nickel strip, previously annealed to two different grain sizes, 0.015 and 0.070 mm. (68.94 % copper, 29.61 % nickel) (0.040-in. stock).

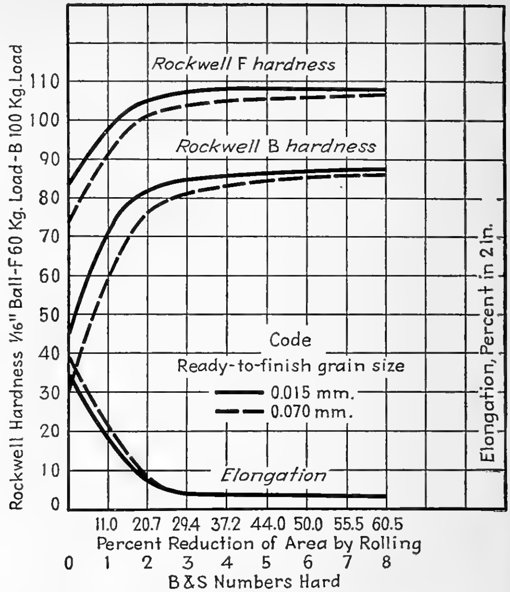


CHART 2.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of 70-30 cupro-nickel strip, previously annealed to two different grain sizes, 0.015 and 0.070 mm. (68.94 % copper, 29.61 % nickel) (0.040-in. stock).

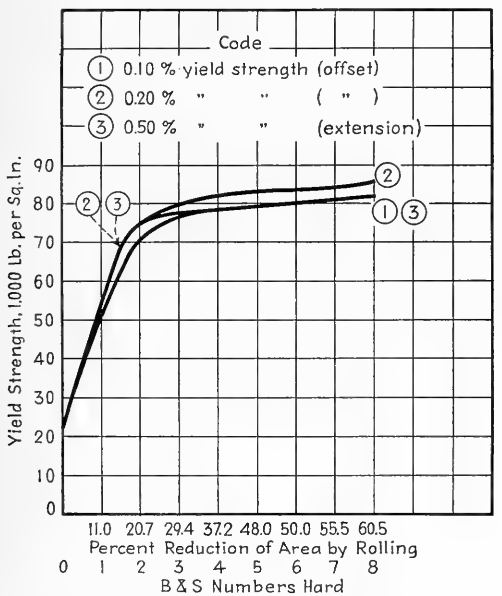


CHART 3.—The effect of cold rolling on the yield strengths of 70-30 cupro-nickel strip, previously annealed to a grain size of 0.015 mm. (68.94 % copper, 29.61 % nickel) (0.040-in. stock).

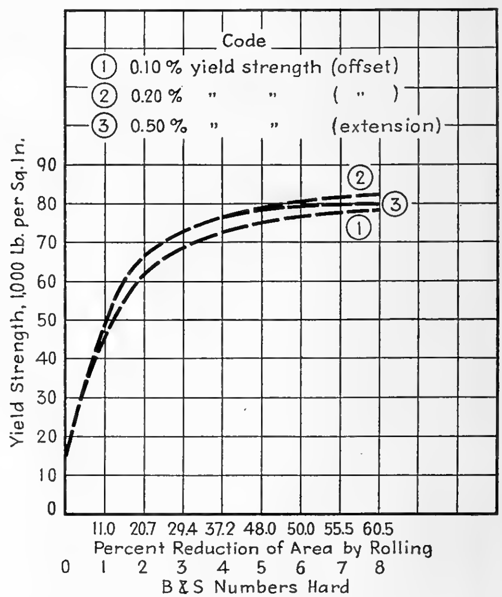


CHART 4.—The effect of cold rolling on the yield strengths of 70-30 cupro-nickel strip, previously annealed to a grain size of 0.070 mm. (68.94 % copper, 29.61 % nickel) (0.040-in. stock)

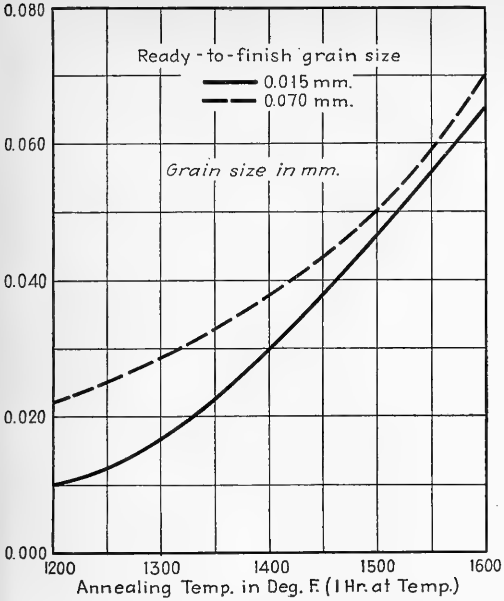


CHART 5.—The effect of annealing on the grain-growing characteristics of 70-30 cupro-nickel strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (68.94 % copper, 29.61 % nickel) (0.040-in. stock).

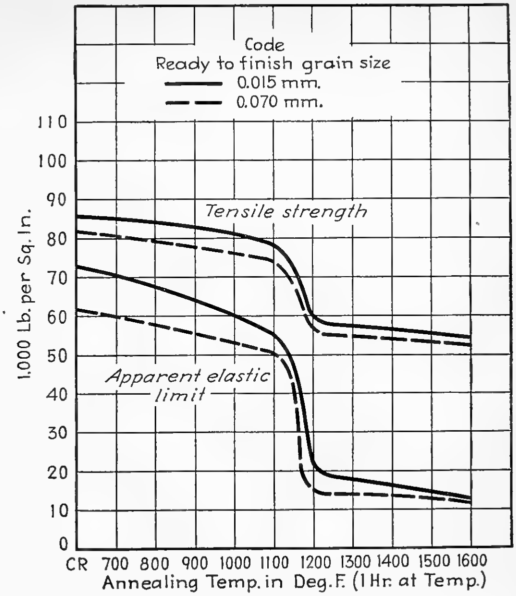


CHART 6.—The effect of annealing on the tensile strength and apparent elastic limit of 70-30 cupro-nickel strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (68.94 % copper, 29.61 % nickel) (0.040-in. stock).

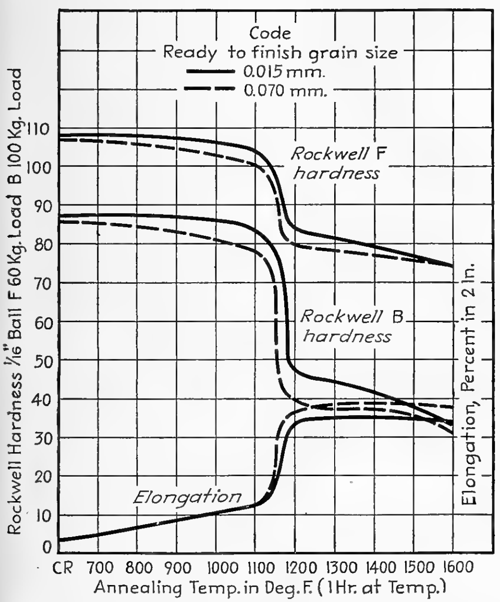


CHART 7.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of 70-30 cupro-nickel strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (68.94 % copper, 29.61 % nickel) (0.040-in. stock).

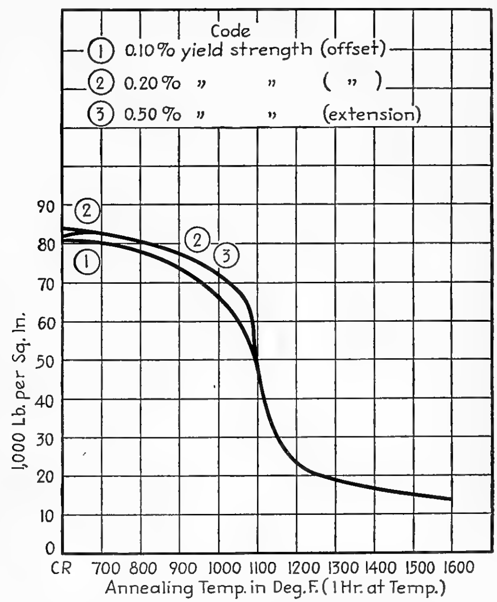


CHART 8.—The effect of annealing on the yield strength of 70-30 cupro-nickel strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (68.94 % copper, 29.61 % nickel) (0.040-in. stock).

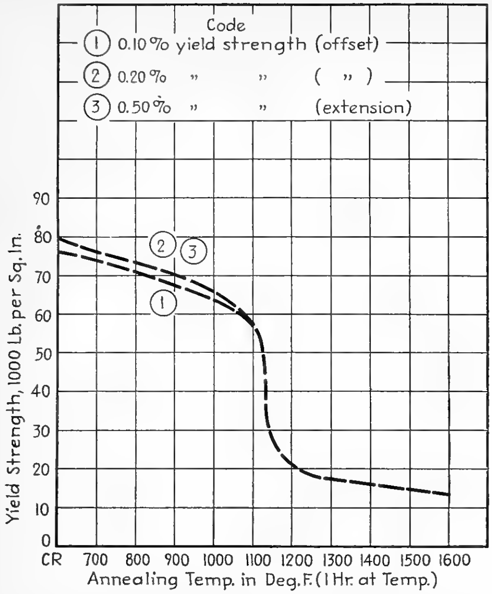


CHART 9.—The effect of annealing on the yield strength of 70-30 cupro-nickel strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.070 mm. (68.94 % copper, 29.61 % nickel) (0.040-in. stock).

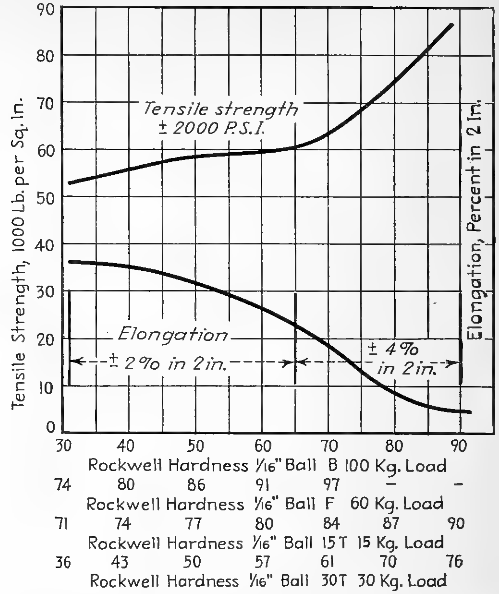


CHART 10.—This chart can be employed to determine the approximate tensile strength and percentage elongation of 70-30 cupro-nickel strip (68.94 % copper, 29.61 % nickel) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

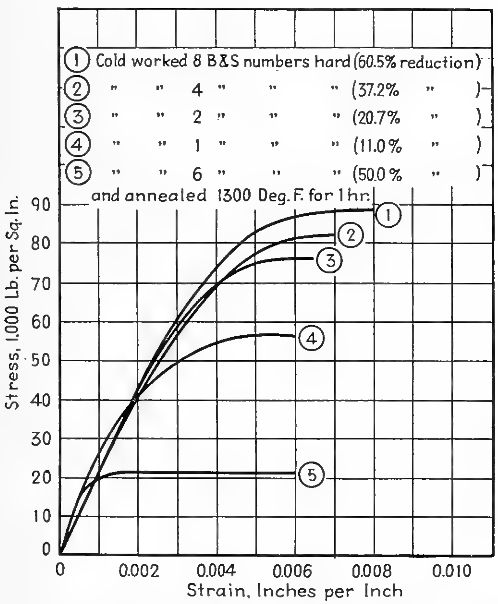


CHART 11.—The effect of cold rolling on the stress-strain characteristics of 70-30 cupro-nickel strip (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (68.94 % copper, 29.61 % nickel.)

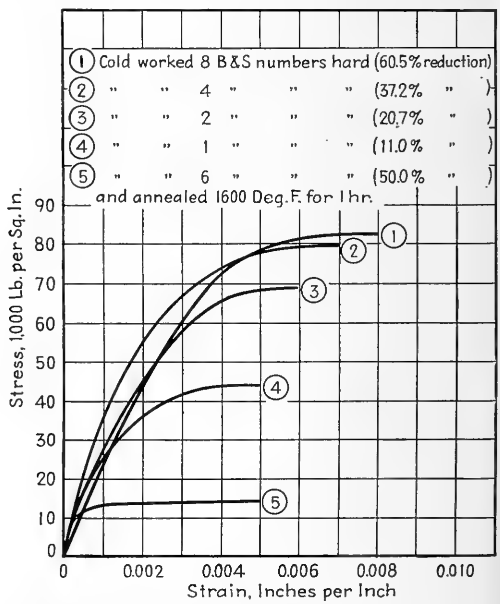


CHART 12.—The effect of cold rolling on the stress-strain characteristics of 70-30 cupro-nickel strip (0.040 in. thick) having a ready-to-finish grain size of 0.070 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used (68.94 % copper, 29.61 % nickel).

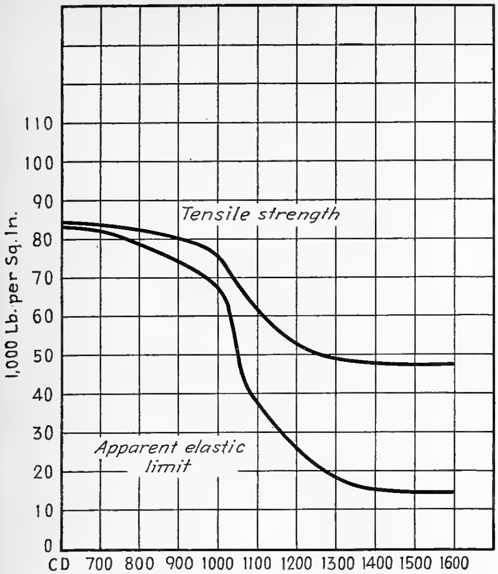


CHART 13.—The effect of annealing on the tensile strength and apparent elastic limit of 70-30 cupro-nickel tube, previously cold-drawn 70 per cent (reduction of area) from a grain size of 0.065 mm. (68.94 % copper, nickel 30.15 %, 0.26 % iron, 0.60 % manganese).

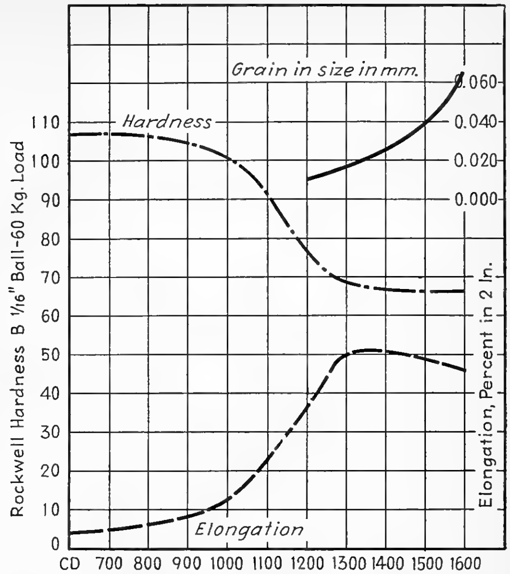


CHART 14.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and grain size of 70-30 cupro-nickel tube, previously cold-drawn 70 per cent (reduction of area) from a grain size of 0.065 mm. (68.94 % copper, 30.15 % nickel, 0.26 % iron, 0.60 % manganese).

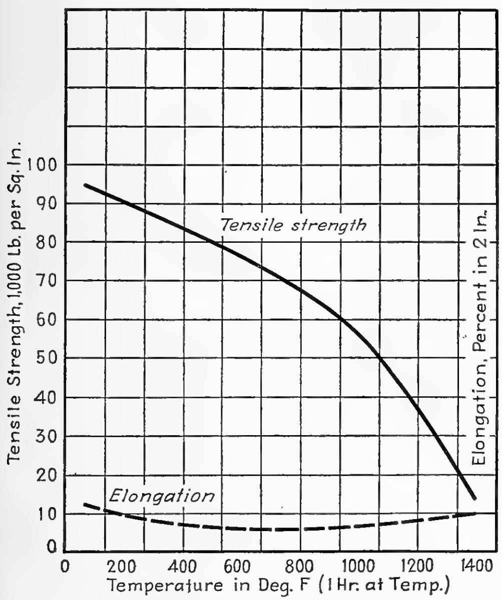


CHART 15.—The effect of elevated temperature on the tensile strength and percentage elongation in 2 in. of 70-30 cupro-nickel rod, previously cold-drawn 80 per cent (reduction of area) from material having a grain size of 0.035 mm. (68.56 % copper, 30.48 % nickel, 0.39 % iron, 0.57 % manganese) (rod under 1 in. in diameter).

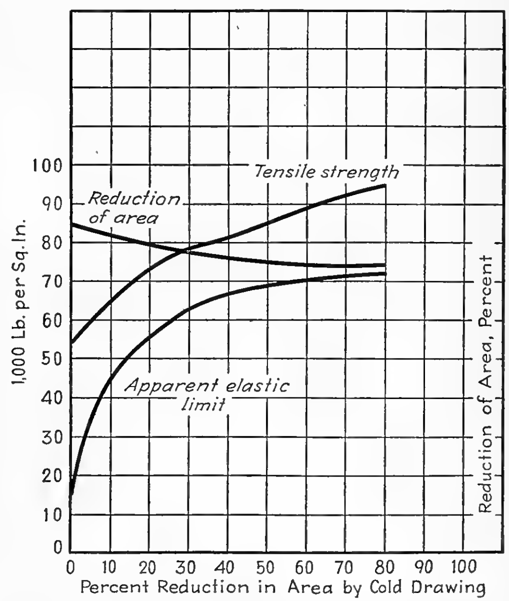


CHART. 16.—The effect of cold drawing on the tensile strength, percentage reduction of area and apparent elastic limit of 70-30 cupro-nickel rod previously annealed to a grain size of 0.035 mm. (68.56 % copper, 30.48 % nickel, 0.39 % iron, 0.57 % manganese) (rod under 1 in. in diameter).

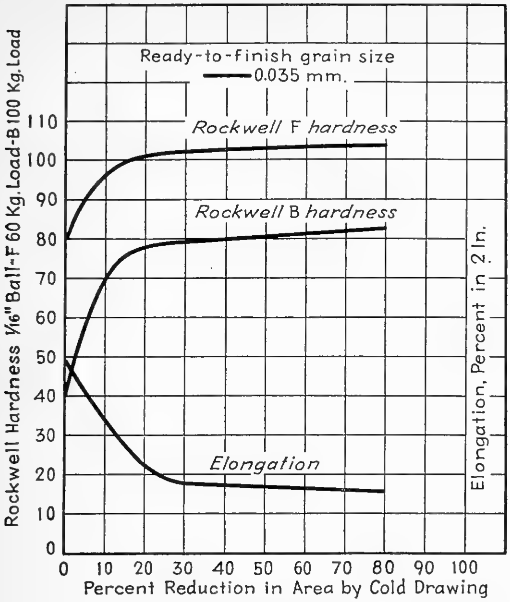


CHART 17.—The effect of cold drawing on the Rockwell hardness and percentage elongation in 2 in. of 70-30 cupro-nickel rod, previously annealed to a grain size of 0.035 mm. (68.56 % copper, 30.48 % nickel, 0.39 % iron, 0.57 % manganese) (rod under 1 in. in diameter).

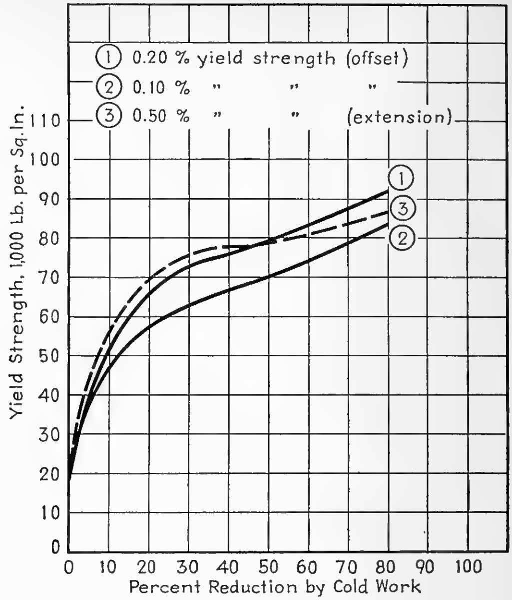


CHART 18.—The effect of cold drawing on the yield strength of 70-30 cupro-nickel rod, previously annealed to a grain size of 0.035 mm. (68.56 % copper, 30.48 % nickel, 0.39 % iron, 0.57 % manganese) (rod under 1 in. in diameter).

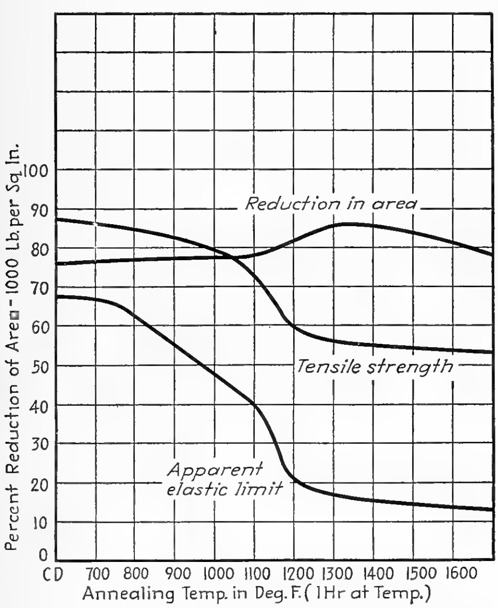


CHART 19.—The effect of annealing on the tensile strength, apparent elastic limit, and percentage reduction in area of 70-30 cupro-nickel rod, previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.035 mm. (68.56 % copper, 30.48 % nickel, 0.39 % iron, 0.57 % manganese) (rod under 1 in. in diameter).

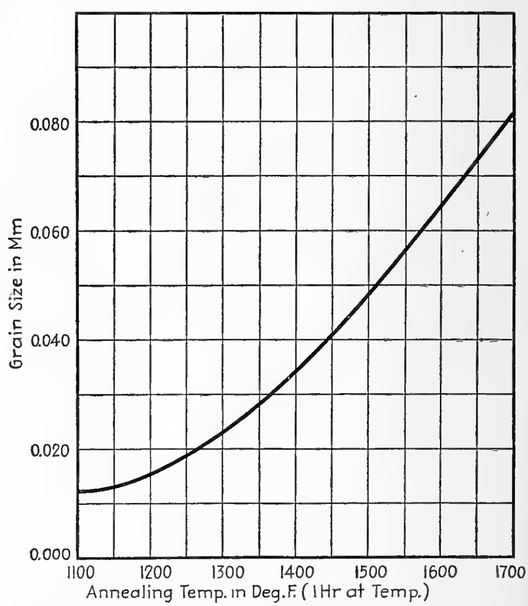


CHART 20.—The effect of annealing on the grain-growing characteristics of 70-30 cupro-nickel rod, previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.035 mm. (68.56 % copper, 30.48 % nickel, 0.39 % iron, 0.57 % manganese) (rod under 1 in. in diameter).

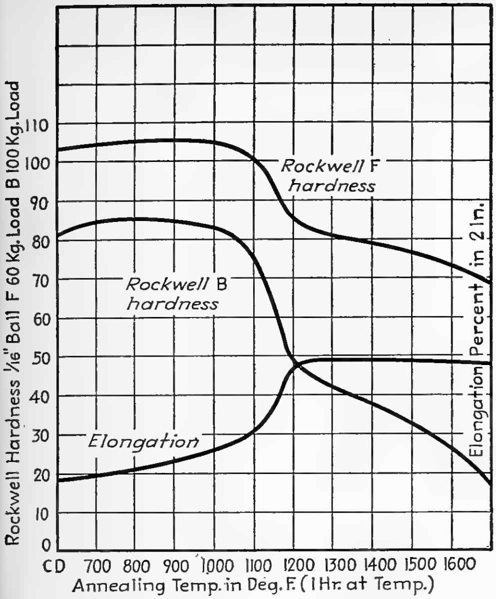


CHART 21.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of 70-30 cupro-nickel rod, previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.035 mm. (68.56 % copper, 30.48 % nickel, 0.39 % iron, 0.57 % manganese) (rod under 1 in. in diameter).

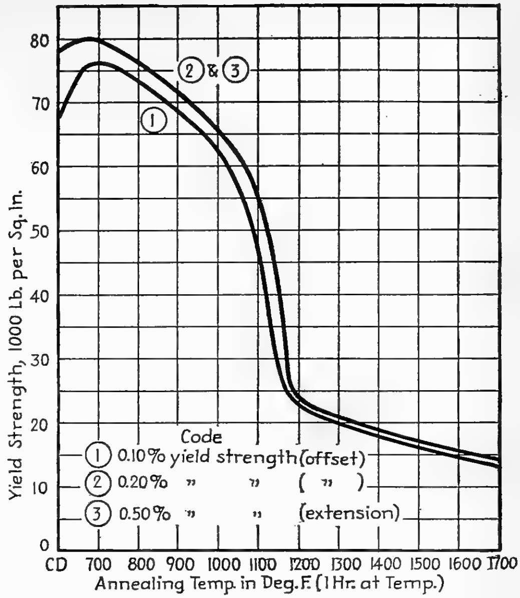


CHART 22.—The effect of annealing on the yield strength of 70-30 cupro-nickel rod, previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.035 mm. (68.56 % copper, 30.48 % nickel, 0.39 % iron, 0.57 % manganese) (rod under 1 in. in diameter).

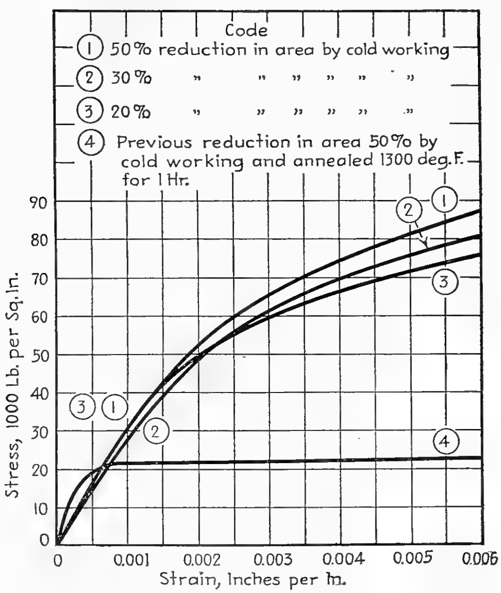


CHART 23.—The effect of cold drawing on the stress-strain characteristics of 70-30 cupro-nickel rod (under 1 in. in diameter) having a ready-to-finish grain size of 0.035 mm.; 100,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used (68.56 % copper, 30.48 % nickel, 0.39 % iron, 0.57 % manganese).

TABLE 2
80-20 CUPRO-NICKEL
GENERAL DATA—TUBE
Copper, 78.18 %; nickel, 20.65 %; manganese, 0.51 %

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	80	49
Elongation, % in 2 in.	3	40
Apparent elastic limit, p.s.i. (000 omitted)	78	17
Rockwell hardness F, 1/16-in. ball, 60-kg. load	107	71
Young's modulus of elasticity, p.s.i.	20,000,000	

GENERAL DATA—STRIP[a]

Property	Hard[d]	Soft[e]
Tensile strength, p.s.i. (000 omitted)	77–81	51
Elongation, % in 2 in.	3	35
Apparent elastic limit, p.s.i. (000 omitted)	64–66	11
Yield strength:		
0.5 % extension, p.s.i. (000 omitted)	75–77	14
0.2 % offset, p.s.i. (000 omitted)	75–79	14
0.1 % offset, p.s.i. (000 omitted)	72–76	14
Endurance limit, p.s.i. (000 omitted)	27	17
Rockwell hardness F, 1/16-in. ball, 60-kg. load	105–107	73
Rockwell hardness B, 1/16-in. ball, 100-kg. load	81–84	23–25
Rockwell hardness G, 1/16-in. ball, 150-kg. load	51–56	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	87–88	68–69
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	71–73	31–33
Young's modulus of elasticity, p.s.i.	20,000,000	

PHYSICAL DATA

Melting point, °F.	2190
Density, lb. per cu. in.	0.323
Electrical conductivity, % I.A.C.S., 68°F.	6.5
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	22

[a] All tests conducted on 0.040-in. stock.
[b] Extruded, reduced, and drawn, to 3/4 by 0.049 in.
[c] Same as footnote *b* after 1300°F. anneal (1 hr.).
[d] 6 B. & S. Nos., hard, 0.055–0.015 mm. grain size at ready-to-finish.
[e] 1600°F. anneal (1 hr. at temperature) of material described in footnote *d*.

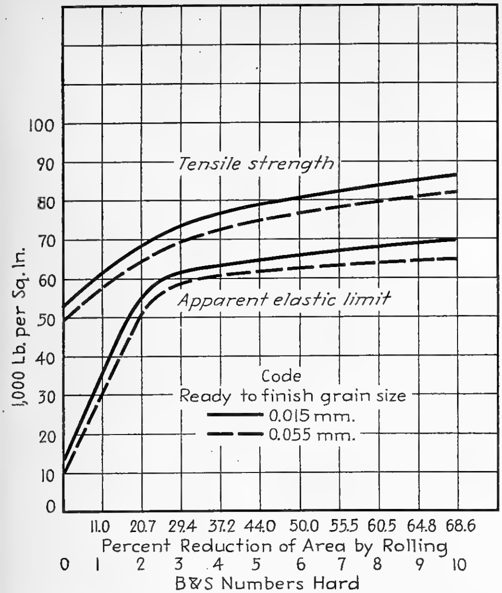


Chart 24.—The effect of cold rolling on the tensile strength and apparent elastic limit of 80-20 cupro-nickel strip, previously annealed to two different grain sizes, 0.015 and 0.055 mm. (78.18 % copper, 20.65 % nickel, 0.51 % manganese) (0.040-in. stock).

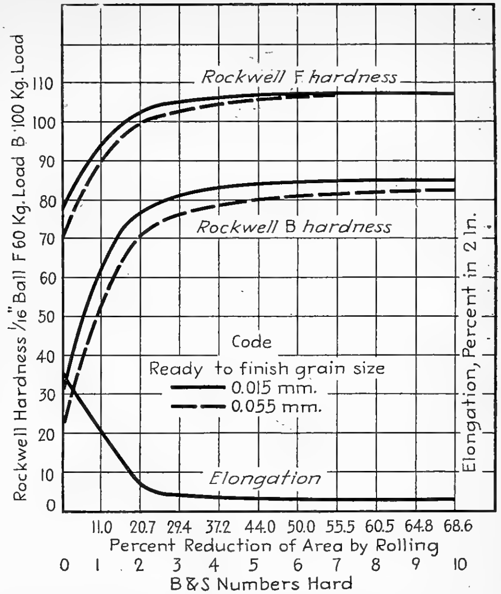


Chart 25.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of 80-20 cupro-nickel strip, previously annealed to two different grain sizes, 0.015 and 0.055 mm. (78.18 % copper, 20.65 % nickel, 0.51 % manganese) (0.040-in. stock).

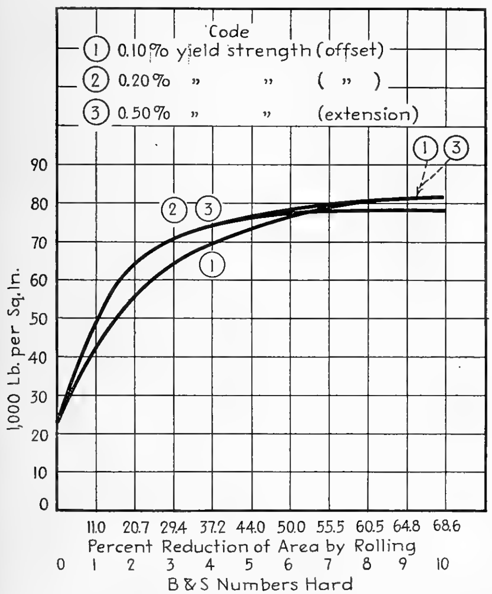


Chart 26.—The effect of cold rolling on the yield strengths of 80-20 cupro-nickel strip, previously annealed to a grain size of 0.015 mm. (78.18 % copper, 20.65 % nickel, 0.51 % manganese) (0.040-in. stock).

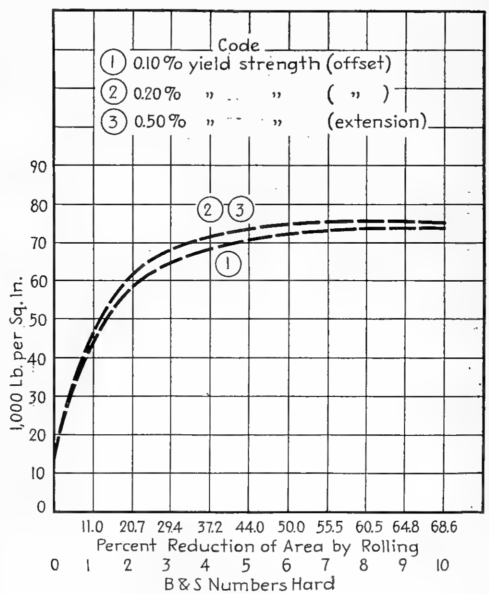


Chart 27.—The effect of cold rolling on the yield strengths of 80-20 cupro-nickel strip, previously annealed to a grain size of 0.055 mm. (78.18 % copper, 20.65 % nickel, 0.51 % manganese) (0.040-in. stock).

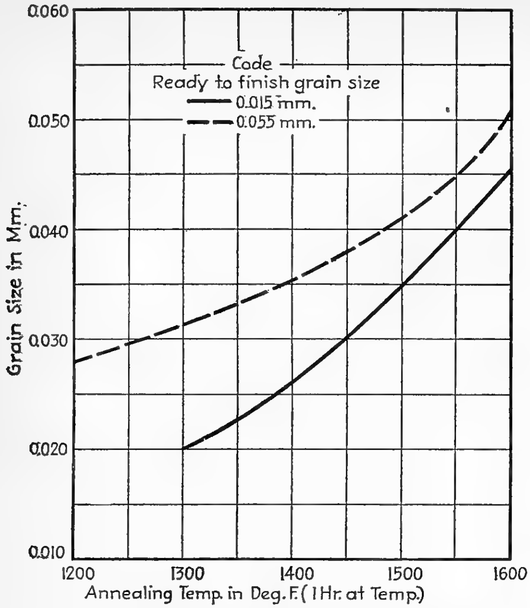


Chart 28.—The effect of annealing on the grain-growing characteristics of 80-20 cupro-nickel strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.055 mm. (78.18 % copper, 20.65 % nickel, 0.51 % manganese) (0.040-in. stock).

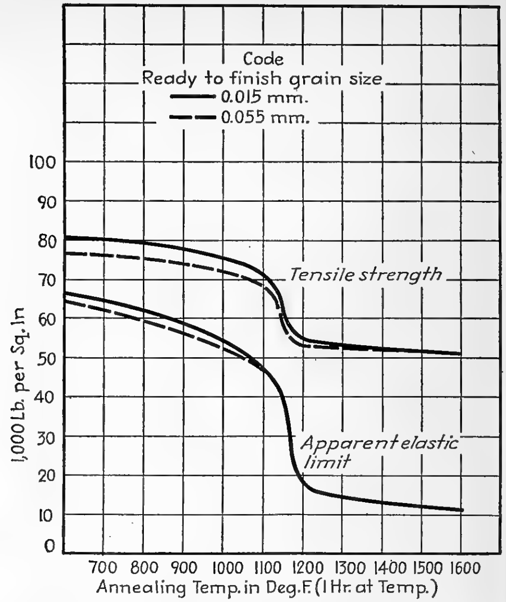


Chart 29.—The effect of annealing on the tensile strength and apparent elastic limit of 80-20 cupro-nickel strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.055 mm. (78.18 % copper, 20.65 % nickel, 0.51 % manganese) (0.040-in. stock).

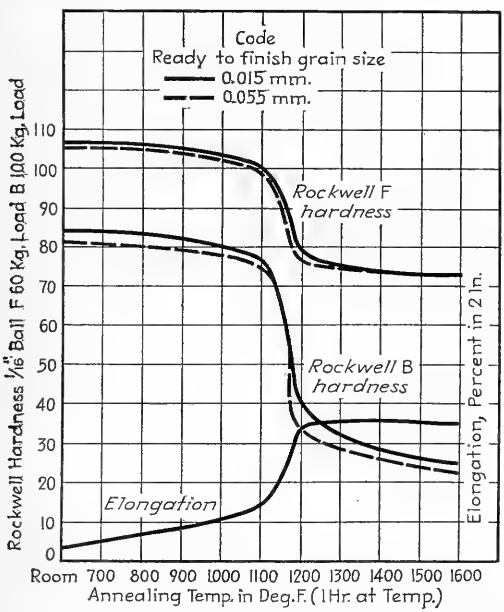


Chart 30.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of 80-20 cupro-nickel strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.055 mm. (78.18 % copper, 20.65 % nickel, 0.51 % manganese) (0.040-in. stock).

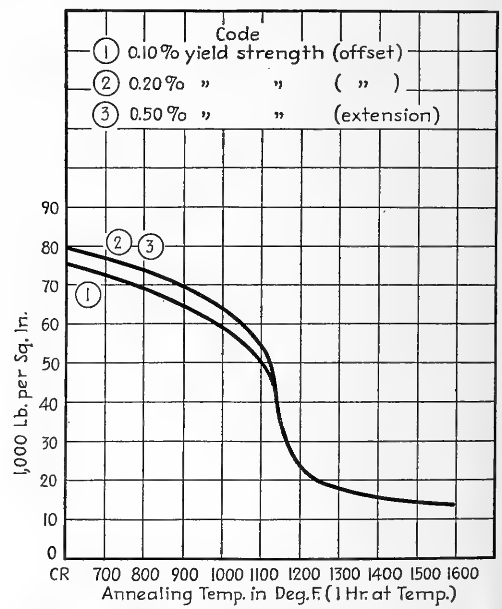


Chart 31.—The effect of annealing on the yield strength of 80-20 cupro-nickel strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (78.18 % copper, 20.65 % nickel, 0.51 % manganese) (0.040-in. stock).

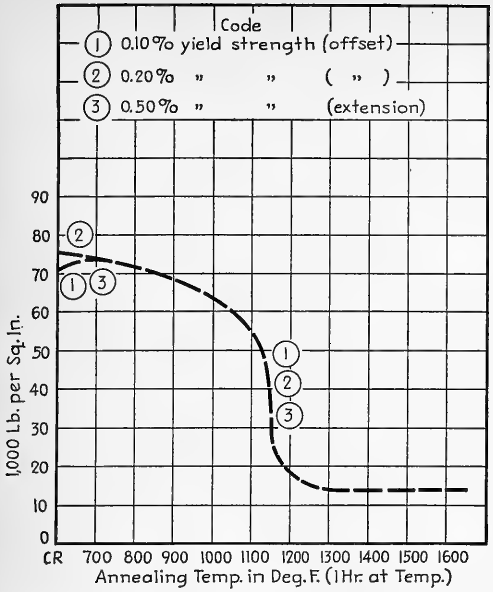


CHART 32.—The effect of annealing on the yield strength of 80-20 cupro-nickel strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.055 mm. (78.18 % copper, 20.65 % nickel, 0.51 % manganese) (0.040-in. stock).

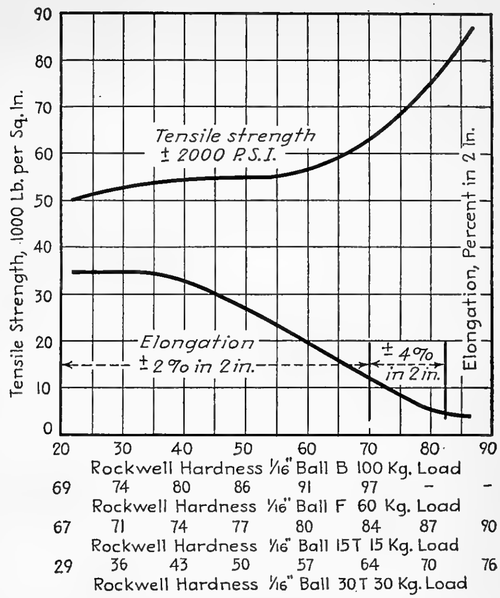


CHART 33.—This chart can be employed to determine the approximate tensile strength and percentage elongation of 80-20 cupro-nickel strip (78.18 % copper, 20.65 % nickel, 0.51 % manganese) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

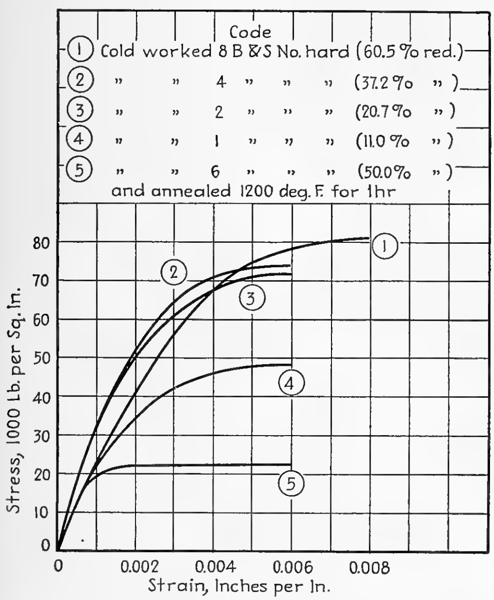


CHART 34.—The effect of cold rolling on the stress-strain characteristics of 80-20 cupro-nickel strip (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (78.18 % copper, 20.65 % nickel, 0.51 % manganese.)

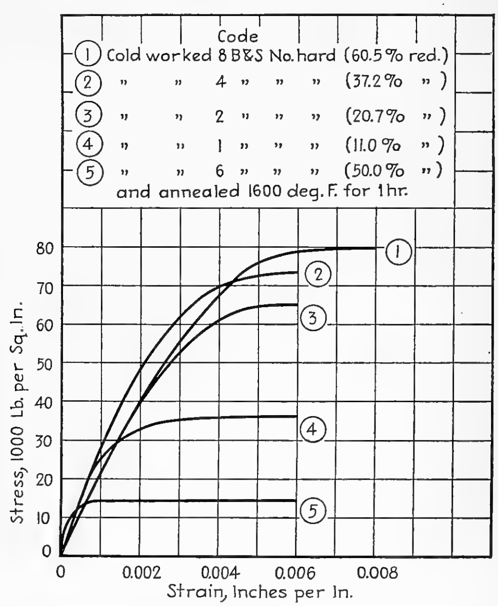


CHART 35.—The effect of cold rolling on the stress-strain characteristics of 80-20 cupro-nickel strip (0.040 in. thick) having a ready-to-finish grain size of 0.055 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used (79.18 % copper, 20.65 % nickel, 0.51 % manganese).

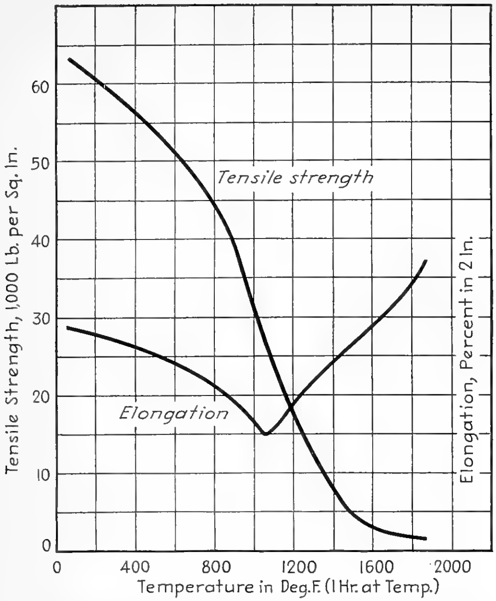


CHART 36.—The effect of elevated temperature on the tensile strength and percentage elongation in 2 in. of 80-20 cupro-nickel rod, previously cold-drawn 20 per cent (reduction of area) from material having a grain size of 0.035 mm. (79.99 % copper, 19.60 % nickel, 0.41 % iron and manganese). Based on data by G. D. Bengough[11,9] (rod under 1 in. in diameter).

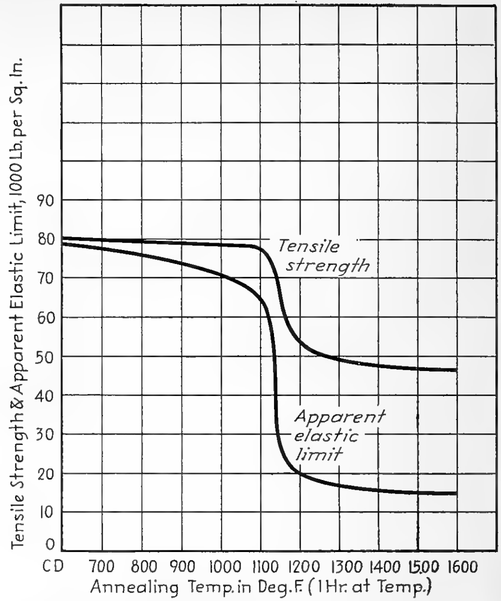


CHART 37.—The effect of annealing on the tensile strength and apparent elastic limit of 80-20 cupro-nickel tube, previously cold-drawn 60 per cent (reduction of area) from material having a grain size of 0.050 mm. (78.18 % copper, 20.65 % nickel, 0.51 % manganese).

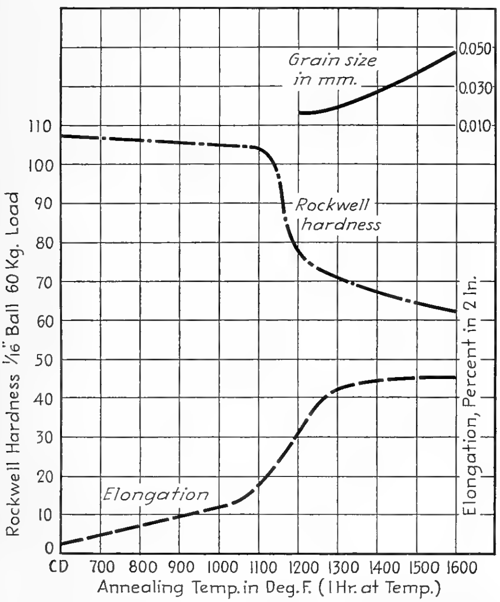


CHART 38.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and grain size of 80-20 cupro-nickel tube, previously cold-drawn 60 per cent (reduction of area) from material having a grain size of 0.050 mm. (78.18 % copper, 20.65 % nickel, 0.51 % manganese).

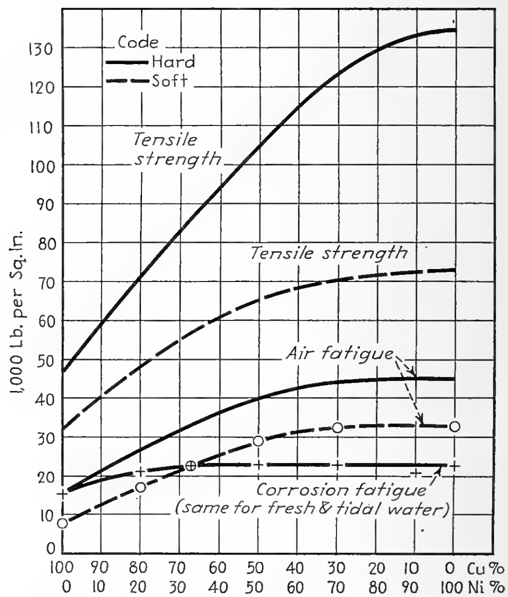


CHART 39.—The tensile strength, fatigue, and corrosion fatigue (for both fresh and tidal waters) of alloys of copper and nickel. Based on data by H. J. Gough.[8]

CHAPTER VIII

THE SILICON BRONZES

The silicon bronzes are essentially alloys of copper and silicon containing usually from 0.25 to 1.25 per cent of one of the four elements: tin, manganese, zinc, iron.

These alloys were introduced in the United States about 1925, and since that time their use has increased continuously. There are many silicon bronzes in commercial use, differing one from the other primarily in the silicon content and nature of the third constituent.

Within the past several years there has been a commercial division of the silicon bronzes into two general types, which are known as Grades A and B.

The Grade A silicon bronzes are those containing the maximum of silicon and of the third constituent and are used in those applications which require the highest tensile properties in combination with a resistance to corrosion equal to or better than that of copper. These Grade A alloys possess welding characteristics similar to those of the mild steels.

Grade B silicon bronzes are those which contain smaller amounts of silicon and of the third constituent and are characterized by unusually good cold-working properties in combination with tensile properties comparable to 70-30 brass, corrosion resistance similar to that of copper, and welding properties only slightly inferior to the Grade A alloys.

Both grades of silicon bronzes have excellent hot-working properties and can be readily rolled, forged, and extruded. As in the case of copper and copper-rich brasses, lead must be controlled to trace amounts in order to avoid cracking in hot forging or hot rolling.

Grade A silicon bronze work-hardens much more rapidly than Grade B silicon bronze. As a consequence it is possible to attain tensile properties greatly in excess of those attainable with Grade B. This latter grade has cold-working and work-hardening properties similar to 70-30 brass, which is one of the most ductile and malleable of the brasses.

Annealing in both grades is carried out within the temperature range of 700 to 1400°F., depending upon the degree of anneal required. When annealing is carried out under oxidizing atmospheres, the scale formed on the silicon bronzes is very refractory and difficult to remove by ordinary cleaning methods. A cleaning solution of 10% H_2SO_4 + 20% HNO_3 + 5% HF, balance water, has been found effective.

TABLE 1
COMMERCIAL SILICON BRONZES

Grade	Name	Copper, %	Silicon, %	Iron, %	Manganese, %	Tin, %	Zinc, %	Lead, %	Nickel, %
A	Herculoy 418	Balance	2.75–3.25	....	....	0.35–0.65			
A	Herculoy 420	Balance	2.75–3.25	....	0.75–1.25				
A	Everdur 1010	Balance	2.85–3.35	0.25 max.	0.85–1.35	....	....	0.05 max.	
A	Olympic A	Balance	2.75–3.25	0.20 max.	....	....	0.5 –1.5	0.05 max.	
A	Duronze 2	Balance	2.75–3.00	0.10–0.15					
A	PMG 10	Balance	2.80–3.50	0.80–1.60	....	....	....	0.05 max.	
A	PMG 94	Balance	2.30–3.00	0.30–0.70	....	....	2.5 –4.5	0.05 max.	
A	PMG 96	Balance	2.30–3.00	0.30–0.70	....	....	....	0.05 max.	
A	New Haven Copper	Balance	2.25–3.25	0.50–1.25	....	....	....	....	0.4–0.60
B	Herculoy 419	Balance	1.75–2.25	....	....	0.15–0.35	....	0.05 max.	
B	Herculoy 421	Balance	1.50–2.00	....	0.15–0.40				
B	Everdur 1015	Balance	1.25–1.75	0.25 max.	0.10–0.50	....	....	0.05 max.	
B	Olympic B	Balance	1.25–1.75	0.20 max.	....	....	0.5 –1.25	0.05 max.	
B	Duronze 5	Balance	1.80–2.00	....	....	....	0.05–max.		
B	Duronze 1	Balance	0.90–1.10	....	....	1.25–1.5			
B	PMG 98	Balance	2.00–2.60	0.30–.70	....	....	....	0.05 max.	

Grade A silicon bronzes are most commonly used in the form of sheet, strip, plate, and rod for the construction of welded tanks, range boilers, chemical equipment, and the like. Since ease of welding in combination with the strength of mild steel and the corrosion resistance of copper is the important specific property of these alloys, detailed recommended practice is given on page 250.

Grade B silicon bronzes are used almost exclusively for the manufacture of products requiring excellent cold-working properties in their manufacture. Cold-headed bolts, nuts, screws, lag bolts, and similar items annually account for the consumption of large quantities of these materials.

The physical and mechanical properties of competitive grades of silicon bronzes are essentially the same.

TABLE 2
SILICON BRONZE—TYPE A
GENERAL DATA—ROD
Silicon, 3%; manganese, 0.5–1.0%; copper, balance

Property	Rod		Forgings	
	Hard[a]	Soft[b]	Hot	Cold[c]
Tensile strength, p.s.i. (000 omitted)	110	62	60–70	68
Apparent elastic limit, p.s.i. (000 omitted)	94	21	20–35	35
Elongation, % in 2 in.	5	72	65–75	60
Reduction of area, %	45	75	55–75	64
Endurance limit, p.s.i. (000 omitted)	30	18		
Rockwell hardness F, 1/16-in. ball, 60-kg. load	112	81	80–95	
Rockwell hardness B, 1/16-in. ball, 100-kg. load	98	45	35–60	70
Modulus of elasticity, p.s.i.	15,000,000			
Melting point, °F.	1860			
Forging range, °F.	1250–1450			
Forging quality	Good			
Type structure	Single phase, alpha			
Density, lb. per cu. in.	0.308			

GENERAL DATA—STRIP
Silicon, 3.19%; tin, 0.46%; copper, balance

Property	Hard[d]	Soft[e]
Tensile strength, p.s.i. (000 omitted)[f]	107–119	62–73
Elongation, % in 2 in.[f]	5	22–47
Apparent elastic limit, p.s.i. (000 omitted)[f]	94–104	22–38
Rockwell hardness F, 1/16-in. ball, 60-kg. load[f]	111–116	87–98
Endurance limit at 10^8 reversals: (1, 6)		
Soft, p.s.i. (000 omitted)	16	
4 B. & S. Nos., hard, p.s.i. (000 omitted)	23	
8 B. & S. Nos., hard, p.s.i. (000 omitted)	25	
Young's modulus of elasticity, p.s.i.	15,000,000	
Melting point, °F.	1860	

PHYSICAL DATA

Coefficient of expansion, per °C. from 25–300°C.	0.0000180
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	27
Electrical conductivity, % I.A.C.S., 68°F.	8.1
Density, lb. per cu. in.	0.308

AVAILABLE CREEP DATA (3)

Previous history: (I) Cold-drawn 0.750-in. round bar; annealed 842°F.; Brinell hardness, 119; tensile strength, 70,300 p.s.i.; % elongation in 2 in., 52; % reduction of area, 46. (II) Fully annealed.

Temperature °F.	Stress, p.s.i. required to produce designated rate of creep per 1,000 hr.	
	0.01%	0.10%
I		
400	8,100	14,900
550	3,750	6,400
II		
400	10,500	22,500

[a] Refers to rod cold-drawn 50%; rod under 1 in. in diameter, ready-to-finish grain size of 0.080–0.100 mm.
[b] Refers to 1300°F. anneal (for 1 hr.).
[c] Material cold-struck from forged condition.
[d] 6 B. & S. Nos., hard, 0.015–0.080 mm. grain size at ready-to-finish, respectively.
[e] Refers to 67% cold-rolled sheet, 900 and 1300°F. anneal which leaves 0.015 and 0.080 mm. grain size, respectively.
[f] Apply to strip only (all tests conducted on 0.040-in. stock).

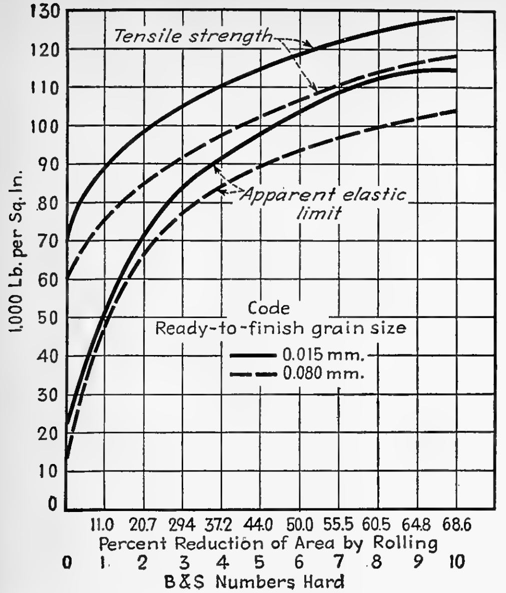


Chart 1.—The effect of cold rolling on the tensile strength and apparent elastic limit of Type A silicon-bronze strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (96.50 % copper, 3.00 % silicon, 0.50 % tin) (0.040-in. stock).

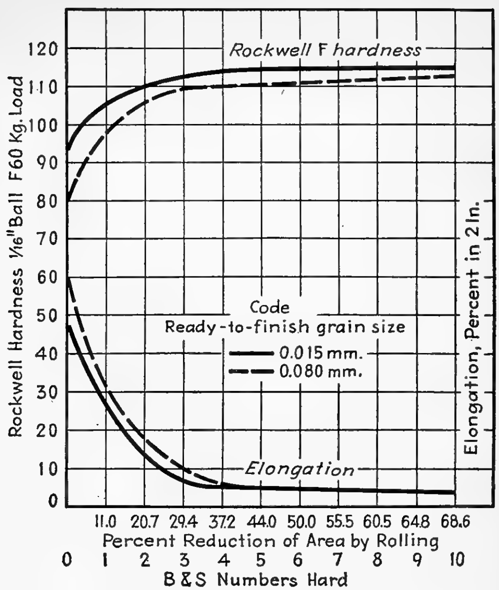


Chart 2.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of Type A silicon-bronze strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (96.50 % copper, 3.00 % silicon, 0.50 % tin) (0.040-in. stock).

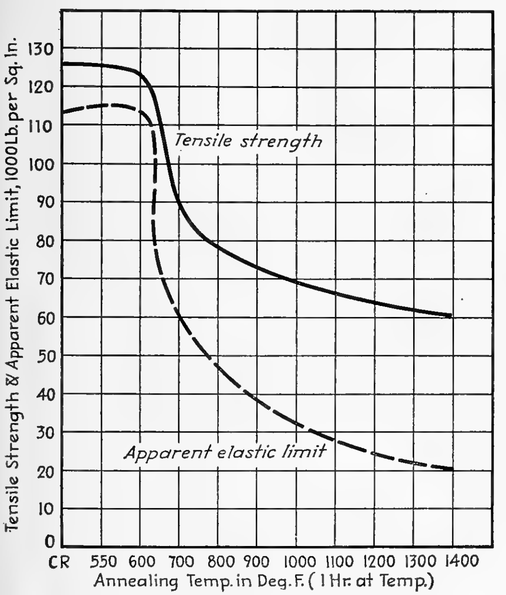


Chart 3.—The effect of annealing on the tensile strength and apparent elastic limit of Type A silicon-bronze strip, previously cold-rolled 10 B. & S. Nos. (67 per cent reduction of area) from a grain size of 0.070 mm. (96.50 % copper, 3.00 % silicon, 0.50 % tin) (0.040-in. stock).

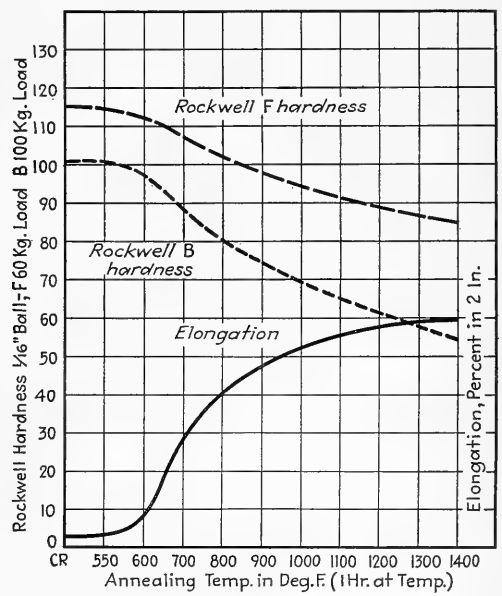


Chart 4.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of Type A silicon-bronze strip, previously cold-rolled 10 B. & S. Nos. (67 per cent reduction of area) from a grain size of 0.070 mm. (96.50 % copper, 3.00 % silicon, 0.50 % tin) (0.040-in. stock).

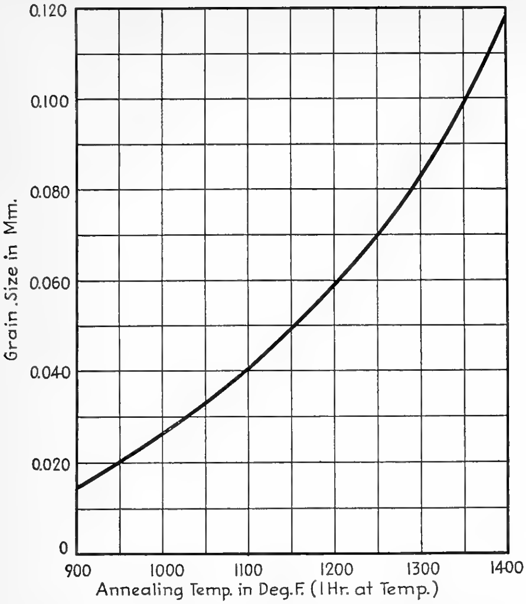


CHART 5.—The effect of annealing on the grain-growing characteristics of Type A silicon-bronze strip, previously cold-rolled 10 B. & S. Nos. (67 per cent reduction of area) from a grain size of 0.070 mm. (96.50 % copper, 3.00 % silicon, 0.50 % tin) (0.040-in. stock).

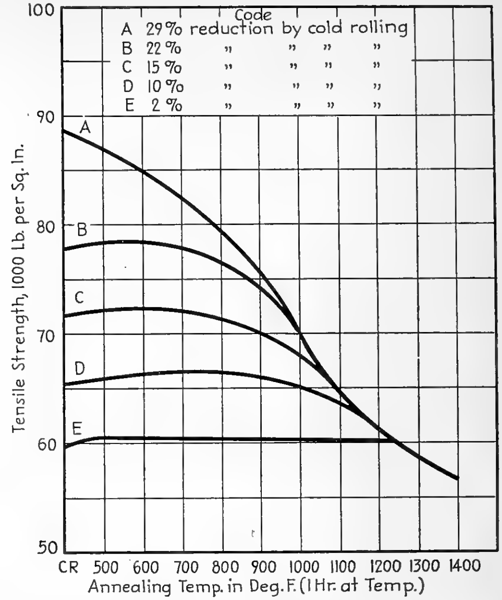


CHART 6.—The effect of annealing on the tensile strength of Type A silicon-bronze strip, previously cold-rolled from 2 to 29 per cent (reduction of area) from a ready-to-finish grain size of 0.090 mm. (96.50 % copper, 3.00 % silicon, 0.50 % tin) (0.040-in. stock).

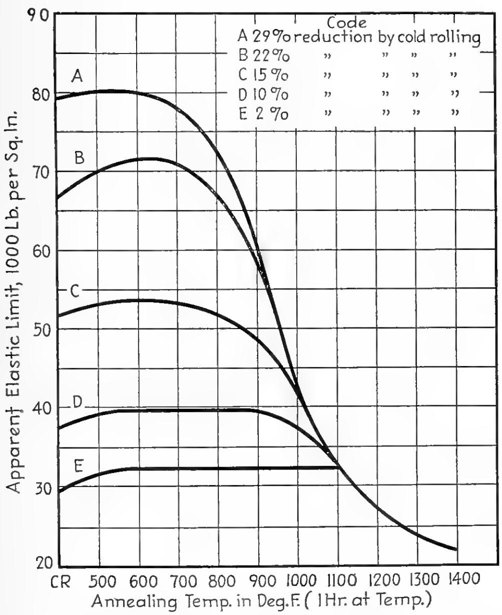


CHART 7.—The effect of annealing on the apparent elastic limit of Type A silicon-bronze strip, previously cold-rolled from 2 to 29 per cent (reduction of area) from a ready-to-finish grain size of 0.090 mm. (96.50 % copper, 3.00 % silicon, 0.50 % tin) (0.040-in. stock).

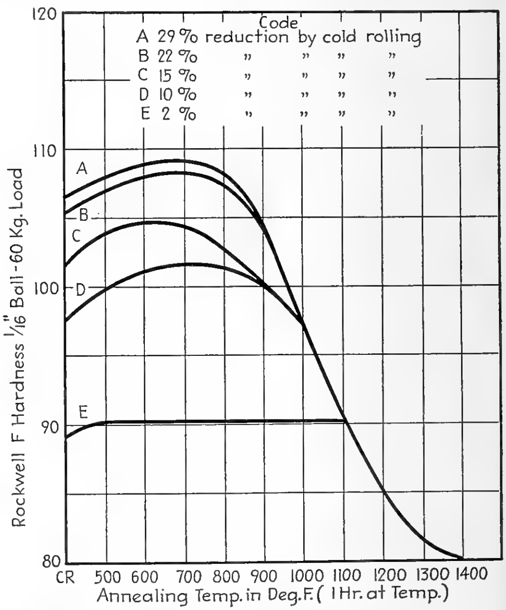


CHART 8.—The effect of annealing on the Rockwell hardness of Type A silicon-bronze strip, previously cold-rolled from 2 to 29 per cent (reduction of area) from a ready-to-finish grain size of 0.090 mm. (96.50 % copper, 3.00 % silicon, 0.50 % tin) (0.040-in. stock).

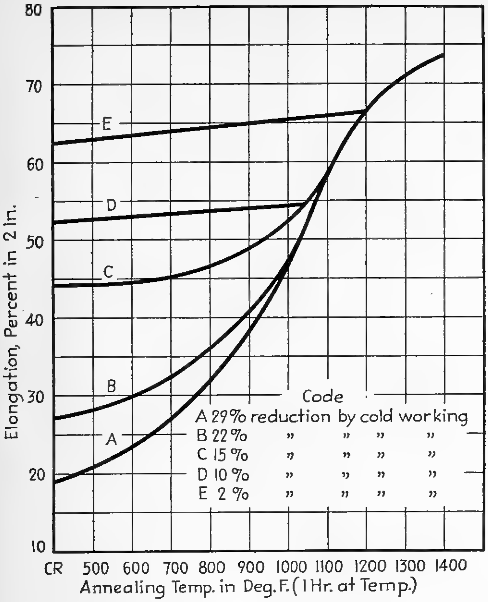


CHART 9.—The effect of annealing on the percentage elongation in 2 in. of Type A silicon-bronze strip, previously cold-rolled from 2 to 29 per cent (reduction of area) from a ready-to-finish grain size of 0.090 mm. (96.50 % copper, 3.00 % silicon, 0.50 % tin) (0.040-in. stock).

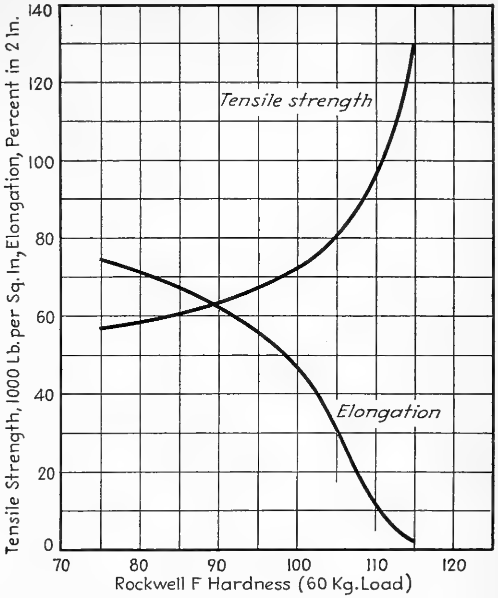


CHART 10.—This chart can be employed to determine the approximate tensile strength and percentage elongation of Type A silicon-bronze strip (96.50 % copper, 3.00 % silicon, 0.50 % tin) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in.

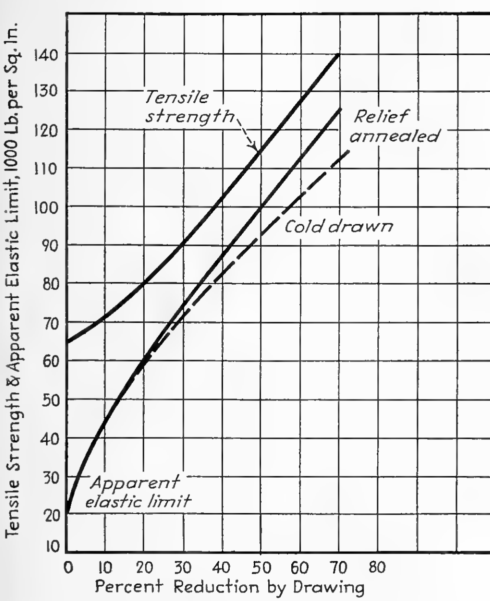


CHART 11.—The effect of cold drawing and cold drawing plus relief annealing on the tensile strength and apparent elastic limit of Type A silicon-bronze rod, previously annealed to a grain size of 0.040 mm. (96.30 % copper, 3.10 % silicon, 0.42 tin) (rod under 1 in. in diameter).

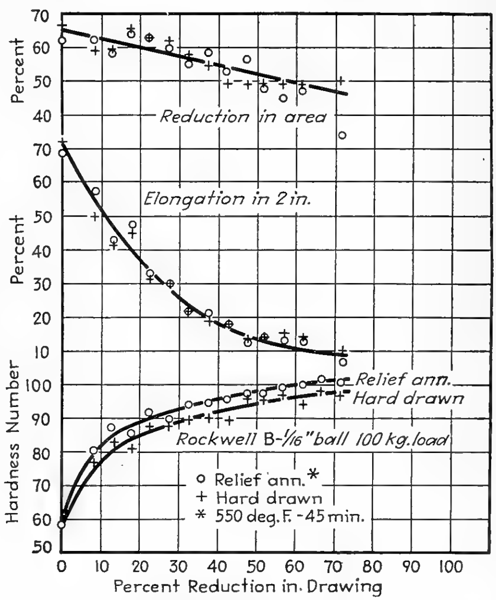


CHART 12.—The effect of cold drawing and cold drawing plus relief annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of Type A silicon-bronze rod, previously annealed to a grain size of 0.040 mm. (96.30 % copper, 3.10 % silicon, 0.42 % tin) (rod under 1 in. in diameter).

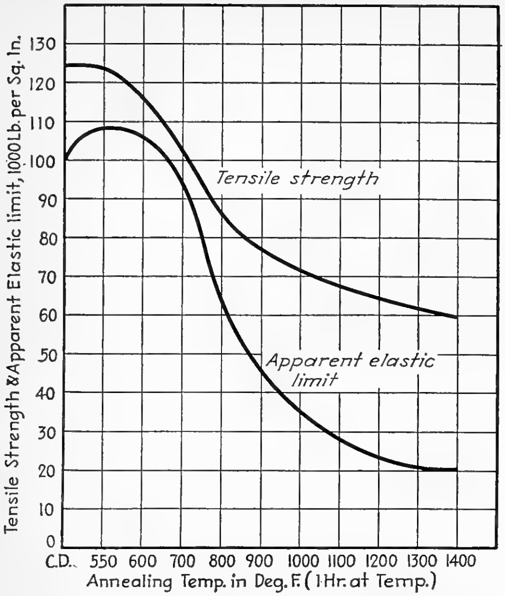


Chart 13.—The effect of annealing on the tensile strength and apparent elastic limit of Type A silicon-bronze rod, previously cold-drawn 55 per cent (reduction of area) from material having a grain size of 0.040 mm. (96.30 % copper, 3.10 % silicon, 0.42 % tin) (rod under 1 in. in diameter).

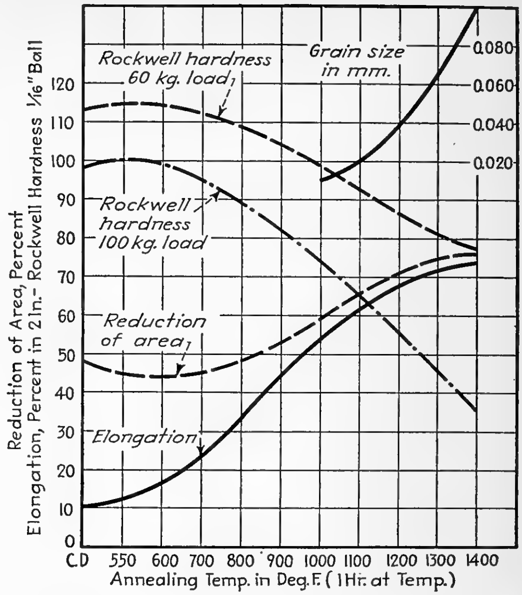


Chart 14.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area and grain size of Type A silicon-bronze rod, previously cold-drawn 55 per cent (reduction of area) from material having a grain size of 0.040 mm. (96.30 % copper, 3.10 % silicon, 0.42 % tin) (rod under 1 in. in diameter).

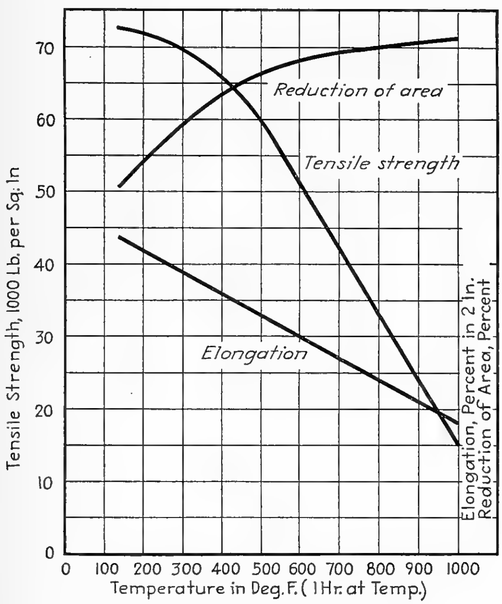


Chart 15.—The effect of elevated temperature on the tensile strength, reduction of area, and percentage elongation in 2 in. of Type A silicon-bronze rod (copper 96.00 %, silicon 3.00 %, manganese 1.00 %) based on data by W. H. Bassett[10,7] (rod under 1 in. in diameter).

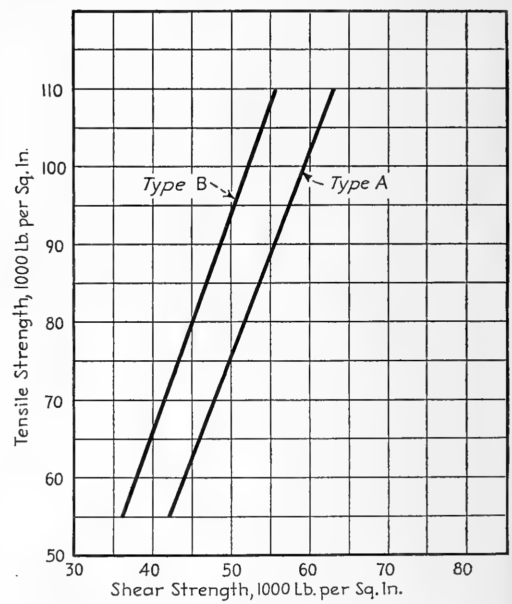


Chart 16.—This chart shows the relationship between shear strength and tensile strength of Types A and B silicon bronzes.[86]

TABLE 3
TYPE B—SILICON BRONZE
GENERAL DATA—ROD
Silicon, 1.91%; copper, balance; manganese, 0.51%

Property	Rod		Forgings		
	Hard[a]	Soft[b]	Hot	Cold[c]	Cold[d]
Tensile strength, p.s.i. (000 omitted)	100	42	42–50	45–55	92
Apparent elastic limit, p.s.i. (000 omitted)	55	7	7–20	20–30	60
Yield strength:					
0.5% extension, p.s.i. (000 omitted)	60	14	35–11	24–58	59
0.2% offset, p.s.i. (000 omitted)	75	13	25–8	24–68	72
0.1% offset, p.s.i. (000 omitted)	65	12	24–7	22–58	63
Elongation, % in 2 in.	70	15	70–50	50–40	15
Reduction of area, %	70	85	85–80	80–80	68
Endurance limit, p.s.i. (000 omitted)	25	15	15–18		
Rockwell hardness F, 1/16-in. ball, 60-kg. load	108	44	44–76	85–100	108
Rockwell hardness B, 1/16-in. ball, 100-kg. load	90	..	48	49–76	90
Brinell hardness, 10-mm. ball, 500-kg. load	..	..	81	82–122	157
Modulus of elasticity, p.s.i.	15,000,000				
Forging range, °F.	1250–1450				
Forging quality	Good				
Type structure	Single phase, alpha				
Density, lb. per cu. in.	0.316				
Melting point, °F.	1900				

GENERAL DATA—STRIP

Property	Hard[e]	Soft[f]
Tensile strength, p.s.i. (000 omitted)[g]	97	51
Elongation, % in 2 in.[g]	9	55
Apparent elastic limit, p.s.i. (000 omitted)[g]	86	17
Rockwell hardness F, 1/16-in. ball, 60-kg. load[g]	111	75
Young's modulus of elasticity, lb. per sq. in.	15,000,000	
Melting point, °F.	1900	
Density, lb. per cu. in.	0.316	

GENERAL DATA—TUBE
Copper, 97.46%; zinc, 0.49%; tin, 0.25%; silicon, 1.91%

Property	Hard[h]	Relief anneal 550°F., 1/2 hr.	Soft[i]
Tensile strength, p.s.i. (000 omitted)	108	100	50
Elongation, % in 2 in.	7	9	40
Apparent elastic limit, p.s.i. (000 omitted)	95	88	22
Rockwell hardness, 1/16-in. ball, 60-kg. load	113	112	73

PHYSICAL DATA

Melting point, °F.	1900
Coefficient of expansion, per °C. from 25–300°C.	0.0000179
Electrical conductivity, % I.A.C.S.	11
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	31
Density, lb. per cu. in.	0.316

[a] Refers to rod cold-drawn 50%; rod under 1 in. in diameter, ready-to-finish grain size 0.080–0.100 mm.
[b] Refers to 1400°F. anneal (for 1 hr.).
[c] Material cold-forged from soft rod (5–40% reduction of area).
[d] Material cold-forged from cold-worked condition (40%).
[e] 6 B. & S. Nos., hard, cold-rolled, relief-annealed.
[f] 10 B. & S. Nos., hard, 1300°F. anneal (1 hr.).
[g] Apply to strip only (all tests conducted on 0.040-in. stock).
[h] Apply to extruded, reduced, and cold-drawn to 3/4 by 0.049 in. with no intermediate anneals.
[i] Apply to h with 1300°F. anneal (1 hr.).

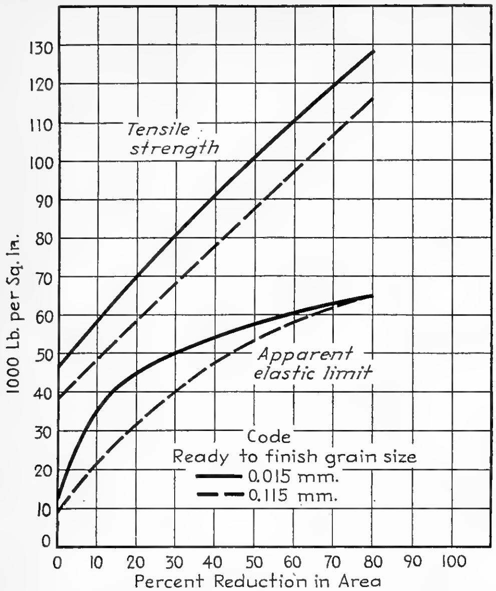


CHART 17.—The effect of cold drawing on the tensile strength and apparent elastic limit of Type B silicon-bronze rod, previously annealed to two different grain sizes, 0.015 and 0.115 mm. (1.76 % silicon, 0.35 % manganese, balance copper) (rod under 1 in. in diameter).

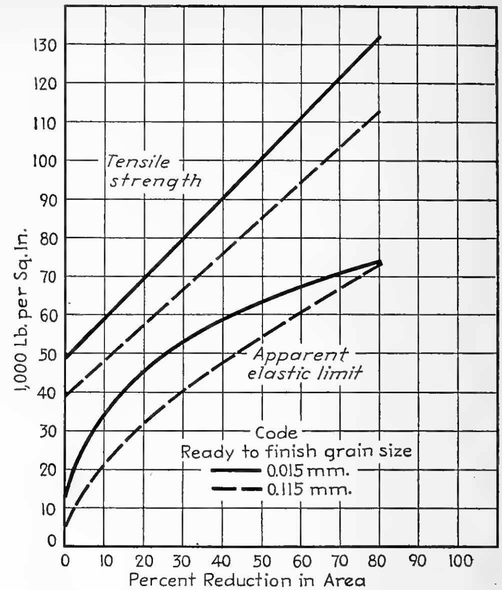


CHART 18.—The effect of cold drawing plus relief annealing for 30 min. at 600°F. on the tensile strength and apparent elastic limit of Type B silicon-bronze rod, previously annealed to two different grain sizes, 0.015 and 0.115 mm. (1.76 % silicon, 0.35 % manganese, balance copper) (rod under 1 in. in diameter).

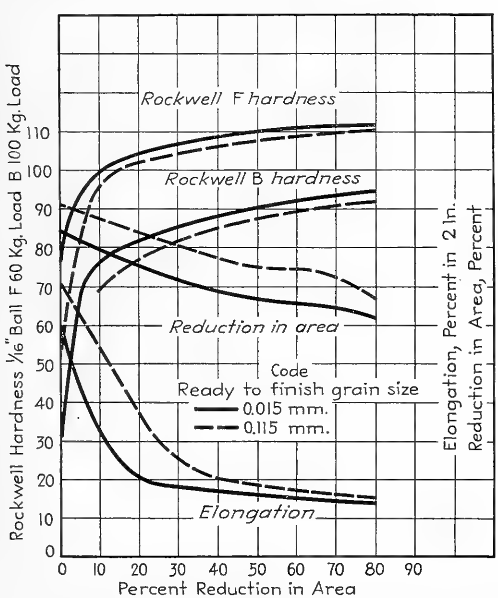


CHART 19.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of Type B silicon-bronze rod, previously annealed to two different grain sizes, 0.015 and 0.115 mm. (1.76 % silicon, 0.35 % manganese, balance copper) (rod under 1 in. in diameter).

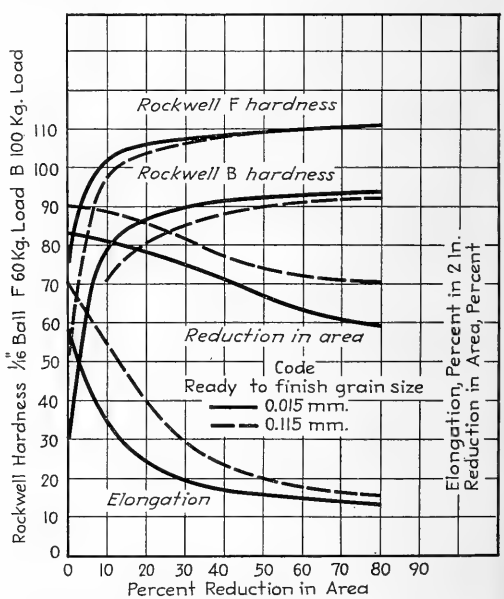


CHART 20.—The effect of cold drawing plus relief annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of Type B silicon-bronze rod, previously annealed to two different grain sizes, 0.015 and 0.115 mm. (1.76 % silicon, 0.35 % manganese, balance copper) (rod under 1 in. in diameter).

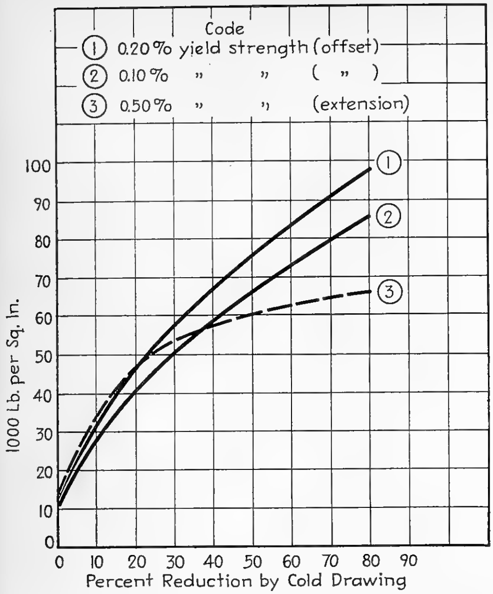


CHART 21.—The effect of cold drawing on the yield strength of Type B silicon-bronze rod, previously annealed to a grain size of 0.115 mm. (1.76 % silicon, 0.35 % manganese, balance copper) (rod under 1 in. in diameter).

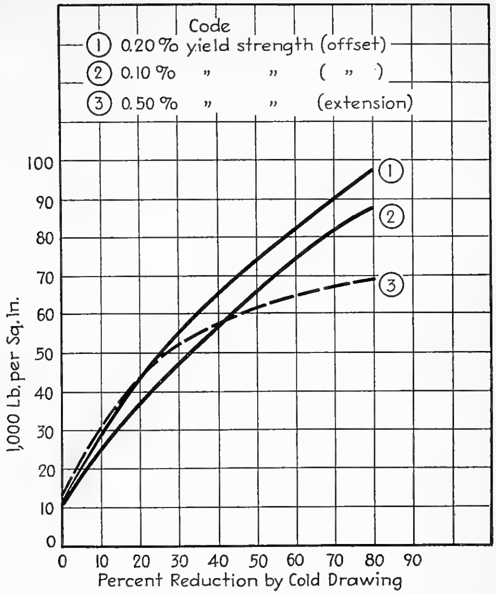


CHART 22.—The effect of cold drawing plus relief annealing at 600°F for 30 min. on the yield strength of Type B silicon-bronze rod, previously annealed to a grain size of 0.115 mm. (1.76 % silicon, 0.35 % manganese, balance copper) (rod under 1 in. in diameter).

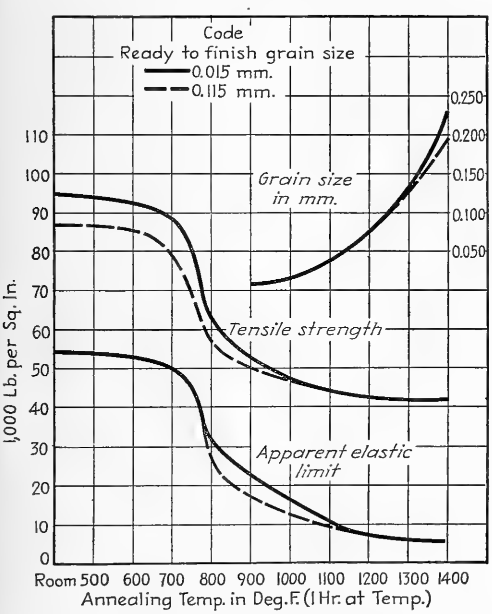


CHART 23.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of Type B silicon-bronze rod, previously cold-drawn 50 per cent (reduction of area) from material having two different grain sizes, 0.015 and 0.115 mm. (1.76 % silicon, 0.35 % manganese, balance copper) (rod under 1 in. in diameter).

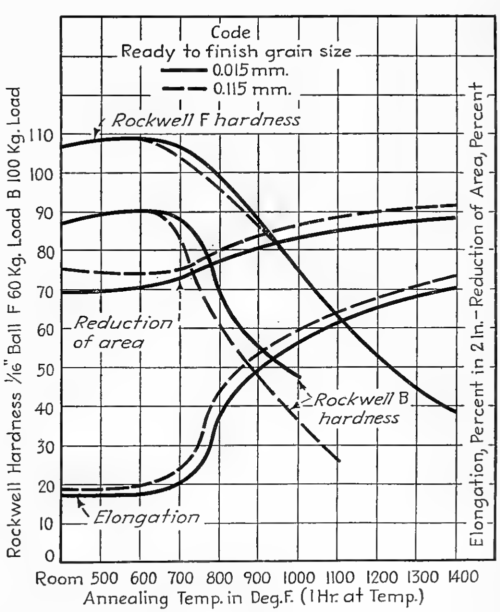


CHART 24.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of Type B silicon-bronze rod, previously cold-drawn 50 per cent (reduction of area) from material have two different grain sizes, 0.015 and 0.115 mm. (1.76 % silicon, 0.35 % manganese, balance copper) (rod under 1 in. in diameter).

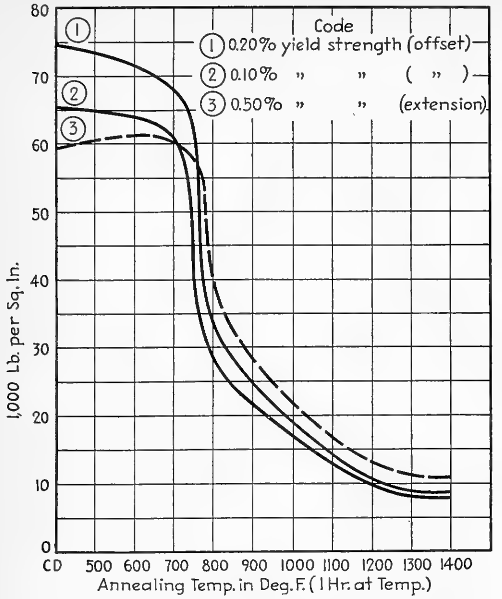


CHART 25.—The effect of annealing on the yield strength of Type B silicon-bronze rod, previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.115 mm. (1.76 % silicon, 0.35 % manganese, balance copper) (rod under 1 in. in diameter).

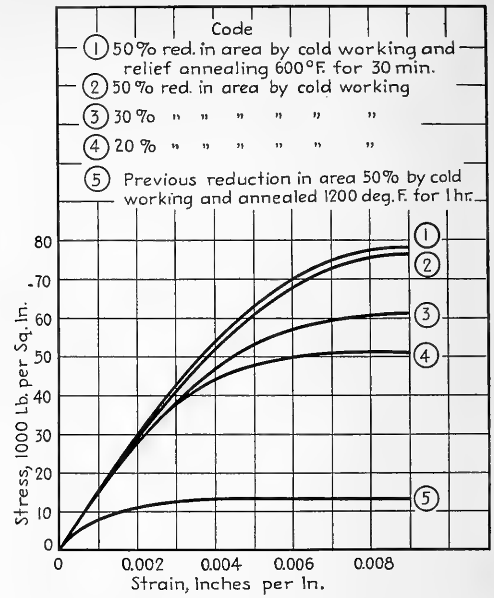


CHART 26.—The effect of cold drawing on the stress-strain characteristics of Type B silicon-bronze rod (under 1 in. in diameter) having a ready-to-finish grain size of 0.115 mm.; 100,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (1.76 % silicon, 0.35 % manganese, balance copper.)

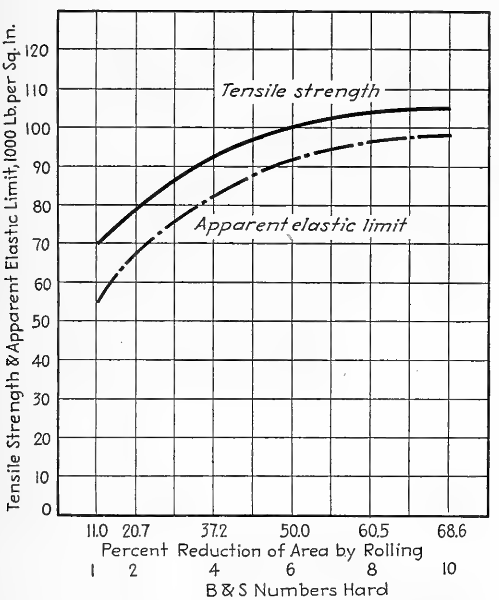


CHART 27.—The effect of cold rolling on the tensile strength and apparent elastic limit of Type B silicon-bronze strip (2.10 % silicon, 0.24 % tin, balance copper) (0.040-in. stock).

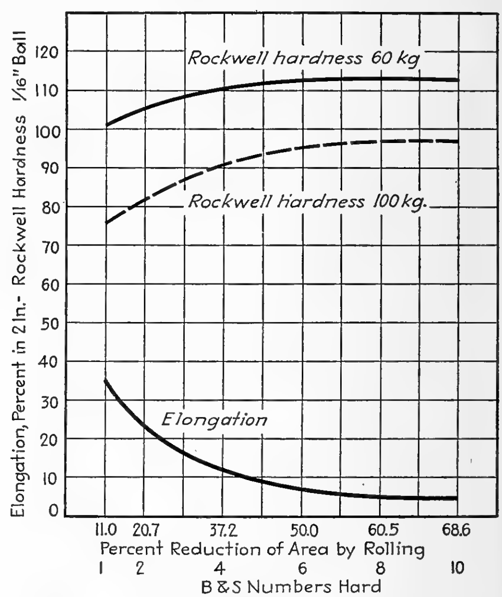


CHART 28.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of Type B silicon-bronze strip (2.10 % silicon, 0.24 % tin, balance copper) (0.040-in. stock).

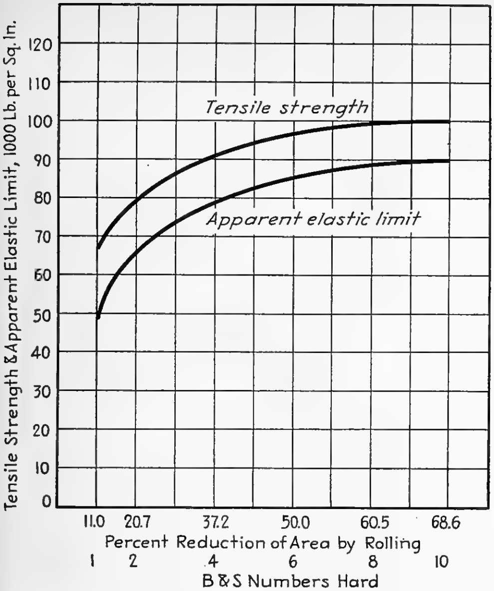


CHART 29.—The effect of cold rolling plus relief annealing at 575°F. for 30 min. on the tensile strength and apparent elastic limit of Type B silicon-bronze strip (2.10 % silicon, 0.24 % tin, balance copper) (0.040-in. stock).

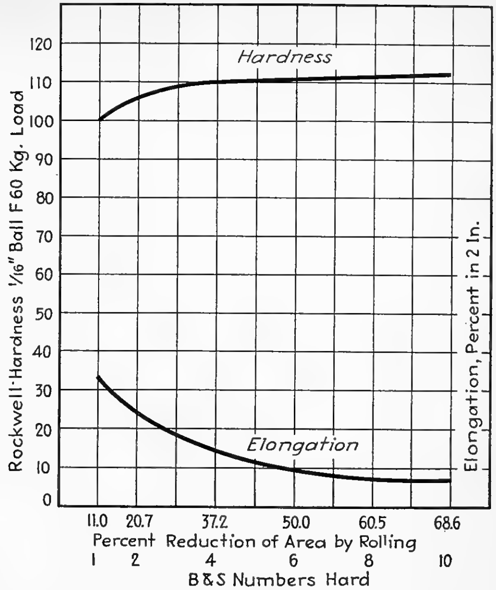


CHART 30.—The effect of cold rolling plus relief annealing at 575°F. for 30 min. on the Rockwell hardness and percentage elongation in 2 in. of Type B silicon-bronze strip (2.10 % silicon, 0.24 % tin, balance copper) (0.040-in. stock).

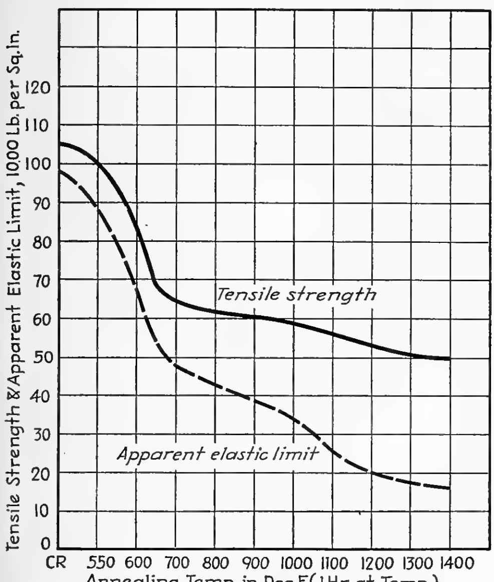


CHART 31.—The effect of annealing on the tensile strength and apparent elastic limit of Type B silicon-bronze strip, previously cold-rolled 10 B. & S. Nos. (67 per cent reduction of area) (2.10 % silicon, 0.24 % tin, balance copper) (0.040-in. stock).

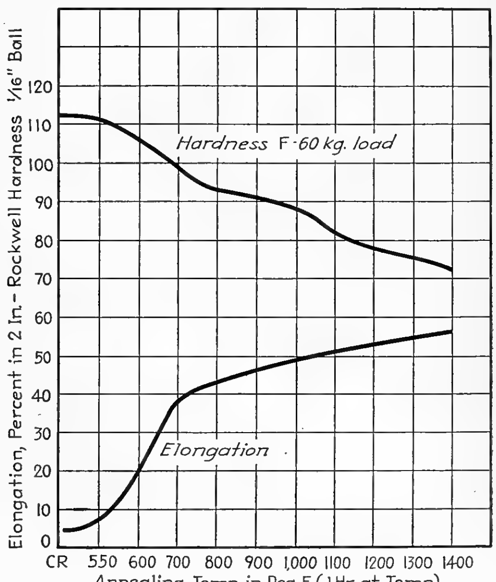


CHART 32.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of Type B silicon-bronze strip, previously cold-rolled 10 B. & S. Nos. (67 per cent reduction of area) (2.10 % silicon, 0.24 % tin, balance copper) (0.040-in. stock).

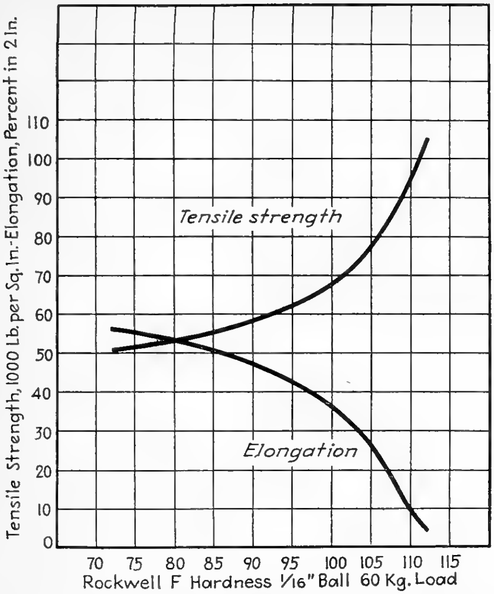


CHART 33.—This chart can be employed to determine the approximate tensile strength and percentage elongation of Type B silicon-bronze strip (2.10 % silicon, 0.24 % tin, balance copper) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in.

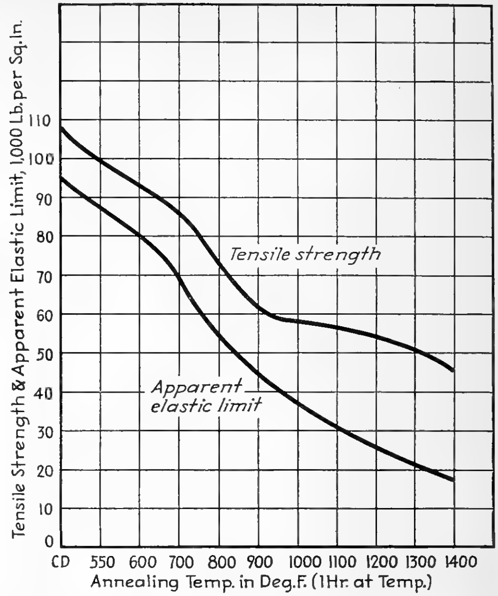


CHART 34.—The effect of annealing on the tensile strength and apparent elastic limit of Type B silicon-bronze tubing (0.25 % tin, 1.91 % silicon, balance copper), previously cold-drawn 70 per cent (reduction of area).

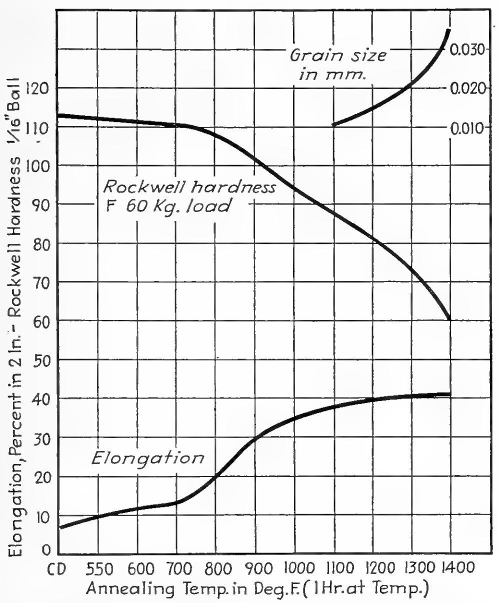


CHART 35.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and grain size of Type B silicon-bronze tubing (0.25 % tin, 1.91 % silicon, balance copper), previously cold-drawn 70 per cent (reduction of area).

JOINING THE TYPE A SILICON BRONZES*

As has been mentioned, the silicon bronzes owe much of the popularity they enjoy to the fact that they are weldable by all the common methods. Welded applications of the silicon bronzes include range boilers or hot-water storage tanks, paper-mill pulp lines, unfired pressure vessels to meet ASME Specifications (Par. U69 and U70, Case 864) and linings for steel vessels.

The silicon bronzes are, to sum up briefly their metallurgical characteristics as they affect weldability, high-shrinkage alloys of medium thermal and electrical conductivity with a hot-short range just below their melting points. Indicative of their low strength when hot is the fact that hot working is not recommended at temperatures above 1475°F. In the liquid state they are comparatively free flowing but are usually covered with a thin film of silicon oxide, which materially increases their surface tension. Such reducing flame gases as carbon monoxide and hydrogen are quite soluble in molten silicon bronzes.

Rapid freezing of the weld metal is recommended to promote a fine grain structure, to prevent overstressing of the weld metal while it is in a weak temperature range, and generally to cut down the exposure time to contaminating flame and ambient air gases.

Although all the common methods of fusion welding—carbon arc, metal arc, and oxyacetylene—have been employed, the carbon arc and oxyacetylene methods find

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widest use, with the inexpensive carbon-arc method generally preferred.

In the execution of welds by the carbon method material gages up to $\frac{3}{16}$ inch are best set up with a copper backer to support the molten weld metal. The surface tension of the molten weld metal and the chill of the base metal are sufficient to permit easy execution of welds in thicknesses of $\frac{3}{16}$ inch and over without backing. As the carbon electrode burns first to carbon monoxide and then to carbon dioxide, the carbon arc flame is both reducing and neutral in nature depending on the distance from the electrode. Experimental work has indicated that the soundest weld is obtained through the use of the longer and more neutral flame. The use of a long arc also reduces difficulties with carbon transfer, which characterizes the very short arc and which often stiffens up the floating slag to the point where easy and rapid blending of weld and parent metals is difficult. In the case of an unbacked weld, the use of a long arc in all passes is impractical because of the tendency for the filler rod to melt ahead of the point of arc contact. In the execution of welds in backed-up seams in light gage material, there is another consideration. The longer the arc, the greater the spread of heat and the larger the size of the weld pool. When the size of the weld pool is out of proportion to its depth or thickness, the surface tension of the molten metal may cause it to recede from the point of arc contact in an effort to assume the smallest surface area possible, thereby resulting in a large gap or discontinuity in the weld bead. Experience indicates an optimum arc length of $1\frac{1}{2}$ to 2 times the optimum filler-rod diameter.

It should be noted that the carbon-arc method has points of similarity to both gas and arc welding, the technique being similar to that used with the former. The carbon-arc method has the flexibility of the gas method in that the source of heat is independent of the size, source, and amount of filler metal added. However, the carbon arc is much more intense and the rate of flow of heat greater than with the oxyacetylene flame, and there are greater possibilities of overheating on one hand and of cold welding in an effort to prevent overheating on the other hand. The proper arc length, the nature and solubility of flame gases, the effect of carbon transfer, and the relation between the speed of welding, pattern of weaving, the arc length, current, and filler-rod diameter all have to be considered with respect to their mutual relationship. Because of the independency of the sources of heat and filler metal, the operator functions as an instrument of control in the correlation of the aforementioned details. With the optimum welding speed varying for each operator, it is important that the proper correlation of the above details be determined and the use of a recommended amperage in conjunction with the use of a mechanized movement of the electrode be avoided.

The center line of the weld is naturally the hottest section. Overheating of the central portion of the weld should be avoided by effecting maximum heating at the edges of the weld and by avoiding crossing the weld at the same point in the center line. This is readily accomplished by "whipping" the electrode across the center line much as is done in the execution of a vertical seam by the metal-arc process. The use of the arc length previously mentioned affords the welder an opportunity to ascertain when sufficient heat has been added, as evidenced by fusion and blending of base and filler metals. Continued application of the arc, once fusion and blending have been obtained, is to be avoided.

Because of the rapidity with which the weld metal freezes, its hot shortness, and characteristic high shrinkage, the crater weld metal is often overstressed in a weak temperature range and may crack unless care is taken to feed the shrink of the crater when welding is discontinued, even momentarily. This is easily accomplished by lengthening the arc slightly and directing it on the end of the filler rod or the size of the weld pool and the attendant total shrinkage, or the tendency to crack may be reduced by increasing the rate of progression to the point where cold welding results when a stop in welding is contemplated.

Silicon bronzes are furnished in both bright-dipped and hot-rolled finishes as the customer desires. In the latter case it is essential that the black oxide on the parent metal edges and surfaces adjacent to the weld seam be removed. In both cases it is advisable to remove either with emery cloth, a scraper, file, or grinder any grease and dirt that may have accumulated in transit or storage. The final cleaning operation should follow any machining, drawing, or stamping and should immediately precede welding. Likewise during welding, each bead surface and the adjacent vee walls should be cleaned of oxide, flux, and slag before any subsequent beads are laid down. It is good practice to clean the welding rod also.

TABLE 4

Metal gage	Filler-rod size, in.		Copper backing-bar groove, in.
	Round (diameter)	Flat[a]	
0.040, 0.050, 0.065	$\frac{3}{32}$–$\frac{1}{8}$	0.080 × 0.220	0.030–0.050 × $\frac{3}{16}$
0.065, 0.070, 0.080, 0.093	$\frac{1}{8}$	0.090 × 0.220	0.050 × $\frac{3}{16}$
0.093, 0.125	$\frac{1}{8}$–$\frac{5}{32}$	0.090 × 0.360	0.060 × $\frac{3}{16}$

[a] Clamped on edge between abutting edges to be joined.

The use of a flux is recommended to keep the oxides developed free-flowing. Proprietary fluxes are available, or a satisfactory flux may be made up with fused borax as a base, and sodium fluoride or barium carbonate added to improve the fluidity. Water-free constituents only should be employed. Likewise, the fluxes should be applied either as a dry powder or preferably, as an alcoholic paste to the base metal and/or the filler rod. Water contained in any fluxing ingredient will volatilize as steam and may be trapped as porosity in the rapidly freezing weld metal.

Filler-rod diameters are chosen so that the melting of an inch of filler rod per inch of seam will provide sufficient filler metal to deposit a layer of ⅛-inch thickness. Thicker layers or passes are to be avoided as they

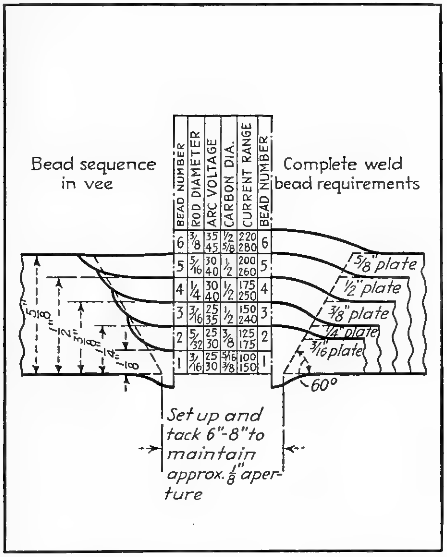

Fig. 1.—Chart of recommended carbon-arc-welding procedure for silicon bronzes, single V welds, 3/16- to ⅝-in. plate, according to Bunn, Hunter, and Seidlitz.(32)

may interfere with the welder's ability to ascertain when fusion and blending have been obtained. Recommended filler-rod sizes for various thicknesses, as well as base-metal preparation, if any, are indicated in Table 4 and Figs. 1 and 2.

The use of the more expensive oxyacetylene method of welding is more or less confined to joining the medium and heavy gages of material. Joint setups employed are the same as those employed for the carbon-arc method; the seams are, however, run as free welds, a tapered aperture of approximately 3/16 inch being desirable to allow for contraction of the weld metal. The oxyacetylene flame is less intense and the rate of heat flow considerably less than the carbon-arc method. Cooling of the weld is, therefore, much slower and it is necessary in order to prevent cracking to begin welding at some point P, 4 to 6 inches from one end of the seam and run to the nearest end. After this section has cooled to a black heat, welding may be started again at P and the seam run to the other end. Tip sizes and filler-rod diameters are essentially the same as employed for the same gage of steel. The flame should be neutral to slightly oxidizing—definitely not reducing. The use of a flux, either in the powder form or applied as a water paste to the base metal and the filler rod, is essential.

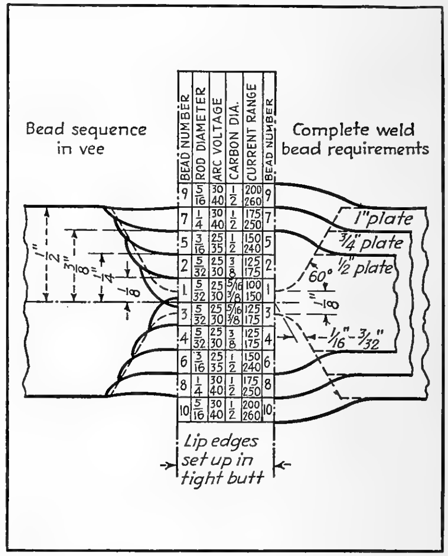

Fig. 2.—Chart of recommended carbon-arc procedure for silicon bronzes, double V welds, ½- to 1-in. plate, according to Bunn, Hunter, and Seidlitz.(32)

Proprietary fluxes are available, or a satisfactory flux may be made up of boric acid (85 to 90 per cent) and borax (10 to 15 per cent).

The metal-arc method has found little application except as a method of depositing bronze overlays on steel for wear surfaces. There are to date no completely satisfactory coated electrodes available. Metal-arc welding with bare electrodes is characterized by globular, intermittent, and somewhat wild transfer of metal across the arc, necessitating maintenance of a comparatively large well pool if any measure of control is to be maintained. In the lighter gages it is necessary to deposit an unduly large bead if cross-bead checks are to be avoided. Welds executed by this method will not, in general, compare with those executed by either the carbon-arc or oxyacetylene methods.

CHAPTER IX

THE ALUMINUM BRONZES

Aluminum bronzes are high-copper alloys with aluminum, most commonly containing between 4 and 10 per cent of aluminum. Additions of iron, nickel, silicon, and manganese are frequently made to the alloys of higher aluminum content to increase strength and hardness.

The industrial use of the aluminum bronzes has until recently been largely restricted to castings for acid-resisting parts. Difficulties in the fabrication of wrought aluminum bronzes have greatly retarded their extensive application. Developing technique and improved manufacturing facilities are gradually rendering wrought forms of these alloys more readily available.

Industrial aluminum bronzes are of two general types: the alpha or single-phase alloys—often referred to as homogeneous alloys; and the alpha-beta, or two-phase alloys—known commercially as duplex bronzes. Under perfect equilibrium conditions 9.8 per cent of aluminum is soluble in copper before the beta phase appears, but in commercial practice perfect equilibrium conditions are practically never reached, and alloys containing in excess of 7.5 per cent of aluminum usually exhibit two phases.

The alpha aluminum bronzes possess excellent cold-working properties. They also have good hot-working properties and can be readily hot-forged, rolled, and extruded. They are most plastic within a temperature range of 1450 to 1650°F. Their hot plasticity increases as the aluminum content increases and, conversely, their cold-working properties decrease with a corresponding increase in sensitivity to work hardening.

The duplex bronzes have excellent hot-working properties through a much wider range than the alpha bronzes. They can be extruded and hot-forged into very intricate shapes. Their hot-working properties compare very favorably to the alpha-beta brasses but like the latter alloys they can be cold-worked only lightly. Generally, these aluminum bronzes are furnished in the hot-rolled or extruded condition. Occasionally, however, they are given light cold-working operations for the purpose of obtaining dimensional accuracy. Hot working is usually performed within a temperature range of 1300 to 1650°F., depending on the alloy composition and the amount of plastic flow required.

The alpha aluminum bronzes have tensile properties comparable to the high brasses and possess the maximum ductility of any of the aluminum bronzes. However, they work-harden rapidly and are not generally used for severe drawing or stamping operations.

Duplex alloys possess very high tensile strength, but are lacking in ductility. These alloys in the heat-treated or hot-worked condition have tensile properties comparable to the work-hardened silicon bronzes.

The annealing characteristics of the alpha aluminum bronzes are similar to those of the alpha brasses and softening of work-hardened alloys can be accomplished by annealing within the temperature range of 800 to 1400°F., depending upon the properties required.

The duplex bronzes are capable of being heat-treated for the general improvement of mechanical properties and are usually furnished or used in this condition. Heat-treatment of these alloys consists of quenching in water from temperatures of 1500 to 1600°F. and reannealing between 700 and 1100°F., according to the thickness of the section and composition of the alloy.

All the aluminum bronzes possess good resistance to scaling or oxidation at elevated temperatures, being better in this respect than any of the other copper-base alloys. The resistance to scaling or oxidation increases with the aluminum content.

The resistance of the aluminum bronzes to corrosion is largely due to the formation on their exposed surface of aluminum oxide (Al_2O_3). Because this film is very resistant to attack by mineral acids, aluminum bronzes have been widely used in constructions requiring resistance to the action of such acids. Since, however, this film is soluble in alkalies, aluminum bronzes offer but mediocre resistance to the attack of strong alkalies. Resistance of aluminum bronzes to acid attack tends to increase with increasing aluminum content. Under certain conditions of corrosion the alpha-beta aluminum bronzes are susceptible to a form of corrosion that is analogous to "dezincification" in brass and has been called "dealuminization."

The alpha bronzes, either plain or modified with up to 4 per cent of nickel to increase resistance to salt- or brackish-water corrosion, have shown signs of being suitable for use in oil-refinery service, and other heat-exchanger fields, as condenser tubes and tube plates. The alloy containing 5 per cent of aluminum is commercially available in the form of strip, rod, and tube.

This alloy has a very pleasing golden color approximating that of 18-karat gold and has found some applications in the costume-jewelry field, for radio faces, and decorative emblems.

In general the wrought aluminum bronzes are used in those applications requiring high tensile properties in combination with good corrosion resistance; in such parts as valve stems, propeller-blade bolts, air pumps, condenser bolts, and for other purposes requiring high strength in combination with good wear-resisting properties, such as slide liners and bushings. The physical and general mechanical properties of the more common aluminum bronzes may be found in Tables 1 to 4 on pages 254 to 263. Charts 1 to 35 on pages 255 to 265 give more detailed data.

TABLE 1
5 PER CENT ALUMINUM BRONZE
GENERAL DATA—ROD
Copper, 95.19%; aluminum, 4.66%

Property	Rod		Forgings		
	Hard[a]	Soft[b]	Hot	Cold[c]	Cold[d]
Tensile strength, p.s.i. (000 omitted)	110	55	55–65	60–90	95
Apparent elastic limit, p.s.i. (000 omitted)	75	18	10–20	30–58	62
Yield strength:					
0.5% extension, p.s.i. (000 omitted)	65	20	30–15	32–60	62
0.2% offset, p.s.i. (000 omitted)	90	20	30–15	32–68	75
0.1% offset, p.s.i. (000 omitted)	78	18	30–15	25–55	62
Elongation, % in 2 in.	60	15	55–65	50–15	15
Reduction of area, %	55	75	70–78	72–62	60
Rockwell hardness F, 1/16-in. ball, 60-kg. load	110	85	65–88	93–107	108
Rockwell hardness B, 1/16-in. ball, 100-kg. load	92	45	55–30	70–85	88
Brinell hardness, 10-mm. ball, 500-kg. load	163	79	89–67	110–142	151
Modulus of elasticity, p.s.i.	17,500,000				
Forging range, °F.	1350–1550				
Forging quality	Good				
Type structure	Single phase, alpha				

GENERAL DATA—TUBING
Copper, 94.62%; aluminum, 4.69%; lead, trace: tin, nil

Property	Hard[e]	Soft[f]
Tensile strength, p.s.i. (000 omitted)	71	57
Elongation, % in 2 in.	30	65
Apparent elastic limit, p.s.i. (000 omitted)	50	10
Rockwell hardness F, 1/16-in. ball, 60-kg. load	106	60
Rockwell hardness B, 1/16-in. ball, 100-kg. load	85	
Rockwell hardness G, 1/16-in. ball, 150-kg. load	58	
Young's modulus of elasticity, p.s.i.	17,500,000	

PHYSICAL DATA

Melting point, °F.	1945
Coefficient of expansion, per °C. from 25–300°C.	0.0000180
Electrical conductivity, % I.A.C.S.	17.7
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F	47.9
Density, lb. per cu. in.	0.295

[a] Refers to rod cold-drawn 50%; rod under 1 in. in diameter, ready-to-finish grain size 0 025 mm.
[b] Refers to 1200°F. anneal (1 hr.).
[c] Material cold-forged from soft rod (5–30% reduction of area).
[d] Material cold-forged from cold-worked condition (30%).
[e] Extruded, reduced, and cold-drawn to 3/4 in. O.D. × 0.049 in. wall thickness.
[f] 1300°F. anneal (1 hr. at temperature) of material described in footnote *e*.

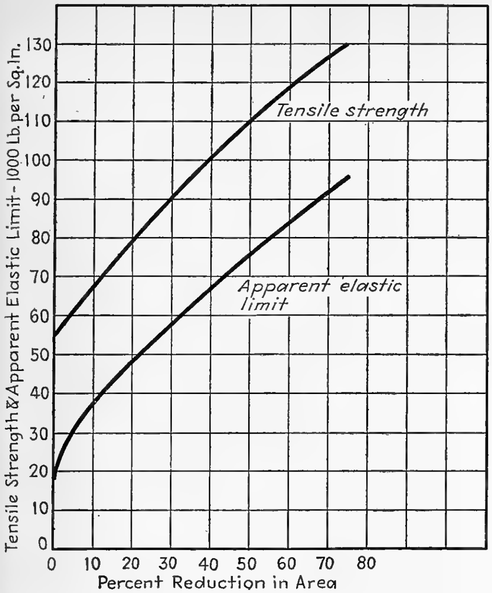

Chart 1.—The effect of cold drawing on the tensile strength and apparent elastic limit of 5 per cent aluminum-bronze rod, previously annealed to a grain size of 0.025 mm. (95.19 % copper, 4.66 % aluminum) (rod under 1 in. in diameter).

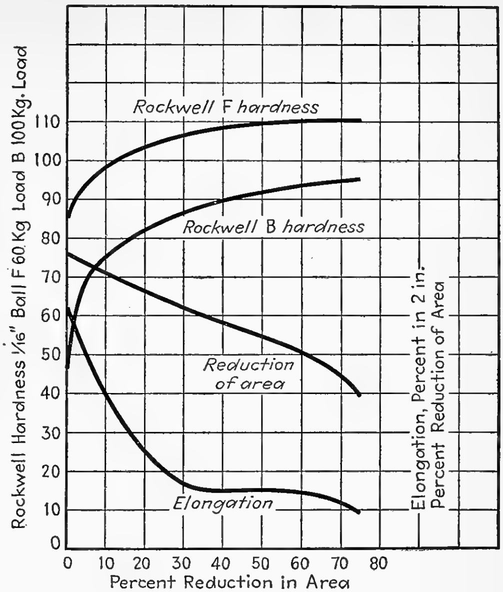

Chart 2.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of 5 per cent aluminum-bronze rod, previously annealed to a grain size of 0.025 mm. (95.19 % copper, 4.66 % aluminum) (rod under 1 in. in diameter).

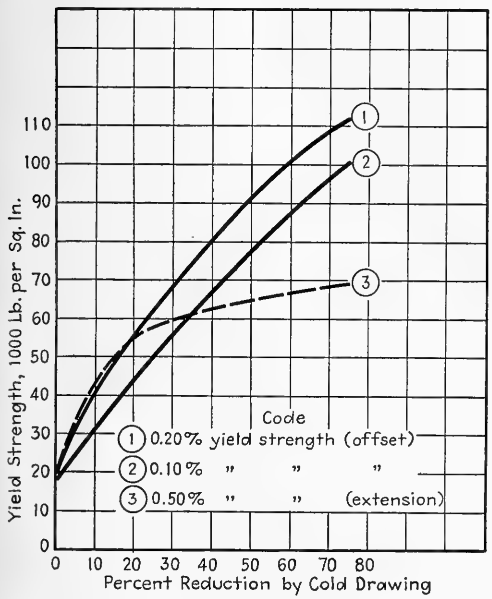

Chart 3.—The effect of cold drawing on the yield strength of 5 per cent aluminum-bronze rod, previously annealed to a grain size of 0.025 mm. (95.19 % copper, 4.66 % aluminum) (rod under 1 in. in diameter).

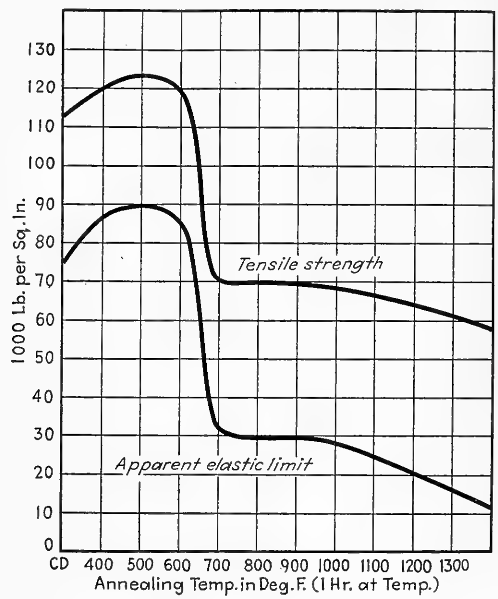

Chart 4.—The effect of annealing on the tensile strength and apparent elastic limit of 5 per cent aluminum-bronze rod, previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.025 mm. (95.19 % copper, 4.66 % aluminum) (rod under 1 in. in diameter).

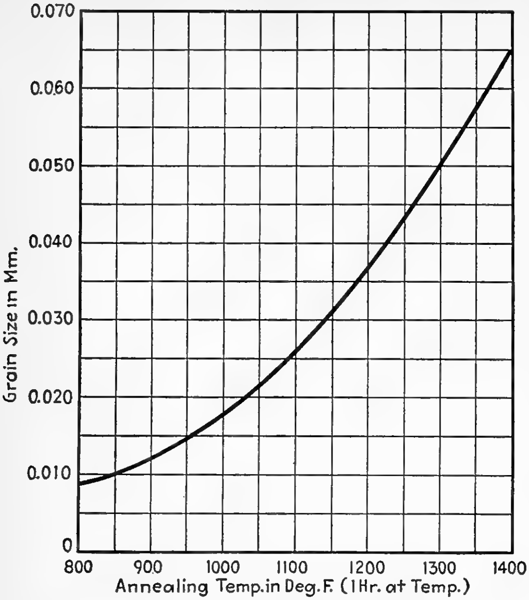

CHART 5.—The effect of annealing on the grain-growing characteristics of 5 per cent aluminum-bronze rod, previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.025 mm. (95.19 % copper, 4.66 % aluminum) (rod under 1 in. in diameter).

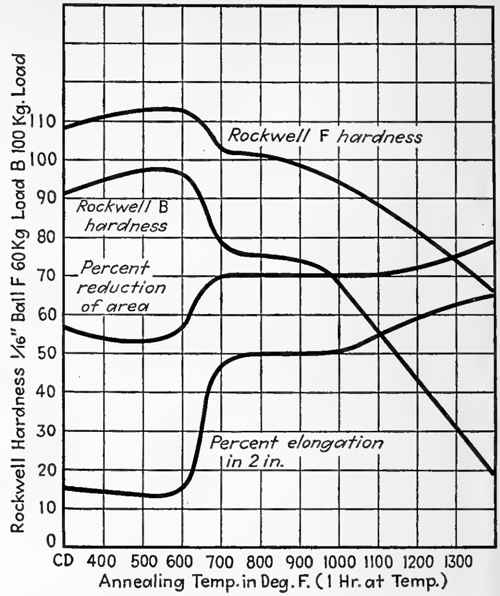

CHART 6.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of 5 per cent aluminum-bronze rod, previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.025 mm. (95.19 % copper, 4.66 % aluminum) (rod under 1 in. in diameter).

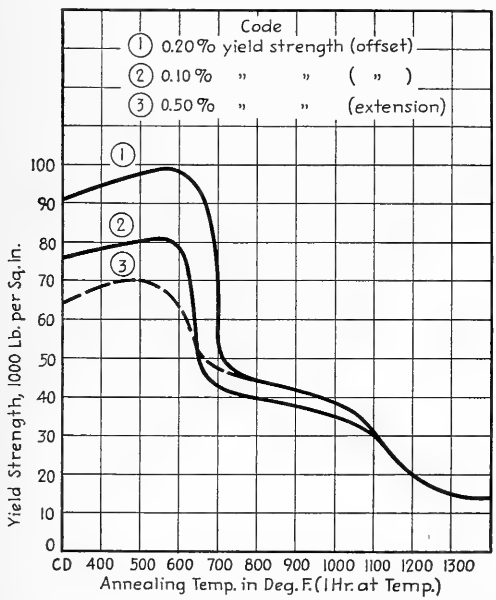

CHART 7.—The effect of annealing on the yield strength of 5 per cent aluminum-bronze rod, previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.025 mm. (95.19 % copper, 4.66 % aluminum) (rod under 1 in. in diameter).

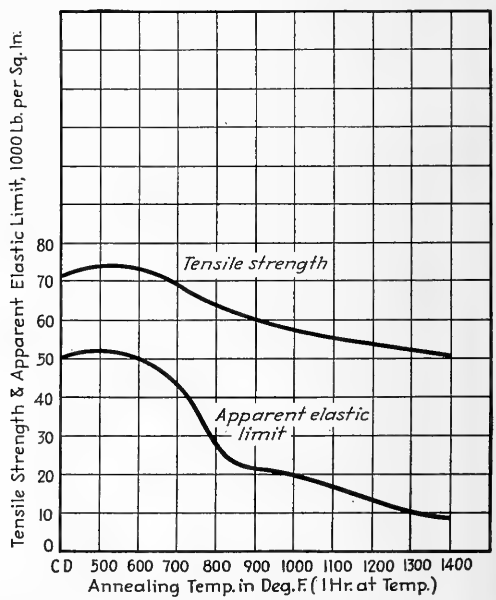

CHART 8.—The effect of annealing on the tensile strength and apparent elastic limit of 5 per cent aluminum-bronze condenser tube, previously cold-drawn 20 per cent (reduction of area) (94.62 % copper, 4.69 % aluminum).

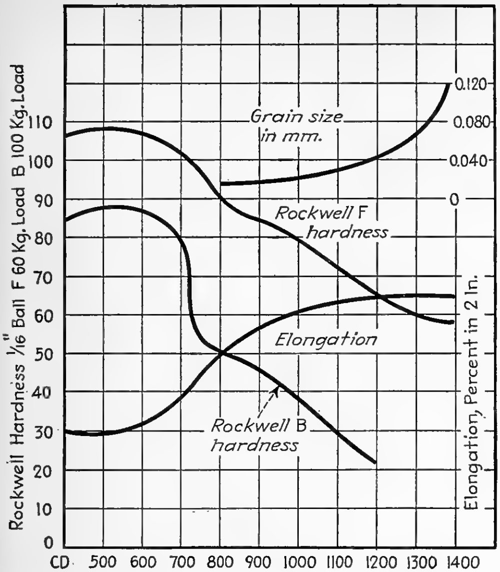

CHART 9.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and grain size of 5 per cent aluminum-bronze condenser tube, previously cold-drawn 20 per cent (reduction of area) (94.62 % copper, 4.69 % aluminum).

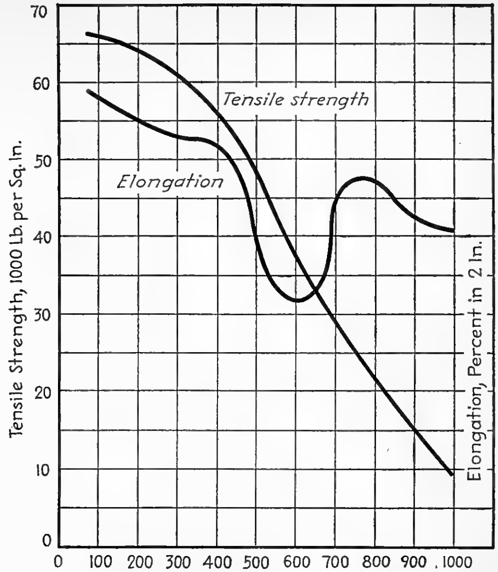

CHART 10.—Effect of elevated temperature on the tensile strength and percentage elongation in 2 in. of 5 per cent aluminum-bronze tube (94.62 % copper, 4.69 % aluminum).

TABLE 2
8 PER CENT ALUMINUM BRONZE[a]
Copper, 91.73%; aluminum, 8.01%; lead, trace; iron, trace; nickel, nil

Property	Rod		Forgings		
	Hard[b]	Soft[c]	Hot	Cold[d]	Cold[e]
Tensile strength, p.s.i. (000 omitted)	140	60	60–70	70–80	85
Apparent elastic limit, p.s.i. (000 omitted)	100	15	15–20	20–40	50
Yield strength:					
0.5% extension, p.s.i. (000 omitted)	65	15	15–40		
0.2% offset, p.s.i. (000 omitted)	88	15	15–40		
0.1% offset, p.s.i. (000 omitted)	67	15	15–40		
Elongation, % in 2 in.	10	70	60–70	50–40	30
Reduction of area, %	40	75	70–75	65–60	50
Endurance limit, p.s.i. (000 omitted)	22	..	22–23		
Rockwell hardness F, 1/16-in. ball, 60-kg. load	108	74	74–84	95–100	104
Rockwell hardness B, 1/16-in. ball, 100-kg. load	89	33	33–48	67–76	
Brinell hardness, 10-mm. ball, 500-kg. load	154	69	69–81	106–122	
Modulus of elasticity, p.s.i.	17,500,000				
Melting point, °F.	1905				
Coefficient of expansion, per °C. from 25–300°C.	0.0000178				
Electrical conductivity, % I.A.C.S., 68°F.	14.8				
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	46				
Density, lb. per cu. in.	0.281				
Forging range, °F.	1400–1600				
Forging quality	Excellent				
Type structure	Single phase, alpha				

[a] This alloy has excellent hot-working properties and can be cold-worked; compares in this respect with Type A silicon bronze.
[b] Refers to rod cold-drawn 50%, rod under 1 in. in diameter, ready-to-finish grain size 0.070 mm.
[c] Refers to 1300°F. anneal (1 hr.).
[d] Material cold-forged from soft rod (5–10% reduction of area).
[e] Material cold-forged from cold-worked condition (10%).

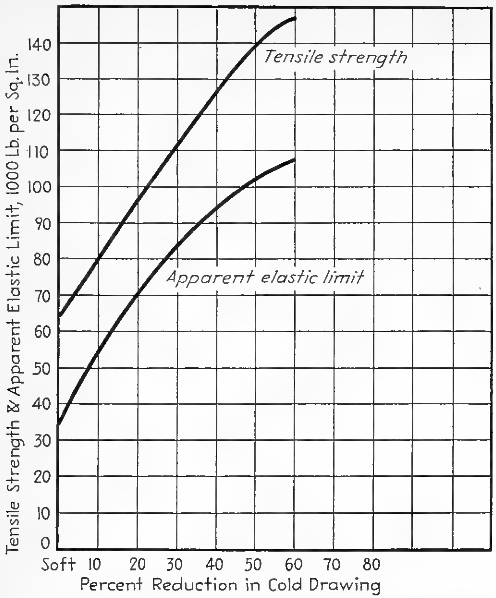

CHART 11.—The effect of cold drawing on the tensile strength and apparent elastic limit of 8 per cent aluminum-bronze rod, previously annealed to a grain size of 0.070 mm. (91.73 % copper, 8.01 % aluminum) (rod under 1 in. in diameter).

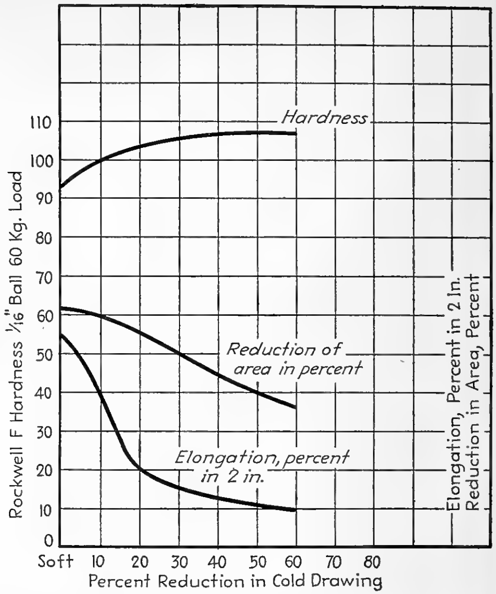

CHART 12.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of 8 per cent aluminum-bronze rod, previously annealed to a grain size of 0.070 mm. (91.73 % copper, 8.01 % aluminum) (rod under 1 in. in diameter).

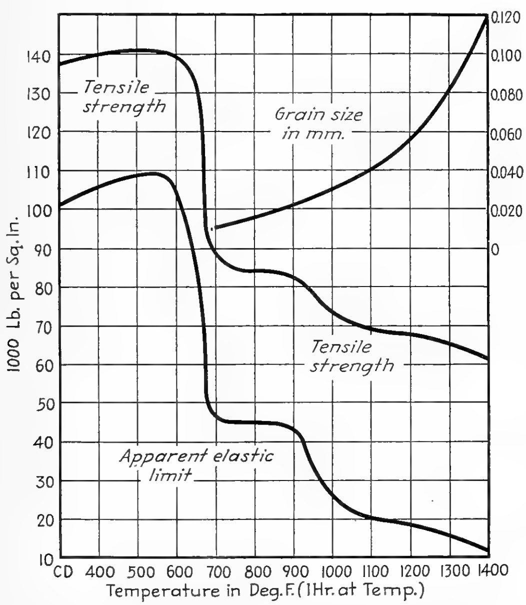

CHART 13.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of 8 per cent aluminum-bronze rod, previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.070 mm. (91.73 % copper, 8.01 % aluminum) (rod under 1 in. in diameter).

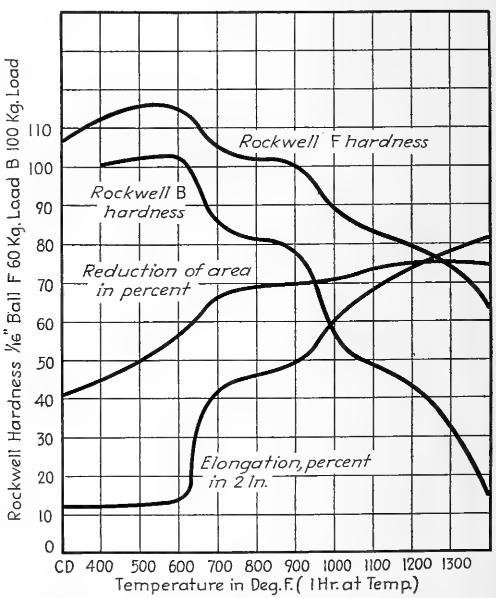

CHART 14.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of 8 per cent aluminum-bronze rod, previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.070 mm. (91.73 % copper, 8.01 % aluminum) (rod under 1 in. in diameter).

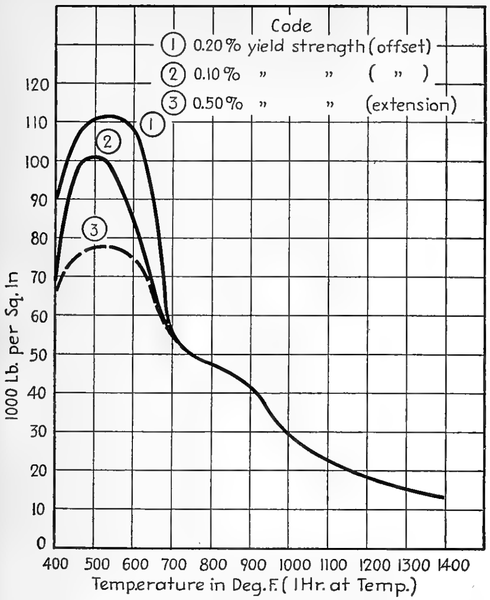

CHART 15.—The effect of annealing on the yield strength of 8 per cent aluminum-bronze rod, previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.070 mm. (91.73 % copper, 8.01 % aluminum) (rod under 1 in. in diameter).

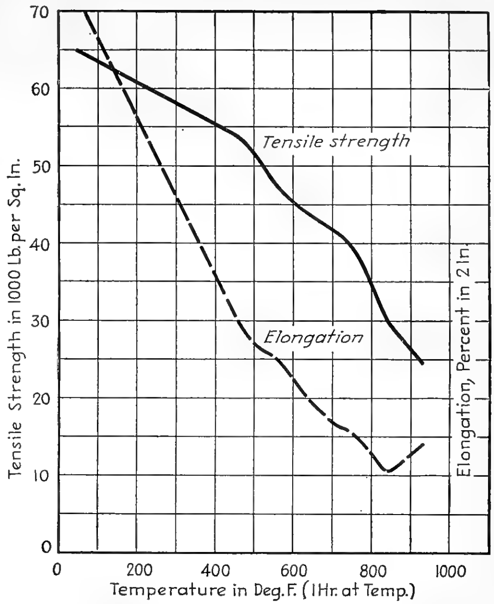

CHART 16.—Effect of temperature on the tensile strength and percentage elongation in 2 in. of 7 per cent aluminum bronze (6.73 % aluminum).[33]

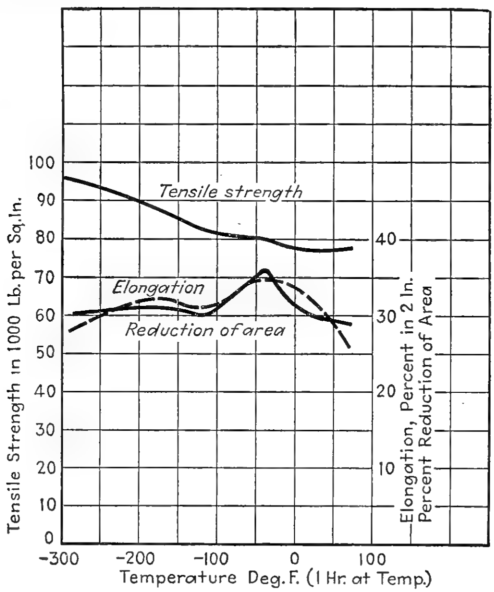

CHART 17.—Effect of low temperature on tensile strength, percentage elongation in 2 in., and percentage reduction of area of 8 per cent aluminum bronze (7.31 % aluminum).[33]

TABLE 3

10 PER CENT ALUMINUM BRONZE[a]

Copper, 88.83%; aluminum, 10.02%; iron, 0.77%; manganese, 0.31%

Property	Rod Hard[b]	Rod Soft[c]	Forgings hot
Tensile strength, p.s.i. (000 omitted)	95	85	85–90
Apparent elastic limit, p.s.i. (000 omitted)	48	22	22–42
Yield strength:			
0.5% extension, p.s.i. (000 omitted)	49	36	36–50
0.2% offset, p.s.i. (000 omitted)	54	34	34–50
0.1% offset, p.s.i. (000 omitted)	45	30	30–45
Elongation, % in 2 in.	23	23	12–23
Reduction of area, %	25	25	12–30
Endurance limit, p.s.i. (000 omitted)	40	37	
Rockwell hardness F, 1/16-in. ball, 60-kg. load	103	102	105–102
Rockwell hardness B, 1/16-in. ball, 100-kg. load	79	81	80–90
Brinell hardness, 10-mm. ball, 500-kg. load	128	133	130–157
Modulus of elasticity, p.s.i.	17,500,000		
Melting point, °F.	1905		
Coefficient of expansion, per °C. from 25–300°C.	0.0000170		
Electrical conductivity, % I.A.C.S., 68°F.	13		
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	36		
Density, lb. per cu. in.	0.274		
Forging range, °F.	1400–1650		
Forging quality	Excellent		
Type structure	Two phase, alpha-beta		

[a] This alloy has excellent hot-forging properties.
[b] Refers to rod cold-drawn 5% from extruded condition (extrusion temp. 1350°F.); rod under 1 in. in diameter.
[c] Refers to rod annealed 1350°F. for 1 hr. with ready-to-finish grain size 0.035 mm.

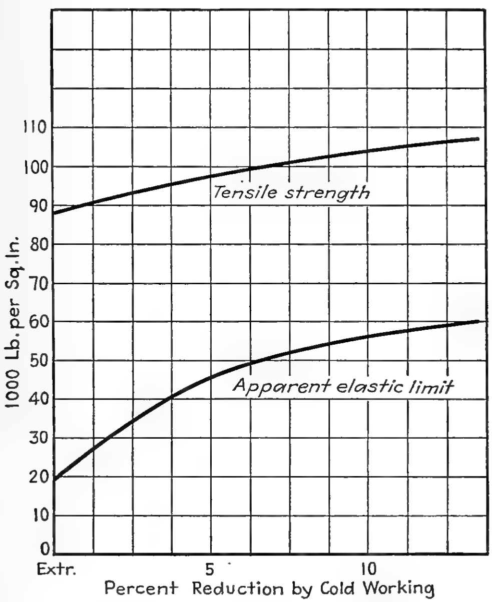

Chart 18.—The effect of cold drawing on the tensile strength and apparent elastic limit of 10 per cent aluminum-bronze rod, previously extruded (88.83% copper, 10.02% aluminum, 0.77% iron, 0.31% manganese) (rod under 1 in. in diameter).

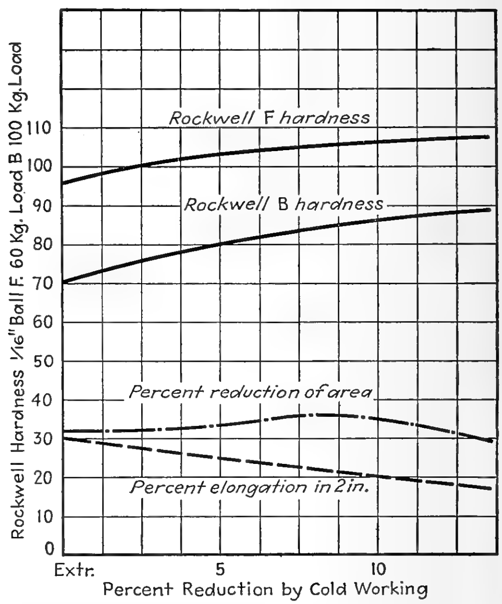

Chart 19.—The effect of cold drawing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of 10 per cent aluminum-bronze rod, previously extruded (88.83% copper, 10.02% aluminum, 0.77% iron, 0.31% manganese) (rod under 1 in. in diameter).

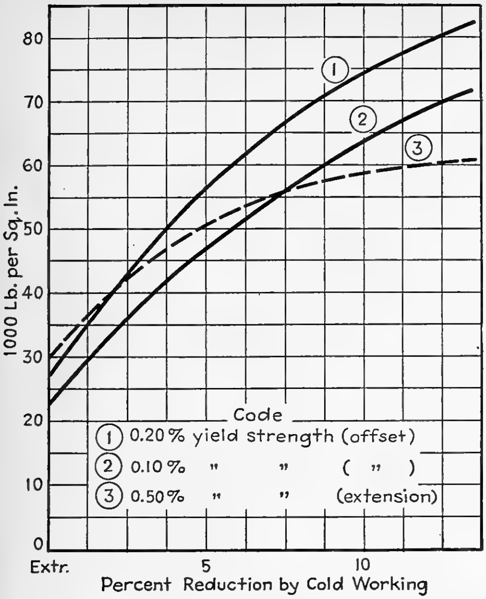

Chart 20.—The effect of cold drawing on the yield strength of 10 per cent aluminum-bronze rod, previously extruded (88.83 % copper, 10.02 % aluminum, 0.77 % iron, 0.31 % manganese) (rod under 1 in. in diameter).

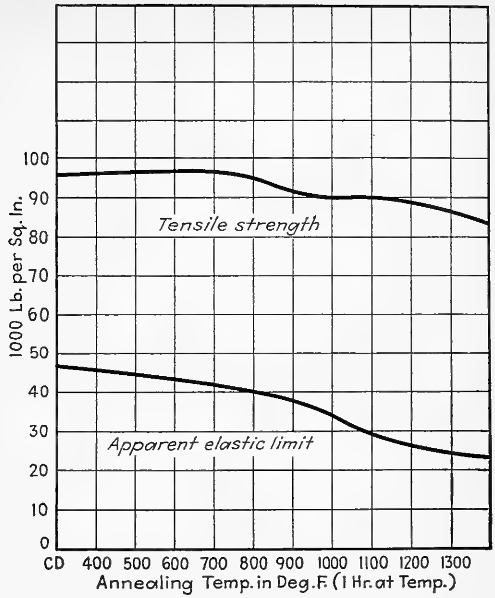

Chart 21.—The effect of annealing on the tensile strength and apparent elastic limit of 10 per cent aluminum-bronze rod, previously cold-drawn 5 per cent (reduction of area) from extruded material (88.83 % copper, 10.02 % aluminum, 0.77 % iron, 0.31 % manganese) (rod under 1 in. in diameter).

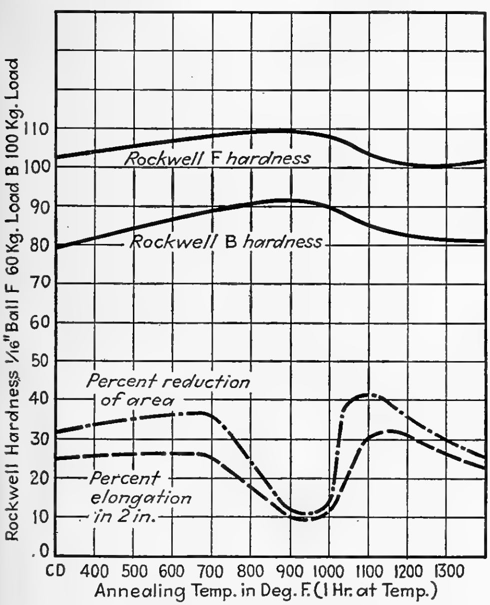

Chart 22.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of 10 per cent aluminum-bronze rod, previously cold-drawn 5 per cent (reduction of area) from extruded material (88.83 % copper, 10.02 % aluminum, 0.77 % iron, 0.31 % manganese) (rod under 1 in. in diameter).

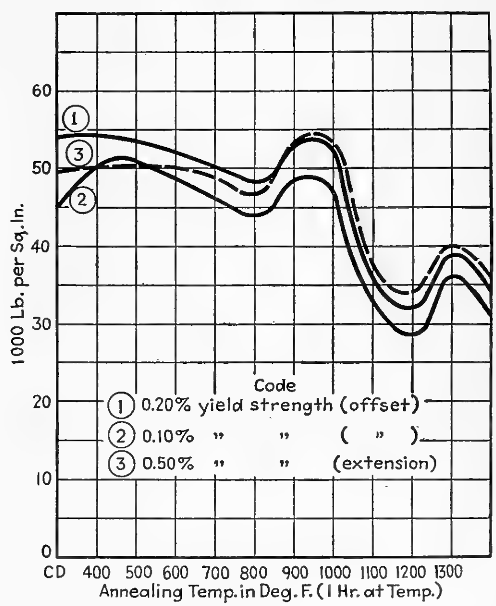

Chart 23.—The effect of annealing on the yield strength of 10 per cent aluminum-bronze rod, previously cold-drawn 5 per cent (reduction of area) from extruded material (88.83 % copper, 10.02 % aluminum, 0.77 % iron, 0.31 % manganese) (rod under 1 in. in diameter).

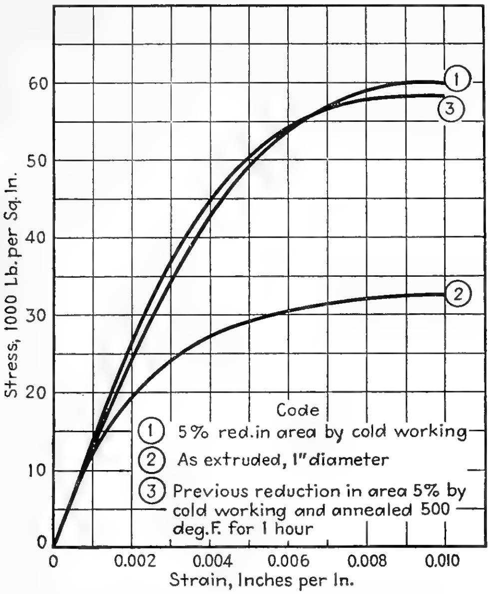

CHART 24.—The effect of cold working and annealing on the stress-strain characteristics of a 10 per cent aluminum-bronze rod, previously extruded (rod under 1.00 in. diameter); 100,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used (88.83 % copper, 10.02 % aluminum, 0.77 % iron, 0.31 % manganese).

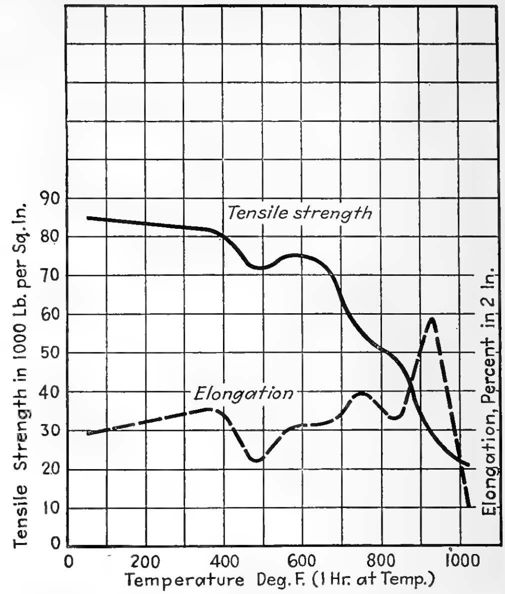

CHART 25.—The effect of elevated temperatures on the tensile strength and percentage elongation of 10 per cent aluminum-bronze rod (9.90 % aluminum).(33)

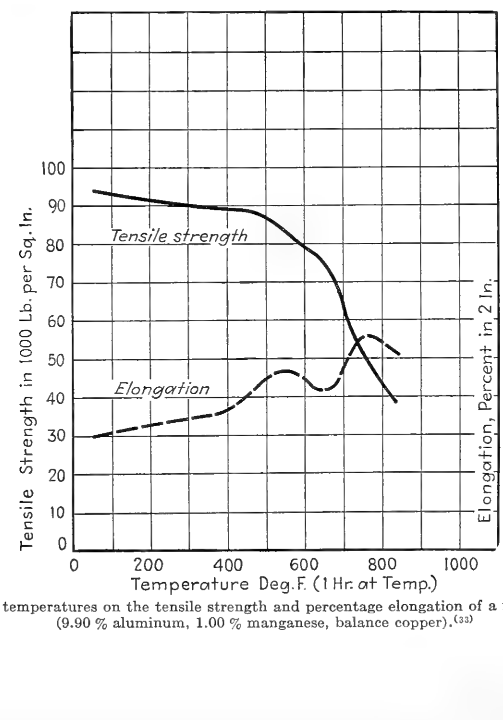

CHART 26.—The effect of elevated temperatures on the tensile strength and percentage elongation of a modified 10 per cent aluminum bronze (9.90 % aluminum, 1.00 % manganese, balance copper).(33)

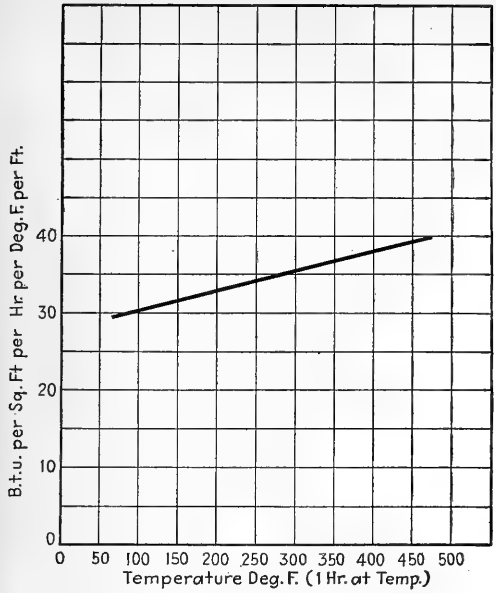

CHART 27.—Effect of elevated temperature on the thermal conductivity of 10 per cent aluminum bronze according to Griffiths and Schoefield.[23]

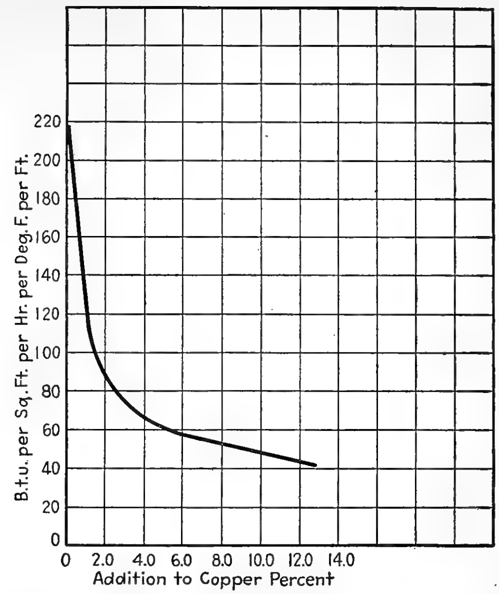

CHART 28.—The effect of aluminum additions on the thermal conductivity of copper, previously annealed at 930°F. according to Hanson and Rogers.[4]

TABLE 4
SILICON-ALUMINUM BRONZE ROD
GENERAL DATA
Copper, 90.72%; silicon, 2.03%; aluminum, balance

Properties	Rod		Forgings
	Hard[a]	Soft[b]	Hot
Tensile strength, p.s.i. (000 omitted)	95	80	78–88
Apparent elastic limit, p.s.i. (000 omitted)	51	21	21–30
Yield strength:			
0.5% extension, p.s.i. (000 omitted)	54	33	31–43
0.2% offset, p.s.i. (000 omitted)	63	32	29–44
0.1% offset, p.s.i. (000 omitted)	51	29	26–40
Elongation, % in 2 in.	25	38	42–33
Reduction of area, %	37	40	43–37
Rockwell hardness B, 1/16-in. ball, 60-kg. load	84	78	74–86
Brinell hardness, 10-mm. ball, 500-kg. load	140	126	118–140
Modulus of elasticity, p.s.i.	14,000,000		
Melting point, °F.	1810		
Density, lb. per cu. in.	0.278		
Specific gravity	7.69		
Electrical conductivity, % I.A.C.S., 68°F.	7		
Electrical resistivity, ohms per mil.-ft. per °F.	148		
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F	22		
Coefficient of linear expansion, per °F	0.0000092		

[a] Refers to rod cold-drawn 10.5% from extruded condition; rod under 1 in. in diameter, ready-to-finish grain size 0.035 mm.
[b] Refers to a 1400°F. anneal (1 hr.).

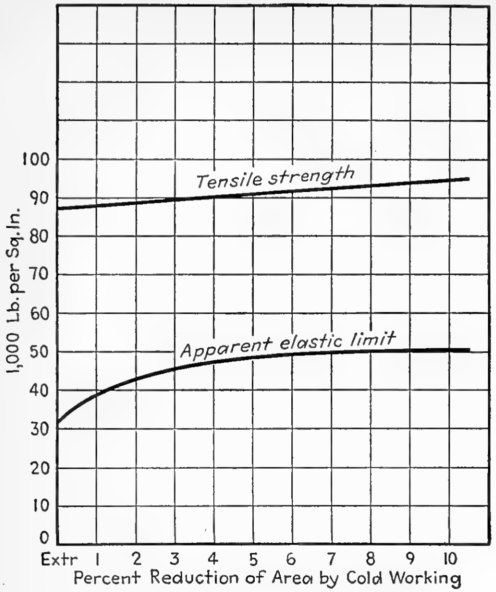

CHART 29.—The effect of cold work on the tensile strength and apparent elastic limit of silicon-aluminum-bronze rod, previously extruded to a grain size of 0.035 mm. (7.01 % aluminum, 1.98 % silicon, balance copper) (rod under 1 in. in diameter)

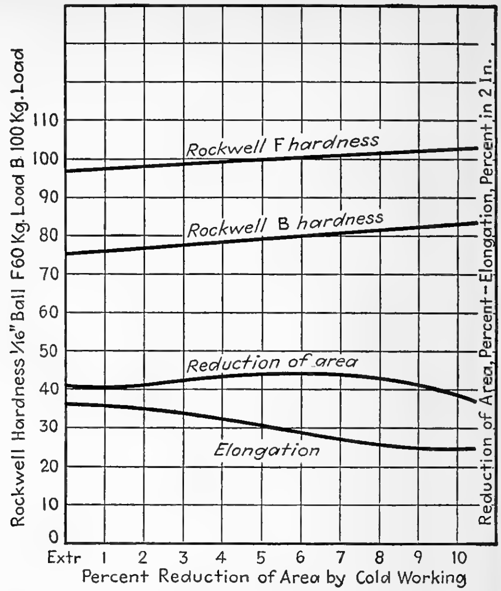

CHART 30.—The effect of cold work on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of silicon-aluminum-bronze rod, previously extruded to a grain size of 0.035 mm. (7.01 % aluminum, 1.98 % silicon, balance copper) (rod under 1 in. in diameter).

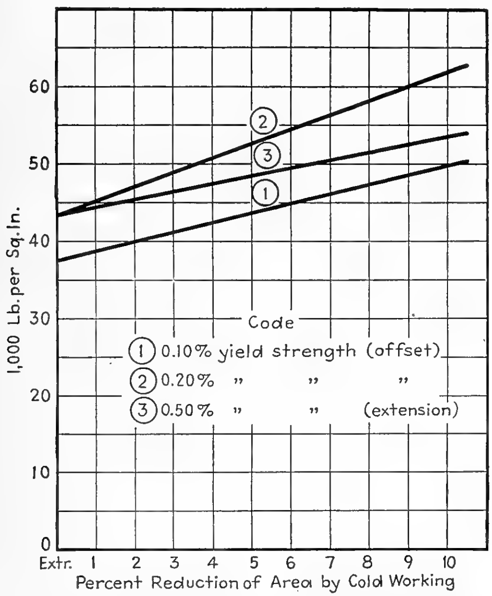

CHART 31.—The effect of cold work on the yield strength of silicon-aluminum-bronze rod, previously extruded to a grain size of 0.035 mm. (7.01 % aluminum, 1.98 % silicon, balance copper) (rod under 1 in. in diameter).

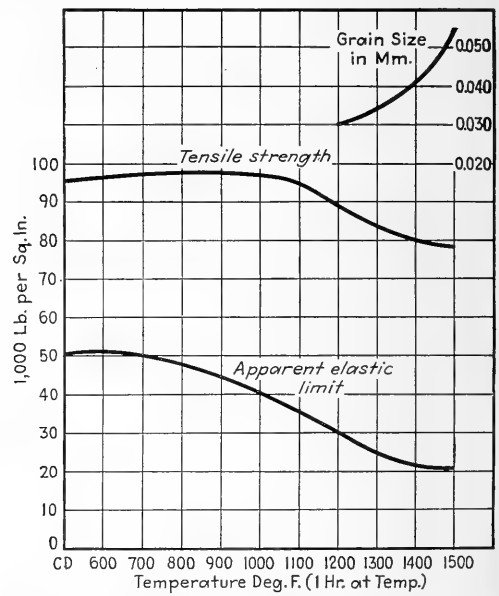

CHART 32.—The effect of annealing on the tensile strength, apparent elastic limit, and grain size of silicon-aluminum-bronze rod, previously cold-drawn 10.5 per cent (reduction of area) from extruded material having a grain size of 0.035 mm. (7.01 % aluminum, 1.98 % silicon, balance copper) (rod under 1 in. in diameter).

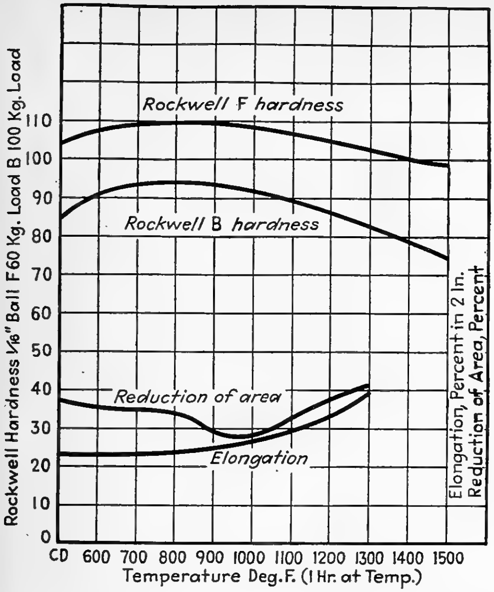

CHART 33.—The effect of annealing on the Rockwell hardness, percentage elongation in 2 in., and percentage reduction of area of silicon-aluminum-bronze rod, previously cold-drawn 10.5 per cent (reduction of area) from extruded material having a grain size of 0.035 mm. (7.01 % aluminum, 1.98 % silicon, balance copper) (rod under 1 in. in diameter).

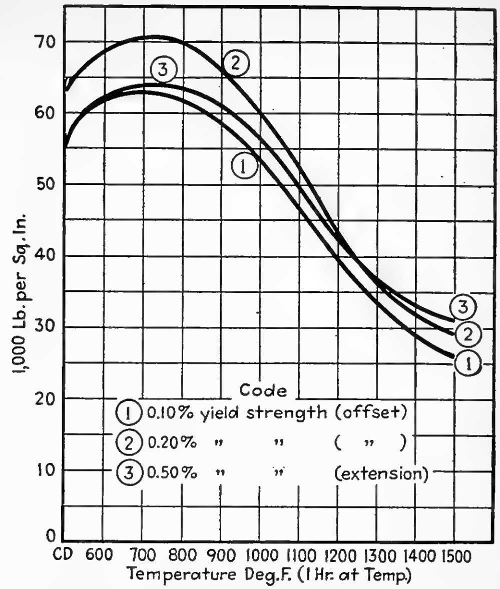

CHART 34.—The effect of annealing on the yield strength of silicon-aluminum-bronze rod, previously cold-drawn 10.5 per cent (reduction of area) from extruded material having a grain size of 0.035 mm. (7.01 % aluminum, 1.98 % silicon, balance copper) (rod under 1 in. in diameter).

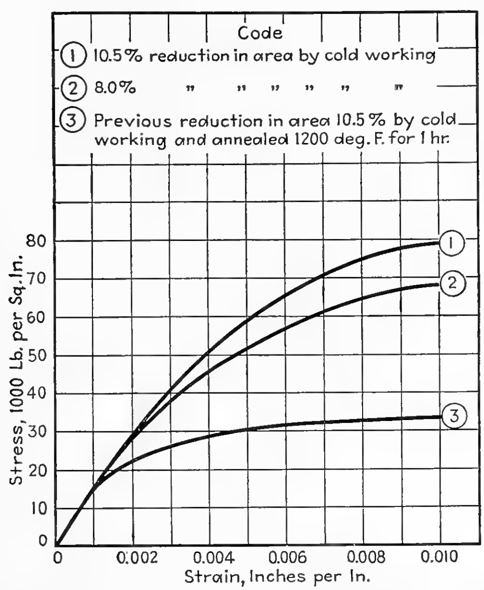

CHART 35.—The effect of cold working and annealing on the stress-strain characteristics of silicon-aluminum-bronze rod, previously extruded (rod under 1 in. in diameter); 100,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used (7.01 % aluminum, 1.98 % silicon, balance copper).

CHAPTER X

THE TIN BRONZES

Tin bronzes are alloys of tin and copper. The commercial wrought bronzes do not usually contain in excess of 10 per cent of tin. In the casting of these alloys it is common practice to add from 0.03 to 0.40 per cent of phosphorus as a deoxidizer in order that sound, dense castings may be secured. Because of the use of this deoxidant, the tin bronzes are known commercially as "phosphor bronzes."

The tin bronzes when in the completely homogenized condition are single-phase alloys having a structure similar to alpha brass. As the tin increases above 5 per cent, it becomes increasingly difficult to cast tin bronzes that are free of inverse segregation. Inverse segregation in tin bronzes has been identified as a tin-rich, lower melting-point phase and is known as "delta." Unless extreme care is taken during melting and casting to keep reducing gases from the molten metal, inverse segregation will occur. In fact, the amount of delta produced in the tin bronzes during solidification is directly proportional to the amount of gas retained.

The two most common types of tin bronzes are those containing 5 and 8 per cent of tin. These alloys have excellent cold-working properties. Tin bronzes are not considered hot-working alloys since they are only slightly hot plastic within a very narrow temperature range 1150° to 1225°F.

The phosphor bronzes have corrosion-resisting properties comparable to those of copper. In addition, they possess higher tensile properties than copper in combination with good resistance to fatigue.

Phosphor bronzes of the Grades A (5 per cent tin), C (8 per cent tin), and D (10 per cent tin) are used extensively in the form of welding wire for carbon-arc and gas welding of many of the non-ferrous alloys and the brazing of cast iron.

Grades A and C phosphor bronzes are used in the manufacture of springs, diaphragms, contact points, and other application requiring good resistance to corrosion and fatigue in combination with high-tensile properties. The physical and general mechanical properties of Grades A and C and other phosphor bronzes may be found in Tables 1 to 10 on pages 266 to 283. Charts 1 to 77 on pages 267 to 290 give more detailed data.

TABLE 1

GRADE A—5 PER CENT PHOSPHOR BRONZE

General Data—Strip[a]

Copper, 95.72%; tin, 4.09%; phosphorus, 0.035%

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	82–97	49
Elongation, % in 2 in.	2	48
Apparent elastic limit, p.s.i. (000 omitted)	60–77	16
Yield strength, 0.5% extension, p.s.i. (000 omitted)	70–20	18–19
Yield strength, 0.2% offset, p.s.i. (000 omitted)	77–93	18–19
Yield strength, 0.1% offset, p.s.i. (000 omitted)	71–81	18–19
Rockwell hardness F, 1/16-in. ball, 60-kg. load	108–113	73
Rockwell hardness B, 1/16-in. ball, 100-kg. load	88–95	35
Rockwell hardness G, 1/16-in. ball, 150-kg. load	63–74	
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	89–92	73
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	75–80	40
Endurance limit (at 10^8 reversals):[1]		
Soft, p.s.i. (000 omitted)	13.75	
4 B. & S. Nos., hard, p.s.i. (000 omitted)	25.5	
8 B. & S. Nos., hard, p.s.i. (000 omitted)	22	
Young's modulus of elasticity, p.s.i.	15,000,000	
Melting point, °F.	1922	
Density, lb. per cu. in.	0.320	
Coefficient of expansion, per °C. from 25–300°C.	0.0000190	
Electrical conductivity,[88] % I.A.C.S. at 68°F	18.4	
Thermal conductivity,[88] B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	47	

[a] All tests conducted on 0.040-in. stock.

[b] 6 B. & S. Nos., hard, 0.070–0.015 mm. grain size at ready-to-finish, respectively.

[c] Refer to 1100°F. anneal (1 hr. at temperature).

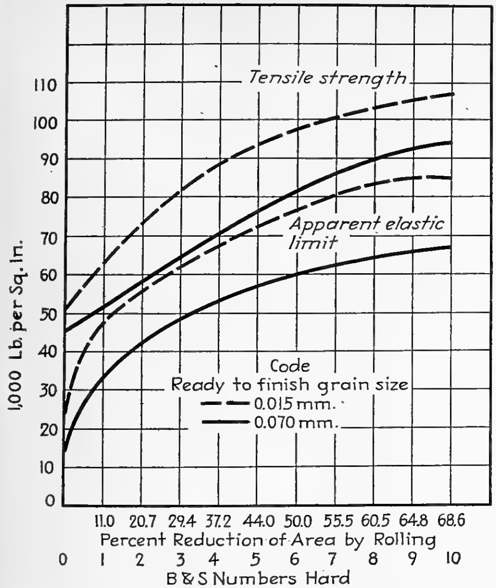

CHART 1.—The effect of cold rolling on the tensile strength and apparent elastic limit of Grade A phosphor-bronze strip, previously annealed to two different grain sizes, 0.015 and 0.070 mm. (4.09 % tin, 0.035 % phosphorus, balance copper) (0.040-in. stock).

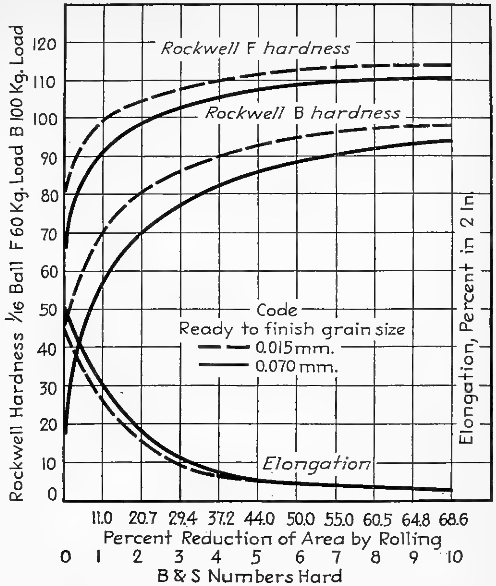

CHART 2.—The effect of cold rolling on the Rockwell hardness and percentage elongation in 2 in. of Grade A phosphor-bronze strip, previously annealed to two different grain sizes, 0.015 and 0.070 mm. (4.09 % tin, 0.035 % phosphorus, balance copper) (0.040-in. stock).

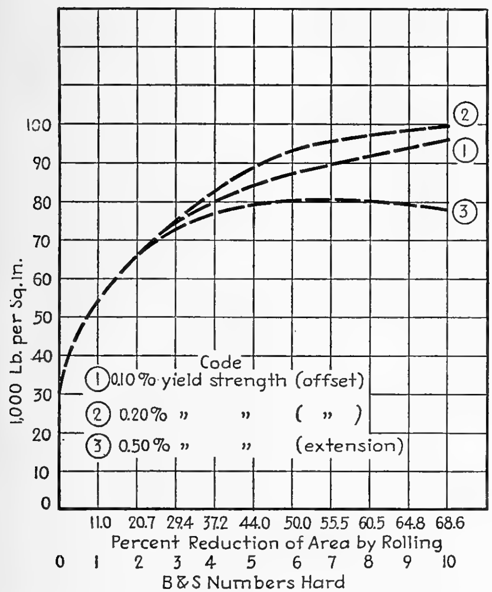

CHART 3.—The effect of cold rolling on the yield strengths of Grade A phosphor-bronze strip, previously annealed to a grain size of 0.015 mm. (4.09 % tin, 0.035 % phosphorus, balance copper) (0.040-in. stock).

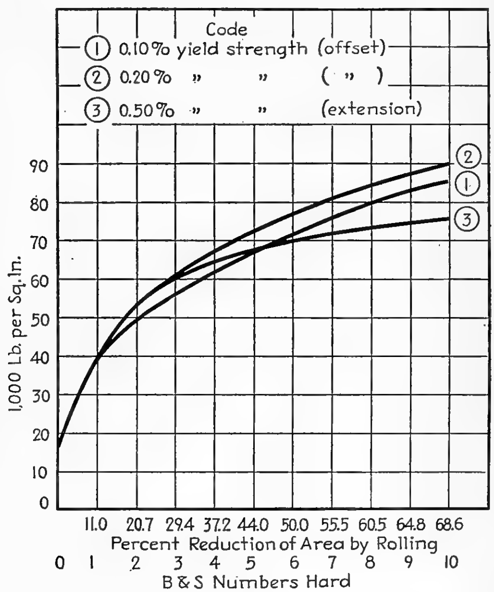

CHART 4.—The effect of cold rolling on the yield strengths of Grade A phosphor-bronze strip, previously annealed to a grain size of 0.070 mm. (4.09 % tin, 0.035 % phosphorus, balance copper) (0.040-in. stock).

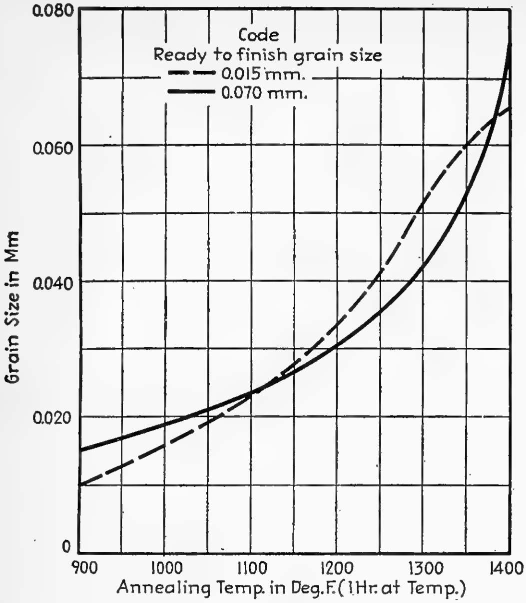

CHART 5.—The effect of annealing on the grain-growing characteristics of Grade A phosphor-bronze strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (4.09 % tin, 0.035 % phosphorus, balance copper) (0.040-in. stock).

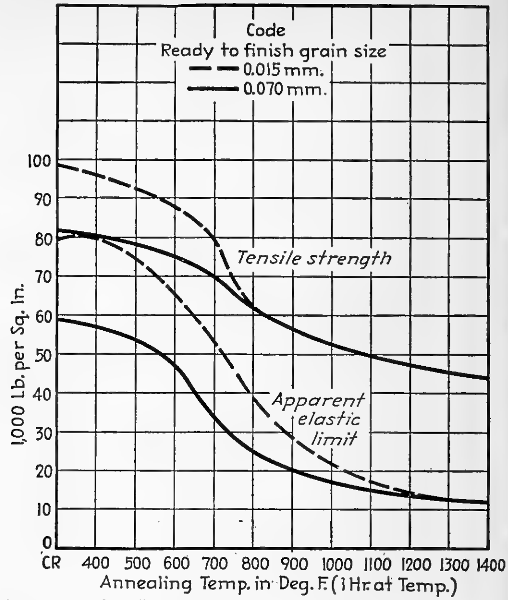

CHART 6.—The effect of annealing on the tensile strength and apparent elastic limit of Grade A phosphor-bronze strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (4.09 % tin, 0.035 % phosphorus, balance copper) (0.040-in. stock).

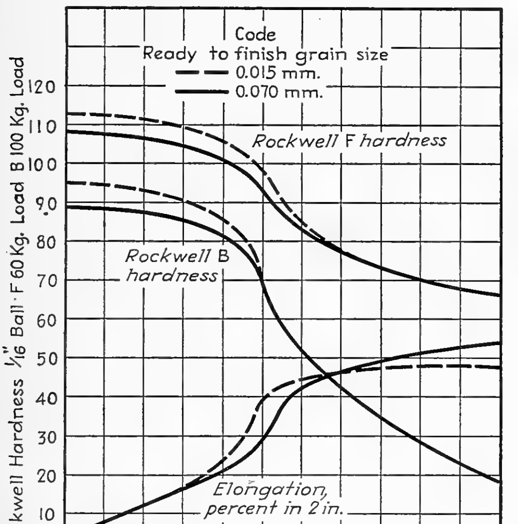

CHART 7.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of Grade A phosphor-bronze strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from two different grain sizes, 0.015 and 0.070 mm. (4.09 % tin, 0.035 % phosphorus, balance copper) (0.040-in. stock).

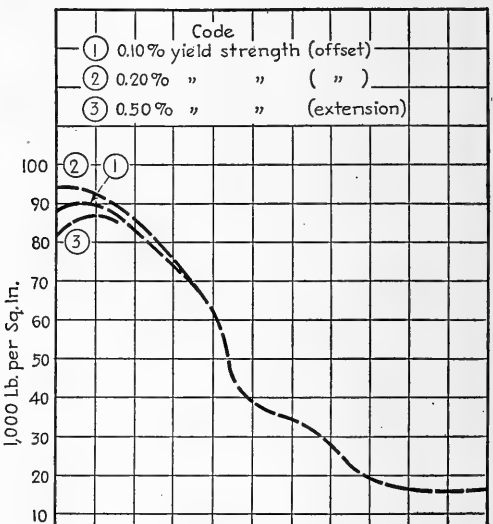

CHART 8.—The effect of annealing on the yield strength of Grade A phosphor-bronze strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.015 mm. (4.09 % tin, 0.035 % phosphorus, balance copper) (0.040-in. stock).

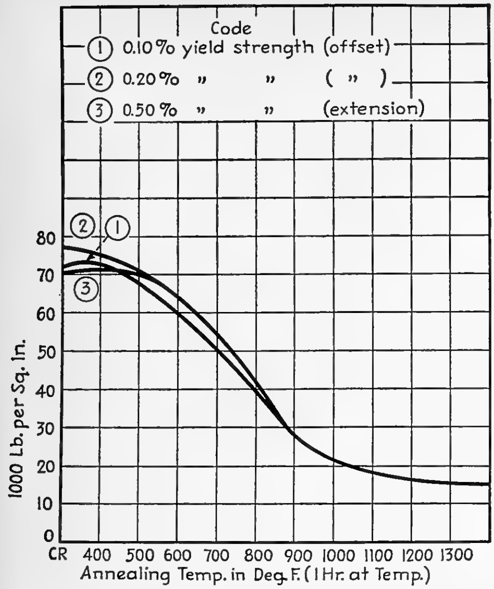

CHART 9.—The effect of annealing on the yield strength of Grade A phosphor-bronze strip, previously cold-rolled 6 B. & S. Nos. (50 per cent reduction of area) from a grain size of 0.070 mm. (4.09 % tin, 0.035 % phosphorus, balance copper) (0.040-in. stock).

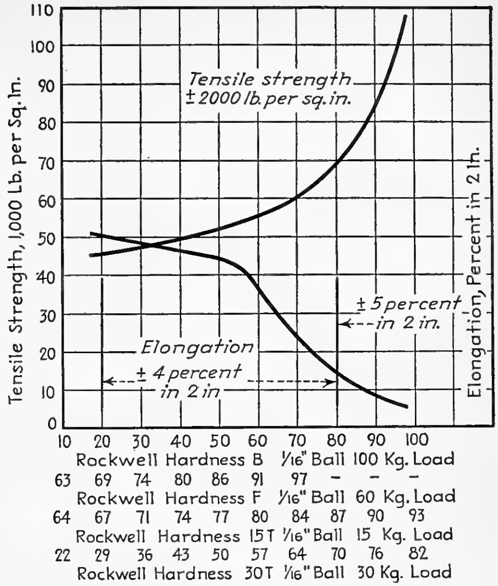

CHART 10.—This chart can be employed to determine the approximate tensile strength and percentage elongation of Grade A phosphor-bronze strip (4.09 % tin, 0.035 % phosphorus, balance copper) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

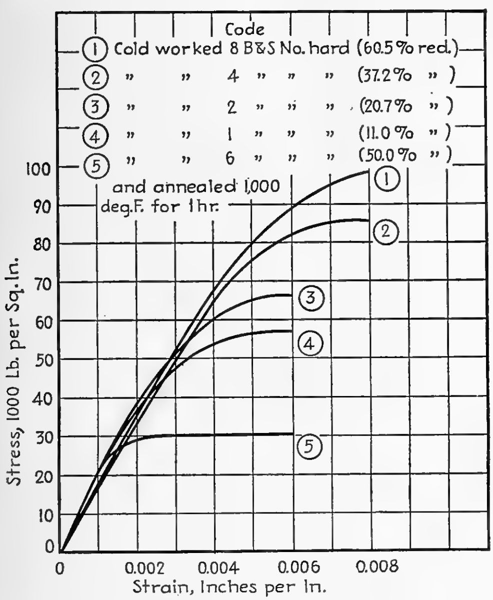

CHART 11.—The effect of cold rolling on the stress-strain characteristics of 5 per cent Grade A phosphor bronze (0.040 in. thick) having a ready-to-finish grain size of 0.015 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used (4.09 % tin, 0.035 % phosphorus, balance copper).

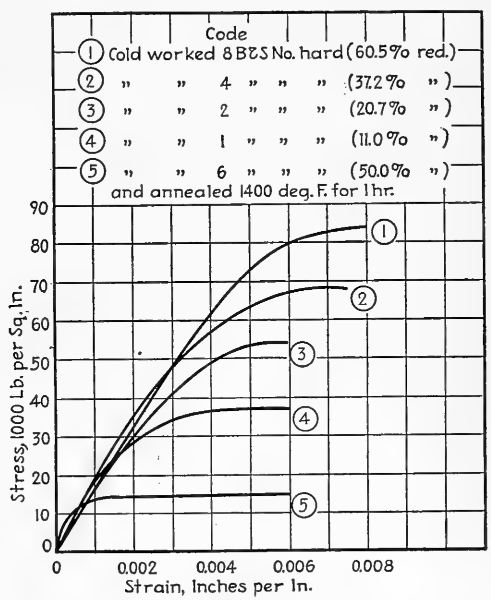

CHART 12.—The effect of cold rolling on the stress-strain characteristics of 5 per cent Grade A phosphor bronze (0.040 in. thick) having a ready-to-finish grain size of 0.070 mm.; 5,000-lb. capacity hydraulic testing machine and Templin automatic extensometer accurate to 0.00001 in. used. (4.09 % tin, 0.035 % phosphorus, balance copper).

TABLE 2

GRADE C—8 PER CENT PHOSPHOR BRONZE[a]

Copper, balance; tin, 7.50%; phosphorus, 0.056%

Property	Hard[b]
Tensile strength, p.s.i. (000 omitted)	107–99
Elongation, % in 2 in.	3–6
Apparent elastic limit, p.s.i. (000 omitted)	92–84
Rockwell hardness F, 1/16-in. ball, 60-kg. load	113–110
Rockwell hardness B, 1/16-in. ball, 100-kg. load	96–94
Rockwell hardness G, 1/16-in. ball, 150-kg. load	71–73
Rockwell hardness 15-T, 1/16-in. ball, 15-kg. load	91
Rockwell hardness 30-T, 1/16-in. ball, 30-kg. load	78–79
Modulus of tensile resilience, in.-lbs. per cu. in.	320–270
Endurance limit (at 10^8 reversals):[1]	
Soft, p.s.i. (000 omitted)	21
4 B. & S. Nos., hard, p.s.i. (000 omitted)	22
10 B. & S. Nos., hard, p.s.i. (000 omitted)	24.5
Young's modulus of elasticity, p.s.i.	15,000,000
Melting point, °F.	1877
Density, lb. per cu. in.	0.318
Coefficient of expansion, per °C. from 25–300°C.	0.0000182
Electrical conductivity,[88] % I.A.C.S. at 68°F.	13.00
Thermal conductivity,[88] B.t.u. per sq. ft. per ft. per hr. per °F., 68°F	36.30

[a] All tests conducted on 0.040-in. stock.

[b] 6 B. & S. Nos., hard, 0.015–0.080 mm. grain size at ready-to-finish, respectively. Applies to first nine properties.

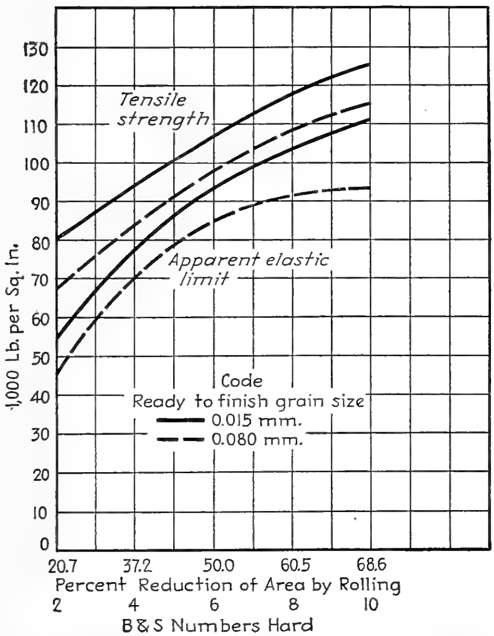

CHART 13.—The effect of cold work on the tensile strength and apparent elastic limit of 8 per cent phosphor-bronze strip, previously annealed to two different grain sizes, 0.015 and 0.080 mm. (7.5% tin, 0.056% phosphorus, balance copper) (0.040-in. stock).

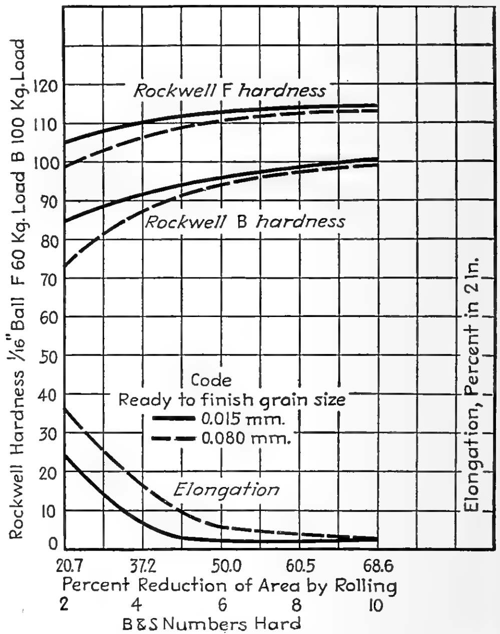

CHART 14.—The effect of cold work on the Rockwell hardness and percentage elongation in 2 in. of 8 per cent phosphor-bronze strip, previously annealed to two different grain sizes, 0.015 mm. and 0.080 mm. (7.5% tin, 0.056% phosphorus, balance copper) (0.040-in. stock).

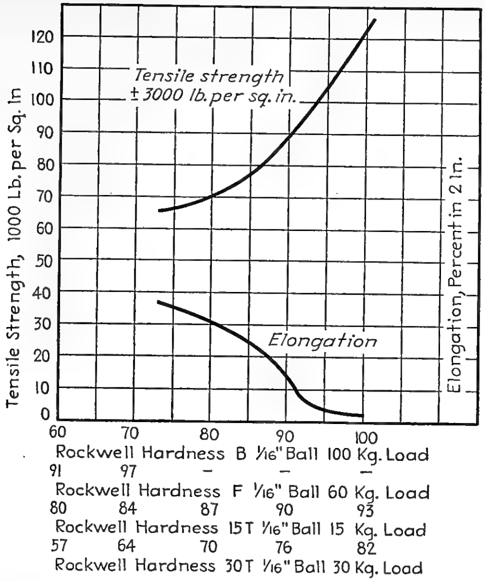

CHART 15.—This chart can be employed to determine the approximate tensile strength and percentage elongation of 8 per cent phosphor-bronze strip (7.5 % tin, 0.056 % phosphorus, balance copper) when only Rockwell hardness is known. It is accurate for all thicknesses between 0.020 and 0.080 in. within the given limits.

TABLE 3
CAROBRONZE
GENERAL DATA—TUBE
Analysis (approximate): copper, 91.70%; tin, 8.00%; phosphorus, 0.30%

Property	Hard[a]	Soft[b]
Tensile strength, p.s.i. (000 omitted)	77–95	59
Apparent elastic limit, p.s.i. (000 omitted)	46–62	20
Yield strength, 0.5% extension, p.s.i. (000 omitted)	....	22–23
Yield strength, 0.2% offset, p.s.i. (000 omitted)	....	22–23
Yield strength, 0.1% offset, p.s.i. (000 omitted)	....	22–23
Elongation, % in 2 in.	34–15	63
Rockwell hardness F, 1/16-in. ball, 60-kg. load	107–114	77
Rockwell hardness B, 1/16-in. ball, 100-kg. load	86–99	38
Young's modulus of elasticity[c] p.s.i.	16,000,000	19,000,000
Melting point, °F.	1877	
Density, lb. per cu. in.	0.318	
Coefficient of expansion,[d]	0.0000182	
Electrical conductivity, % I.A.C.S., 68°F.	13.00	
Thermal conductivity, B.t.u. per sq. ft. per ft. per hr. per °F., 68°F.	36	

PROPERTIES AT ELEVATED TEMPERATURE[e]

Temperature, °F	Tensile strength, p.s.i. (000 omitted)	Elongation, %
70	78	30
210	78	32
390	77	28
570	74	27
750	47	15
930	40	11

[a] 5/8 in. O.D. × 0.050 in. wall thickness. Ready-to-finish grain, 0.035 mm. 15–30% reduction in area by cold drawing.
[b] 1200°F. anneal (1 hr. at temperature) of material described in footnote *a*.
[c] Secant modulus to the apparent elastic limit.
[d] Average linear coefficient per °C. from 25–300°C.
[e] Tests made in the laboratory of the Skodawerke in Pilsen, on material of medium tensile strength.

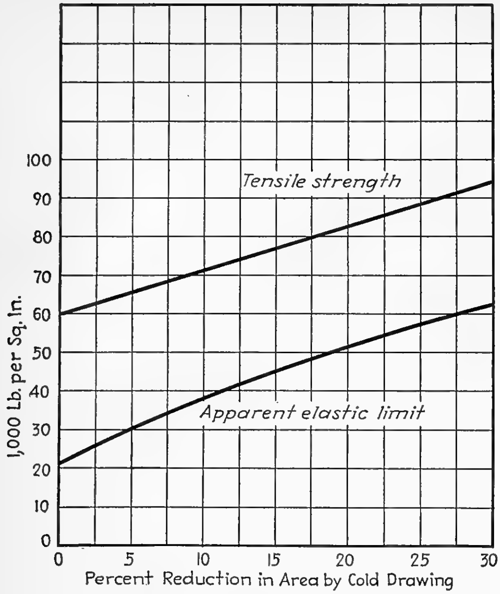

Chart 16.—The effect of cold drawing on the tensile strength and apparent elastic limit of Carobronze tube (8.00 % tin, 0.30 % phosphorus, balance copper), previously annealed to a grain size of 0.035 mm.

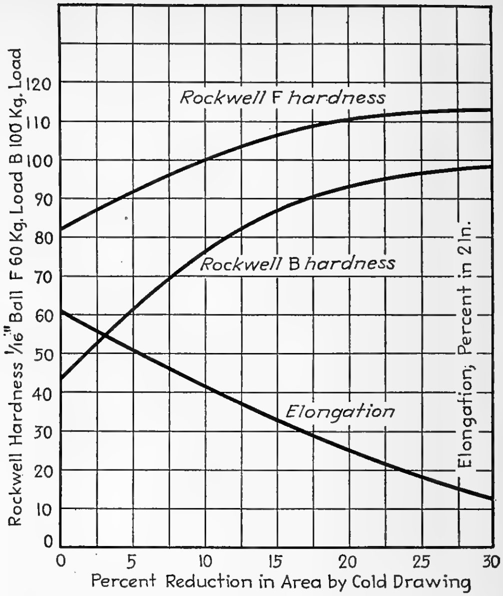

Chart 17.—The effect of cold drawing on the Rockwell hardness and percentage elongation in 2 in. of Carobronze tube, previously annealed to a grain size of 0.035 mm. (8.00 % tin, 0.30 % phosphorus, balance copper).

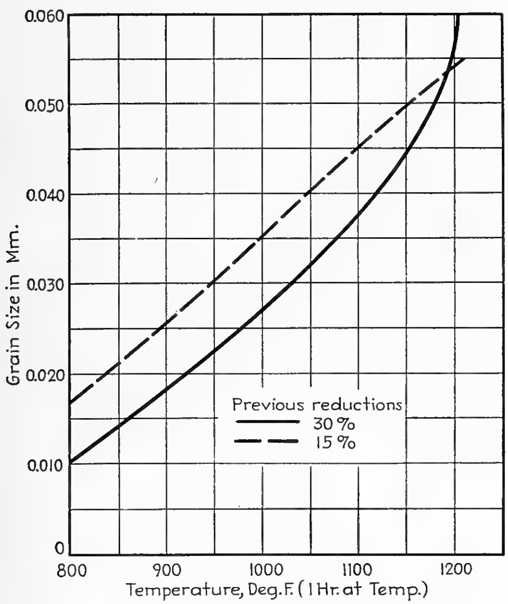

Chart 18.—The effect of annealing on the grain-growing characteristics of Carobronze tube, previously cold-drawn 15 and 30 per cent (reduction of area) from a grain size of 0.035 mm. (8.00 % tin, 0.30 % phosphorus, balance copper).

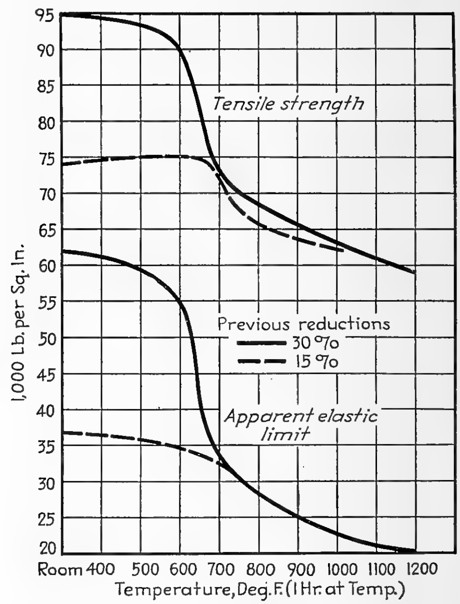

Chart 19.—The effect of annealing on the tensile strength and apparent elastic limit of Carobronze tube, previously cold-drawn 15 and 30 per cent (reduction of area) from a grain size of 0.035 mm. (8.00 % tin, 0.30 % phosphorus, balance copper).

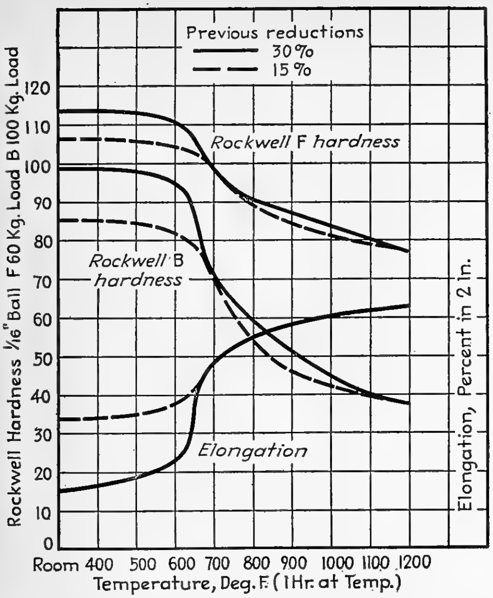

CHART 20.—The effect of annealing on the Rockwell hardness and percentage elongation in 2 in. of Carobronze tube, previously cold-drawn 15 and 30 per cent (reduction of area) from a grain size of 0.035 mm. (8.00 % tin, 0.30 % phosphorus, balance copper).

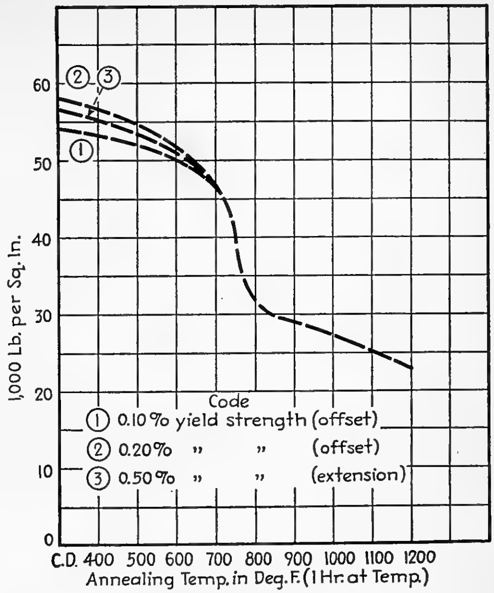

CHART 21.—The effect of annealing on the yield strength of Carobronze tube, previously cold-drawn 15 per cent (reduction of area) from a grain size of 0.035 mm. (8.00 % tin, 0.30 % phosphorus, balance copper).

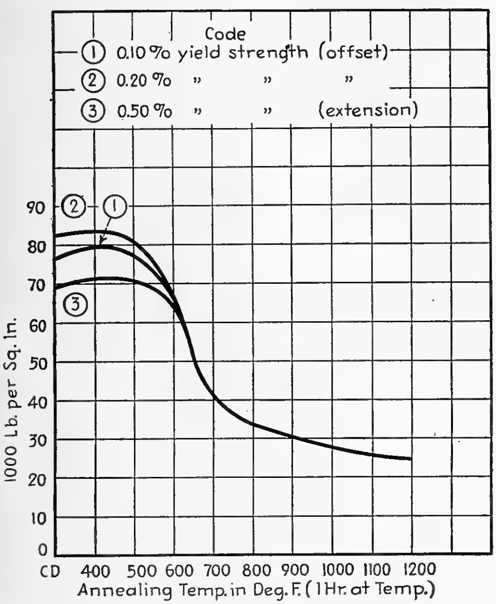

CHART 22.—The effect of annealing on the yield strength of Carobronze tube, previously cold-drawn 30 per cent (reduction of area) from a grain size of 0.035 mm. (8.00 % tin, 0.30 % phosphorus, balance copper).

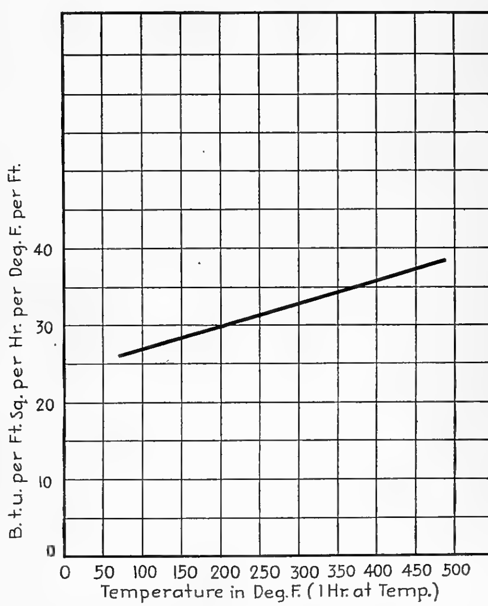

CHART 23.—The effect of temperature on the thermal conductivity of an 8 per cent phosphor bronze (91.7 % copper, 8.0 % tin, 0.30 % phosphorus, balance copper) based on data by Griffiths and Schoefield [23]

TABLE 4
3 PER CENT PHOSPHOR BRONZE
General Data[a]—Strip
Copper, 96.50%; tin, 3.09%; phosphorus, 0.39%

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	84	47
0.10% proof strength, p.s.i. (000 omitted)	7	
Limit of proportionality, p.s.i. (000 omitted)	57	
Shear strength, p.s.i. (000 omitted)	.....	35.4
Elongation, % in 2 in.	10	58
Rockwell hardness B, 1/16-in. ball, 100-kg. load	88	
Rockwell hardness E, 1/8-in. ball, 100-kg. load	109	
Diamond pyramid, 10-kg. load	190	69
Erichsen value, mm.	.....	12.8
Brinell hardness, 10 kg., 1-mm. ball	170	
Shore Scleroscope, M. H.	58	
S. & S., Shore Scleroscope, U. H., and self-recorder	34	
Specific gravity	8.883	8.8886
Density lb. per cu. in.	0.320	
Coefficient of thermal expansion, $\times 10^{-6}$:		
At 20–100°C.	16.6	
At 20–200°C.	17.5	
At 20–300°C.	18.2	
At 20–400°C.	18.8	
Thermal conductivity:		
At 70°F., B.t.u. per sq. ft. per ft. per hr. per °F.	38.72	
At 400°F., B.t.u. per sq. ft. per ft. per hr. per °F.	56.66	
Temperature coefficient of thermal conductivity	0.0024	
Specific resistance, ohm-cm. $\times 10^{-6}$ at 20°C.	12.23	
Modulus of elasticity, p.s.i.	14,500,000	
Electrical conductivity, % I.A.C.S.	14.1	

[a] Based on data by Cook and Tallis[30].
[b] Refers to strip cold-rolled 50% (ready-to-finish anneal 2 hr. at 1150°F.).
[c] Refers to 1150°F. anneal 2 hr. at temperature.

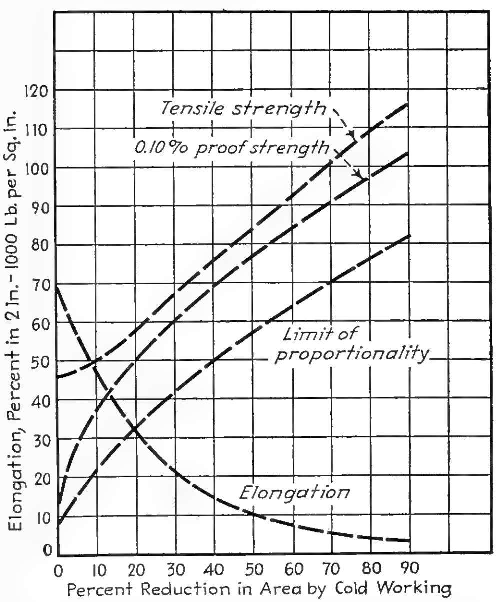

Chart 24.—The effect of cold rolling on the tensile strength, proof strength, proportional limit, and percentage elongation in 2 in. of a phosphor bronze (3.09% tin, 0.39% phosphorus, balance copper), previously annealed 1150°F. for 2 hr. according to Cook and Tallis.[30]

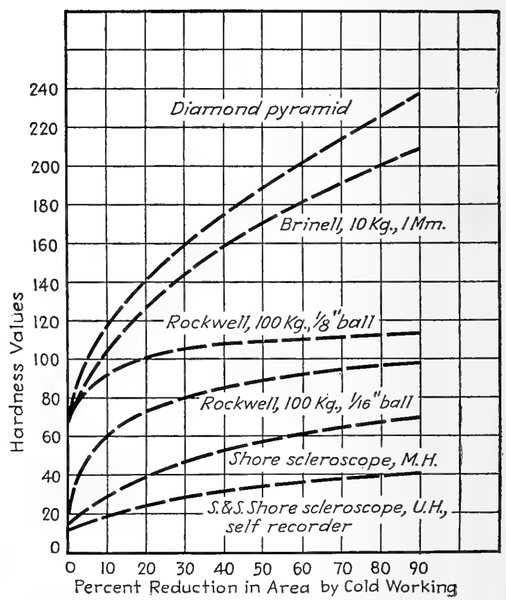

Chart 25.—The effect of cold rolling on the hardness of a phosphor bronze (3.09% tin, 0.39% phosphorus, balance copper), previously annealed for 2 hr. at 1150°F. according to Cook and Tallis.[30]

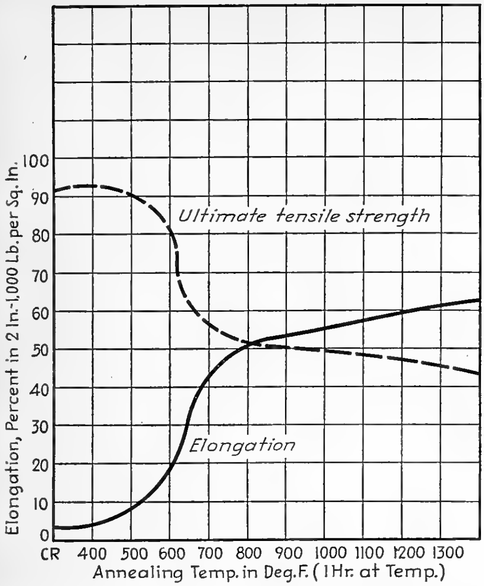

Chart 26.—The effect of annealing on the tensile strength and hardness of a phosphor bronze (3.09 % tin, 0.39 % phosphorus, balance copper) previously cold-rolled 60 per cent (reduction of area) according to Cook and Tallis.[30]

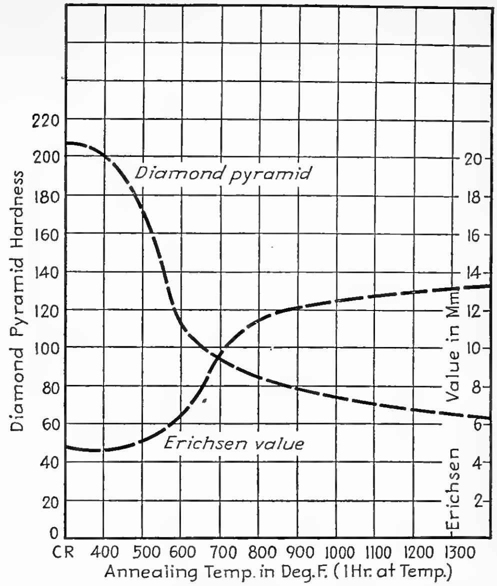

Chart 27.—The effect of annealing on the Erichsen ductility value and percentage elongation in 2 in. of a phosphor bronze (3.09 % tin, 0.39 % phosphorus, balance copper), previously cold-rolled 60 per cent (reduction of area) according to Cook and Tallis.[30]

TABLE 5

3 PER CENT PHOSPHOR BRONZE

General Data[a]—Strip

Copper, 96.84 %; tin, 3.11 %; phosphorus, 0.02 %

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	77	45
0.10 % proof strength, p.s.i. (000 omitted)	70	
Limit of proportionality, p.s.i. (000 omitted)	45	
Shear strength, p.s.i. (000 omitted)	.....	33
Elongation, % in 2 in.	9	55
Rockwell hardness B, 1/16-in. ball, 100-kg. load	84	
Rockwell hardness E, 1/8-in. ball, 100-kg. load	109	
Diamond pyramid, 10 kg.	175	66
Erichsen value, mm.	.....	12.5
Brinell hardness, 10 kg., 1 mm.	153	
Shore Scleroscope, M. H.	53	
S. & S., Shore Scleroscope, U. H., and self-recorder	31	
Specific gravity	8.927	8.929
Density, lb. per cu. in.	0.322	
Coefficient of thermal expansion, $\times 10^{-6}$:		
At 20–100°C.	16.9	
At 20–200°C.	17.5	
At 20–300°C.	18.1	
At 20–400°C.	18.5	
Thermal conductivity:		
At 70°F., B.t.u. per sq. ft. per ft. per hr. per °F.	67.76	
At 400°F., B.t.u. per sq. ft. per ft. per hr. per °F.	84.40	
Temperature coefficient of thermal conductivity	0.0014	
Specific resistance, ohm-cm. $\times 10^{-6}$ at 20°C.	6.37	
Modulus of elasticity, lb. per sq. in.	14,500,000	
Electrical conductivity, % I.A.C.S. at 68°F.	27.0	

[a] Based on data by Cook and Tallis[30].

[b] Refers to strip cold-rolled 50 % (ready-to-finish anneal 2 hr. at 1150°F.).

[c] Refers to 1150°F. anneal 2 hr. at temperature.

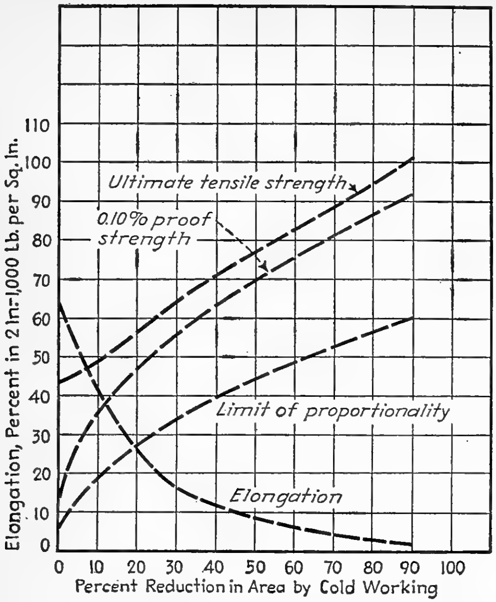

CHART 28.—The effect of cold rolling on the tensile strength, proof strength, proportional limit, and percentage elongation in 2 in. of a phosphor bronze (3.11 % tin, 0.02 % phosphorus, balance copper), previously annealed for 2 hr. at 1150°F. according to Cook and Tallis.(30)

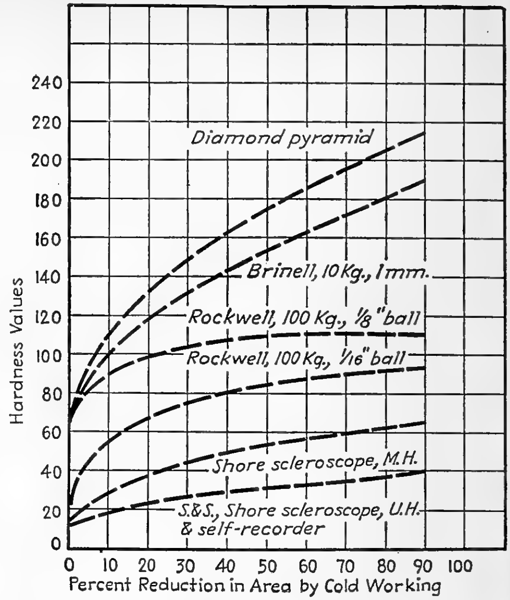

CHART 29.—The effect of cold rolling on the hardness of a phosphor bronze (3.11 % tin, 0.02 % phosphorus, balance copper) previously annealed for 2 hr. at 1150°F. according to Cook and Tallis.(30)

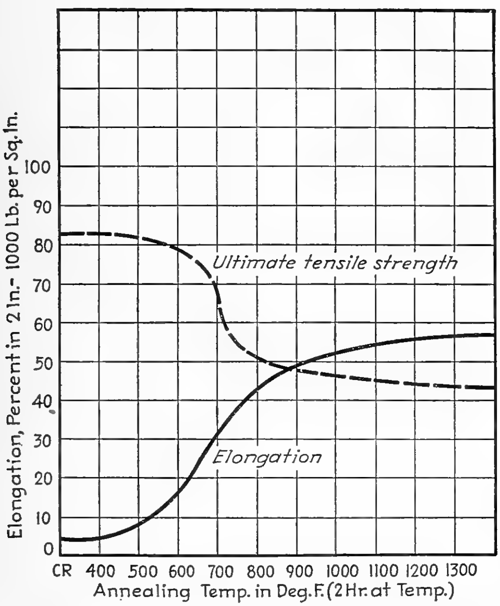

CHART 30.—The effect of annealing on the tensile strength and percentage elongation in 2 in. of a phosphor bronze (3.11 % tin, 0.02 % phosphorus, balance copper), previously cold-rolled 60 per cent (reduction of area) according to Cook and Tallis.(30)

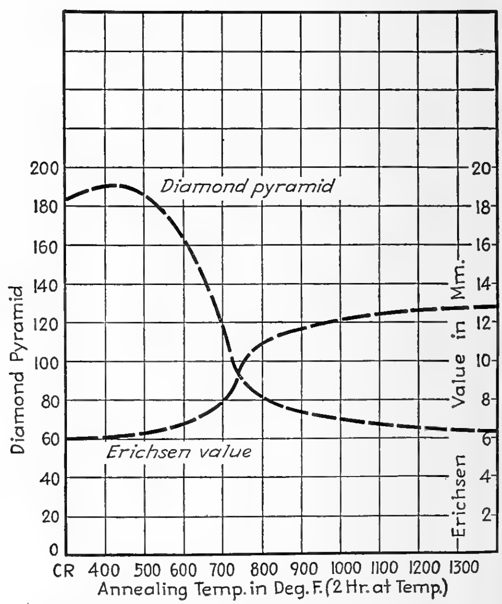

CHART 31.—The effect of annealing on the Erichsen ductility value and hardness of a phosphor bronze (3.11 % tin, 0.02 % phosphorus, balance copper), previously cold-rolled 60 per cent (reduction of area) according to Cook and Tallis.(30)

TABLE 6
4 PER CENT PHOSPHOR BRONZE
GENERAL DATA[a]—STRIP
Copper, 96.16%; tin, 3.71%; phosphorus, 0.12%

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	85	48
0.10% proof strength, p.s.i. (000 omitted)	78	
Limit of proportionality, p.s.i. (000 omitted)	51	
Shear strength, p.s.i. (000 omitted)	.....	36
Elongation, % in 2 in.	9	52
Rockwell hardness B, 1/16-in. ball, 100-kg. load	89	
Rockwell hardness E, 1/8-in. ball, 100-kg. load	110	
Diamond pyramid, 10-kg. load	182	72
Erichsen value, mm	.....	13.4
Brinell hardness	170	
Shore Scleroscope, M. H.	54	
S. & S., Shore Scleroscope, U. H., and self-recorder	34	
Specific gravity	8.919	8.916
Density, lb. per cu. in.	0.322	
Coefficient of thermal expansion, $\times 10^{-6}$:		
At 20–100°C.	17.6	
At 20–200°C.	18.4	
At 20–300°C.	18.8	
At 20–400°C.	19.4	
Thermal conductivity:		
At 70°F., B.t.u. per sq. ft. per ft. per hr. per °F.	48.40	
At 400°F., B.t.u. per sq. ft. per ft. per hr. per °F.	62.92	
Temperature coefficient of thermal conductivity	0.0016	
Specific resistance, ohm-cm. $\times 10^{-6}$ at 20°C.	9.17	
Modulus of elasticity, p.s.i.	14,500,000	
Electrical conductivity, % I.A.C.S. at 68°F.	18.8	

[a] Based on data by Cook and Tallis[30].
[b] Refers to strip cold-rolled 50% (ready-to-finish anneal 2 hr. at 1150°F.).
[c] Refers to 1150°F. anneal 2 hr. at temperature.

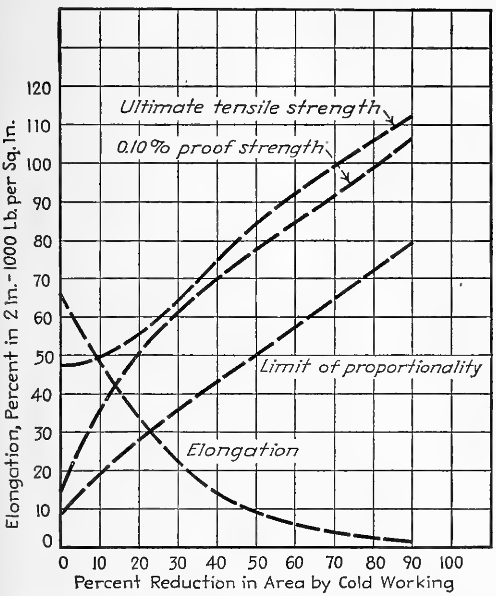

CHART 32.—The effect of cold rolling on the tensile strength, proof strength, proportional limit, and percentage elongation in 2 in. of a phosphor bronze (3.71% tin, 0.12% phosphorus, balance copper), previously annealed at 1150°F. for 2 hr. according to Cook and Tallis.[30]

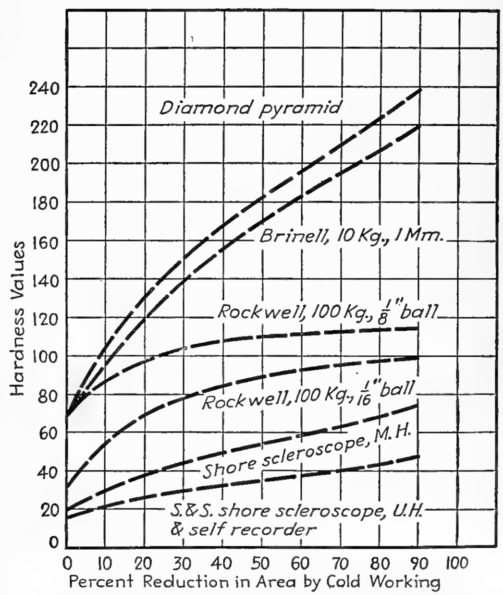

CHART 33.—The effect of cold rolling on the hardness of a phosphor bronze (3.71% tin, 0.12% phosphorus, balance copper), previously annealed for 2 hr. at 1150°F. according to Cook and Tallis.[30]

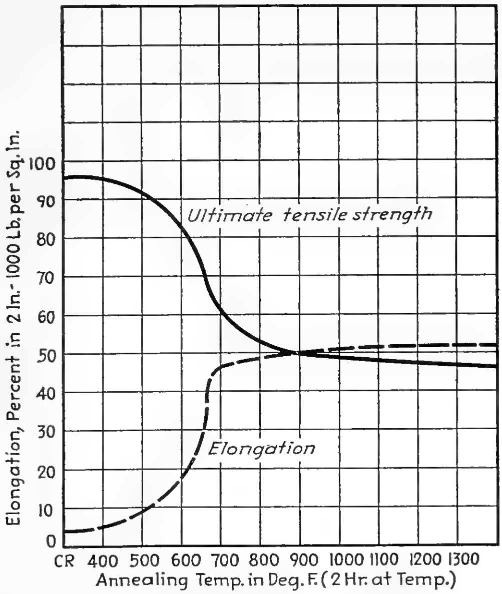

CHART 34.—The effect of annealing on the tensile strength and percentage elongation in 2 in. of a phosphor bronze (3.71 tin, 0.12 % phosphorus, balance copper), previously cold-rolled 60 per cent (reduction of area) according to Cook and Tallis.[30]

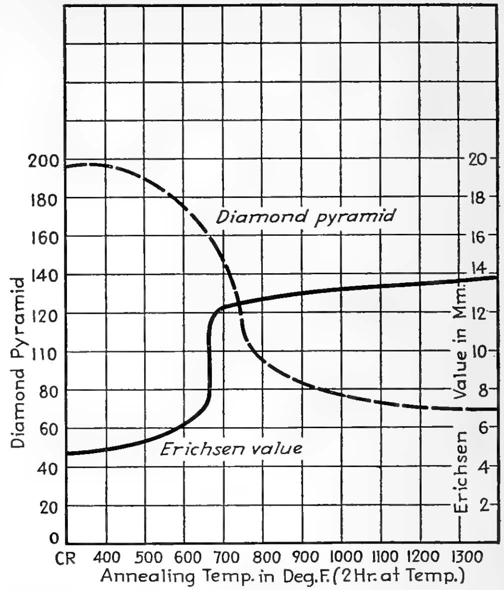

CHART 35.—The effect of annealing on the Erichsen ductility value and hardness of a phosphor bronze (3.71 % tin, 0.12 % phosphorus, balance copper), previously cold-rolled 60 per cent (reduction of area) according to Cook and Tallis.[30]

TABLE 7
5 PER CENT PHOSPHOR BRONZE
GENERAL DATA[a]—STRIP
Copper, 94.60%; tin, 5.27%; phosphorus, 0.09%

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	95	46
0.10% proof strength, p.s.i. (000 omitted)	84	
Limit of proportionality, p.s.i. (000 omitted)	62	
Shear strength, p.s.i. (000 omitted)	.....	37.8
Elongation, % in 2 in.	8.5	60
Rockwell hardness B, 1/16-in. ball, 100-kg. load	96	
Rockwell hardness E, 1/8-in. ball, 100-kg. load	113	
Diamond pyramid, 10-kg. load	198	75
Erichsen value, mm	.....	14.2
Brinell hardness, 10 kg., 1-mm. ball	178	
Shore Scleroscope, M. H.	59	
S. & S., Shore Scleroscope, U. H., and self-recorder	40	
Specific gravity	8.923	8.919
Density, lb. per cu. in.	0.322	
Coefficient of thermal expansion, $\times 10^{-6}$:		
At 20–100°C	17.0	
At 20–200°C	17.5	
At 20–300°C	18.0	
At 20–400°C	18.4	
Thermal conductivity:		
At 70°F., B.t.u. per sq. ft. per ft. per hr. per °F	43.56	
At 400°F., B.t.u. per sq. ft. per ft. per hr. per °F	58.08	
Temperature coefficient of thermal conductivity	0.0018	
Specific resistance, ohm-cm. $\times 10^{-6}$ at 20°C	10.25	
Modulus of elasticity, p.s.i.	14,500,000	
Electrical conductivity, % I.A.C.S., 68°F	16.8	

[a] Based on data by Cook and Tallis[30].
[b] Refers to strip cold-rolled 50% (ready-to-finish anneal 2 hr. at 1150°F.).
[c] Refers to 1150°F. anneal 2 hr. at temperature.

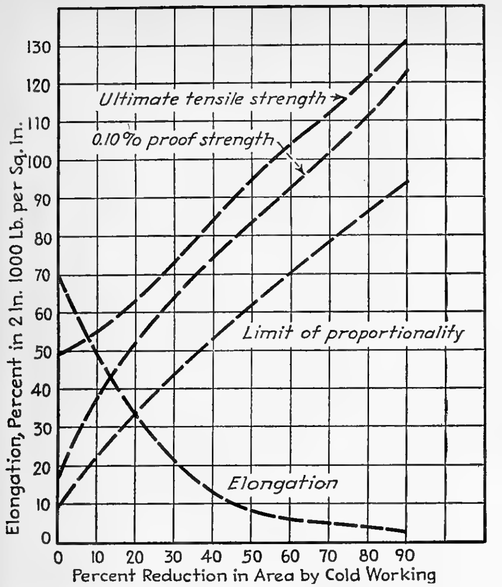

CHART 36.—The effect of cold rolling on the tensile strength, proof strength, proportional limit, and percentage elongation in 2 in. of a phosphor bronze (5.27 % tin, 0.09 % phosphorus, balance copper), previously annealed at 1150°F. for 2 hr. according to Cook and Tallis.(30)

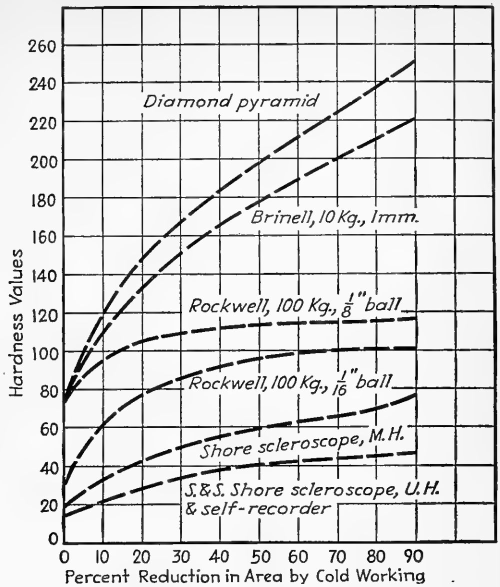

CHART 37.—The effect of cold rolling on the hardness of a phosphor bronze (5.27 % tin, 0.09 % phosphorus, balance copper) previously annealed for 2 hr. at 1150°F. according to Cook and Tallis.(30)

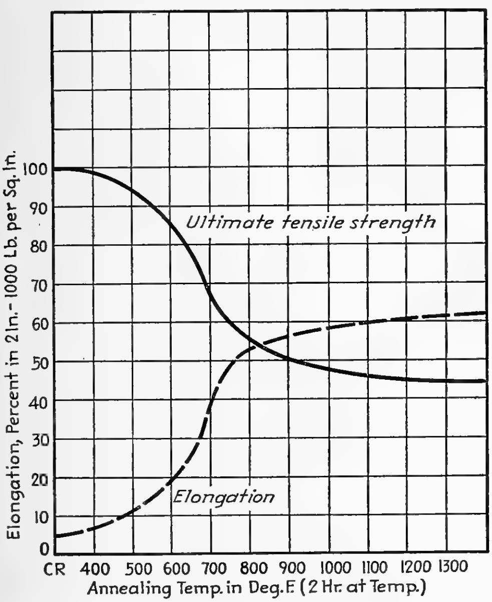

CHART 38.—The effect of annealing on the tensile strength and percentage elongation in 2 in. of a phosphor bronze (5.27 % tin, 0.09 % phosphorus, balance copper), previously cold-rolled 60 per cent (reduction of area) according to Cook and Tallis.(30)

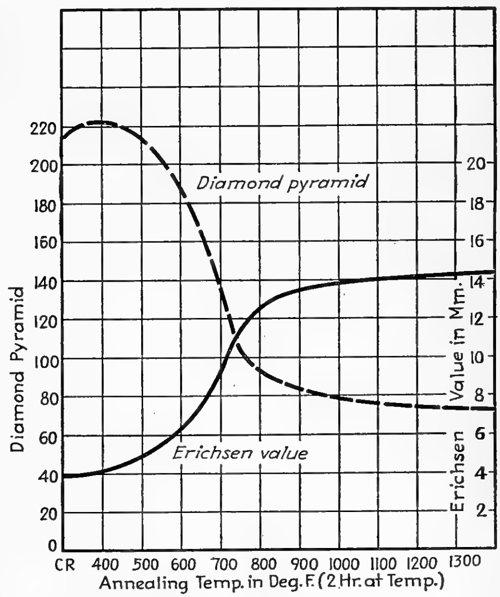

CHART 39.—The effect of annealing on the Erichsen ductility value and hardness of a phosphor bronze (5.27 % tin, 0.09 % phosphorus, balance copper), previously cold-rolled 60 per cent (reduction of area) according to Cook and Tallis.(30)

TABLE 8
6.5 PER CENT PHOSPHOR BRONZE
GENERAL DATA[a]—STRIP
Copper, 93.19%; tin, 6.65%; phosphorus, 0.12%

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	98	54
0.10% proof strength, p.s.i. (000 omitted)	87	
Limit of proportionality, p.s.i. (000 omitted)	65	
Shear strength, p.s.i. (000 omitted)	.....	42
Elongation, % in 2 in.	11	66
Rockwell hardness B, 1/16-in. ball, 100-kg. load	97	
Rockwell hardness E, 1/8-in. ball, 100-kg. load	112	
Diamond pyramid, 10-kg. load	210	82
Erichsen value, mm	.....	14.6
Brinell hardness, 10 kg., 1-mm. ball	196	
Shore Scleroscope, M. H.	64	
S. & S., Shore Scleroscope, U. H., and self-recorder	37	
Specific gravity	8.918	8.914
Density, lb. per cu. in.	0.322	
Coefficient of thermal expansion, $\times 10^{-6}$:		
At 20–100°C.	17.2	
At 20–200°C.	17.9	
At 20–300°C.	18.3	
At 20–400°C.	18.9	
Thermal conductivity:		
At 70°F., B.t.u. per sq. ft. per ft. per hr. per °F.	36.30	
At 400°F., B.t.u. per sq. ft. per ft. per hr. per °F.	48.40	
Temperature coefficient of thermal conductivity	0.0023	
Specific resistance, ohm-cm. $\times 10^{-6}$ at 20°C.	12.83	
Modulus of elasticity, p.s.i.	14,500,000	
Electrical conductivity, % I.A.C.S., 68°F.	13.6	

[a] Based on data by Cook and Tallis[30].
[b] Refers to strip cold-rolled 50% (ready-to-finish anneal 2 hr. at 1150°F.).
[c] Refers to 1150°F anneal 2 hr. at temperature.

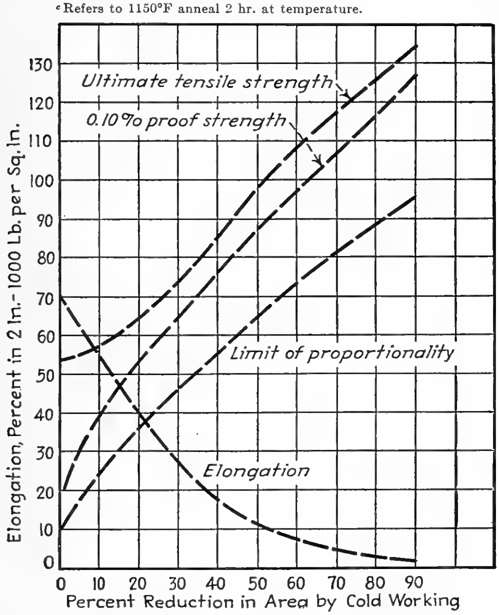

CHART 40.—The effect of cold rolling on the tensile strength, proof strength, proportional limit, and percentage elongation in 2 in. of a phosphor bronze (6.65% tin, 0.12% phosphorus, balance copper), previously annealed for 2 hr. at 1150°F. according to Cook and Tallis.[30]

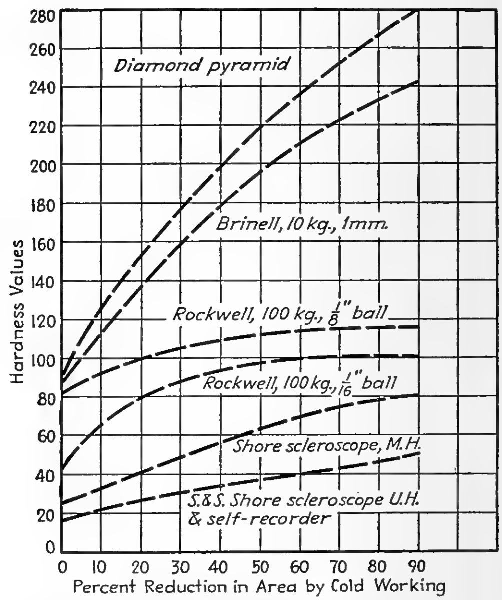

CHART 41.—The effect of cold rolling on the hardness of a phosphor bronze (6.65% tin, 0.12% phosphorus, balance copper), previously annealed at 1150°F. for 2 hr. according to Cook and Tallis.[30]

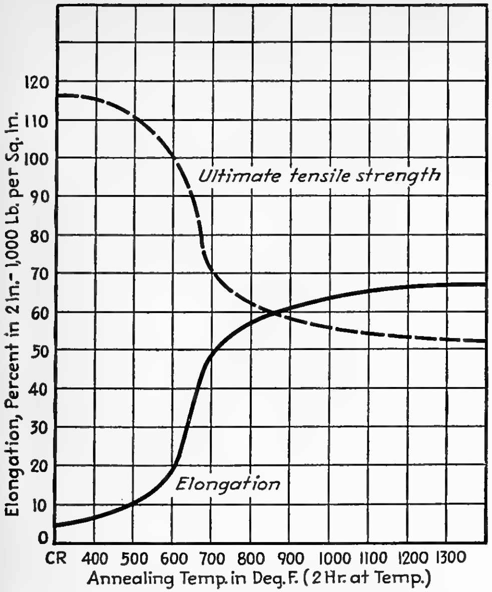

Chart 42.—The effect of annealing on the tensile strength and percentage elongation in 2 in. of a phosphor bronze (6.65 % tin, 0.12 % phosphorus, balance copper), previously cold-rolled 60 per cent (reduction of area) according to Cook and Tallis.(30)

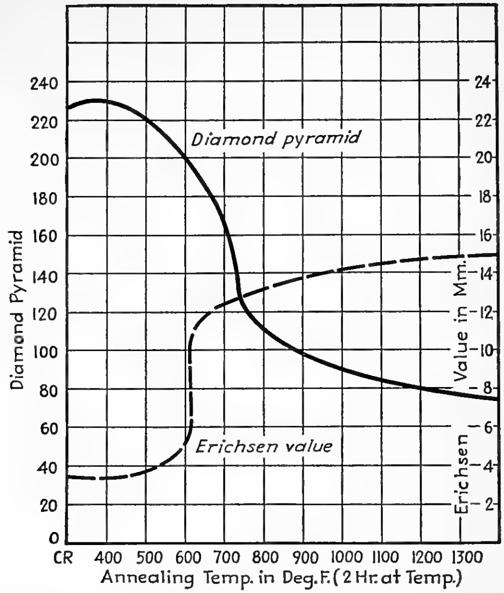

Chart 43.—The effect of annealing on the Erichsen ductility value and hardness of a phosphor bronze (6.65 % tin, 0.12 % phosphorus, balance copper), previously cold-rolled 60 per cent (reduction of area) according to Cook and Tallis.(30)

TABLE 9
8 PER CENT PHOSPHOR BRONZE

General Data[a]—Strip

Copper, 92.60%; tin, 7.31%; phosphorus, 0.02%

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	99	54
0.10% proof strength, p.s.i. (000 omitted)	90	
Limit of proportionality, p.s.i. (000 omitted)	64	
Shear strength, p.s.i. (000 omitted)	.....	41
Elongation, p.s.i. (000 omitted)	14	74
Rockwell hardness B, 1/16-in. ball, 100-kg. load	96	
Rockwell hardness E, 1/8-in. ball, 100-kg. load	112	
Diamond pyramid, 10-kg. load	212	80
Erichsen value, mm	.....	12.8
Brinell hardness, 10 kg., 1-mm. ball	192	
Shore Scleroscope, M. H.	60	
S. & S., Shore Scleroscope, U. H., and self-recorder	40	
Specific gravity	8.932	8.928
Density, lb. per cu. in.	0.322	
Coefficient of thermal expansion, $\times 10^{-6}$:		
At 20–100°C	17.6	
At 20–200°C	18.2	
At 20–300°C	18.5	
At 20–400°C	18.9	
Thermal conductivity:		
At 70°F., B.t.u. per sq. ft. per ft. per hr. per °F	38.72	
At 400°F., B.t.u. per sq. ft. per ft. per hr. per °F	53.24	
Temperature coefficient of thermal conductivity	0.0021	
Specific resistance, ohm-cm. $\times 10^{-6}$ at 20°C	12.31	
Modulus of elasticity, p.s.i.	14,500,000	
Electrical conductivity, % I.A.C.S., 68°F	14.0	

[a] Based on data by Cook and Tallis[30].

[b] Refers to strip cold-rolled 50 % (ready-to-finish anneal 2 hr. at 1150°F.).

[c] Refers to 1150°F. anneal 2 hr. at temperature.

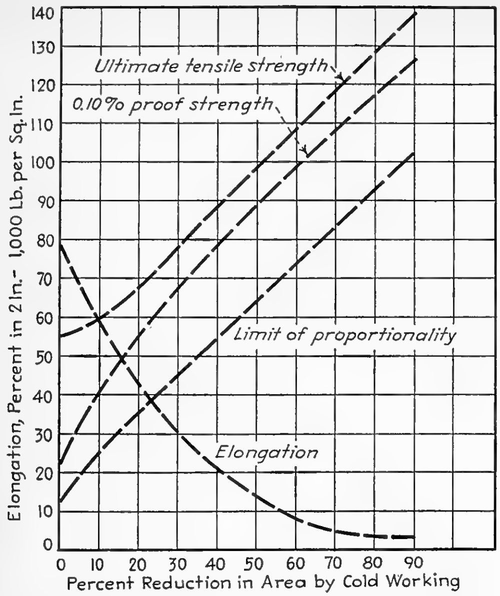

CHART 44.—The effect of cold rolling on the tensile strength, proof strength, proportional limit, and percentage elongation in 2 in. of a phosphor bronze (7.31 % tin, 0.02 % phosphorus, balance copper) previously annealed at 1150°F. for 2 hr. according to Cook and Tallis.(30)

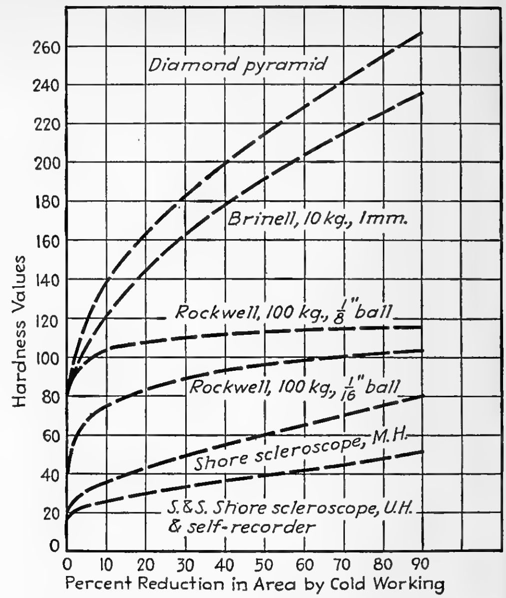

CHART 45.—The effect of cold rolling on the hardness of a phosphor bronze (7.31 % tin, 0.02 % phosphorus, balance copper), previously annealed at 1150°F. for 2 hr. according to Cook and Tallis.(30)

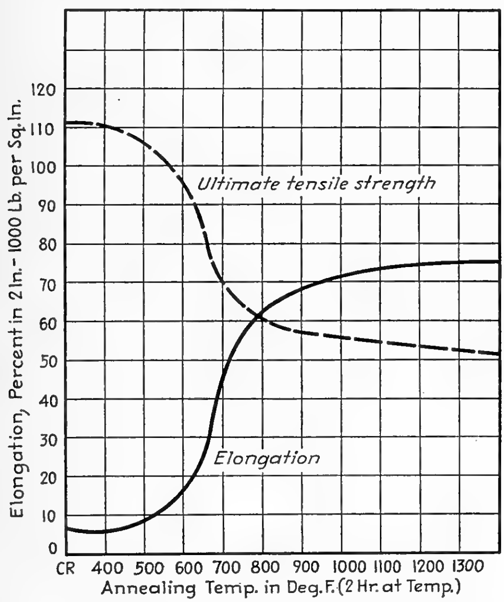

CHART 46.—The effect of annealing on the tensile strength and percentage elongation in 2 in. of a phosphor bronze (7.31 % tin, 0.02 % phosphorus, balance copper), previously cold-rolled 60 per cent (reduction of area) according to Cook and Tallis.(30)

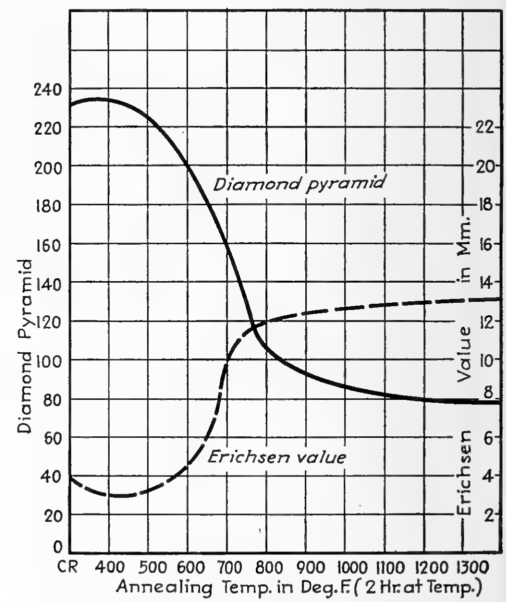

CHART 47.—The effect of annealing on the Erichsen ductility value and hardness of a phosphor bronze (7.31 % tin, 0.02 % phosphorus, balance copper), previously cold-rolled 60 per cent (reduction of area) according to Cook and Tallis.(30)

TABLE 10
8 PER CENT PHOSPHOR BRONZE
GENERAL DATA[a]—STRIP
Copper, 92.20%; tin, 7.41%; phosphorus, 0.38%

Property	Hard[b]	Soft[c]
Tensile strength, p.s.i. (000 omitted)	109	62
0.10% proof strength, p.s.i. (000 omitted)	96	
Limit of proportionality, p.s.i. (000 omitted)	71.5	
Shear strength, p.s.i. (000 omitted)	.....	47
Elongation, % in 2 in.	11	73
Rockwell hardness B, 1/16-in. ball, 100-kg. load	98	
Rockwell hardness E, 1/8-in. ball, 100-kg. load	112	
Diamond pyramid, 10-kg. load	228	93
Erichsen value, mm	.....	13.1
Brinell hardness	203	
Shore Scleroscope, M. H.	72	
S. & S., Shore Scleroscope, U. H., and self-recorder	41	
Specific gravity	8.887	8.885
Density, lb. per cu. in.	0.321	
Coefficient of thermal expansion, $\times 10^{-6}$:		
At 20–100°C.	17.4	
At 20–200°C.	18.3	
At 20–300°C.	19.0	
At 20–400°C.		
Thermal conductivity:		
At 70°F., B.t.u. per sq. ft. per ft. per hr. per °F.	26.62	
At 400°F., B.t.u. per sq. ft. per ft. per hr. per °F.	36.30	
Temperature coefficient of thermal conductivity	0.0026	
Specific resistance, ohm-cm. $\times 10^{-6}$ at 20°C.	17.64	
Modulus of elasticity, p.s.i.	14,500,000	
Electrical conductivity, % I.A.C.S., 68°F.	9.7	

[a] Based on data by Cook and Tallis[30].
[b] Refers to strip cold-rolled 50% (ready-to-finish anneal 2 hr. at 1150°F.).
[c] Refers to 1150°F. anneal 2 hr. at temperature.

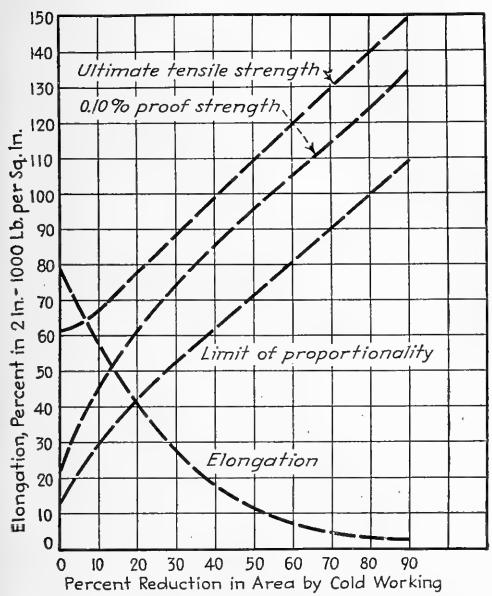

CHART 48.—The effect of cold rolling on the tensile strength, proof strength, proportional limit, and percentage elongation in 2 in. of a phosphor bronze (7.41% tin, 0.38% phosphorus, balance copper), previously annealed at 1150°F. for 2 hr. according to Coo^k and Tallis.[30]

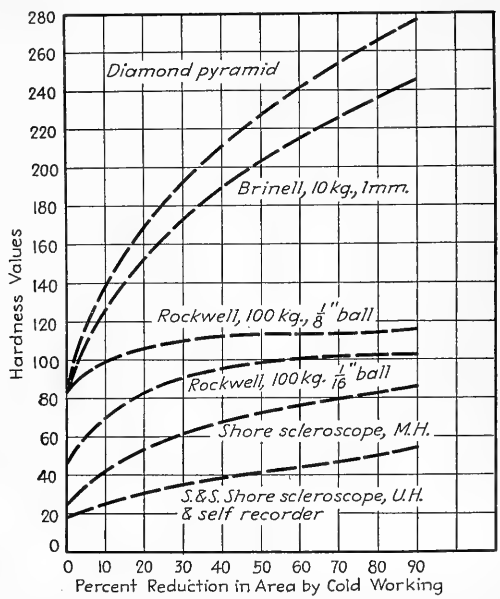

CHART 49.—The effect of cold rolling on the hardness of a phosphor bronze (7.41% tin, 0.38% phosphorus, balance copper), previously annealed at 1150°F. for 2 hr. according to Cook and Tallis.[30]

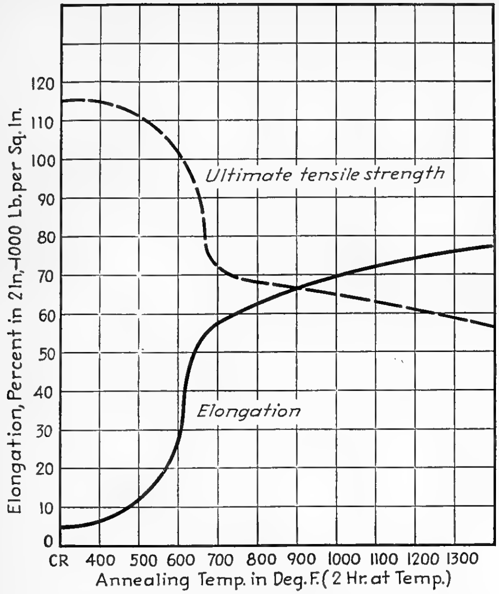

CHART 50.—The effect of annealing on the tensile strength and percentage elongation in 2 in. of a phosphor bronze (7.41 % tin, 0.38 % phosphorus, balance copper), previously cold-rolled 60 per cent (reduction of area) according to Cook and Tallis.[30]

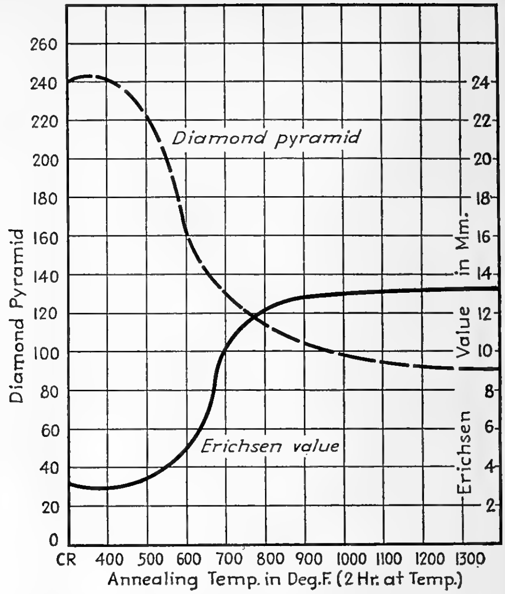

CHART 51.—The effect of annealing on the Erichsen ductility value and hardness of a phosphor bronze (7.41 % tin, 0.38 % phosphorus, balance copper), previously cold-rolled 60 per cent (reduction of area) according to Cook and Tallis.[30]

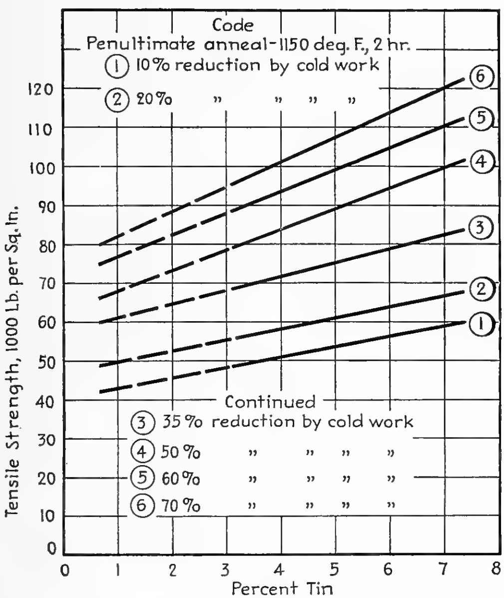

CHART 52.—The effect of tin on the tensile strength of copper containing 0.05 per cent phosphorus (cold-rolled varying amounts from a ready-to-finish anneal of 1150°F. for 2 hr.) based on data by Cook and Tallis.[30] (Solid line based on actual data; dotted line extrapolated.)

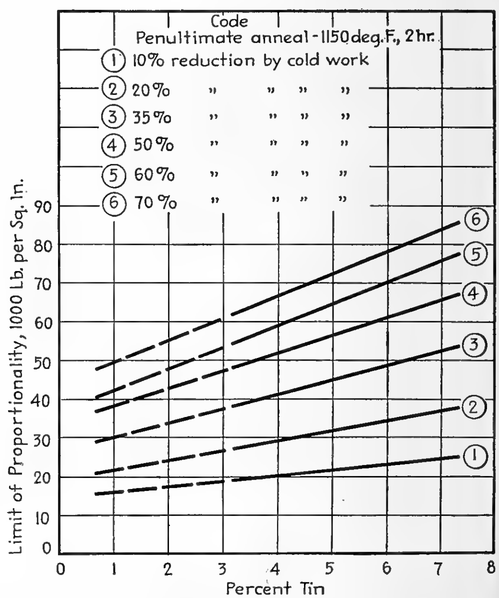

CHART 53.—The effect of tin on the proportional limit of copper containing 0.05 per cent phosphorus (cold-rolled varying amounts from a ready-to-finish anneal of 1150°F. for 2 hr.) based on data by Cook and Tallis.[30] (Solid line based on actual data; dotted line extrapolated.)

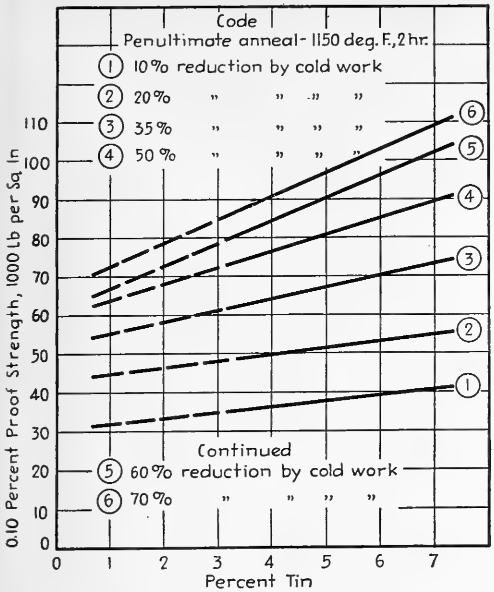

CHART 54.—The effect of tin on the proof strength of copper containing 0.05 per cent phosphorus (cold-rolled varying amounts from a ready-to-finish anneal of 1150°F. for 2 hr.) based on data by Cook and Tallis.[30] (Solid line based on actual data; dotted line extrapolated.)

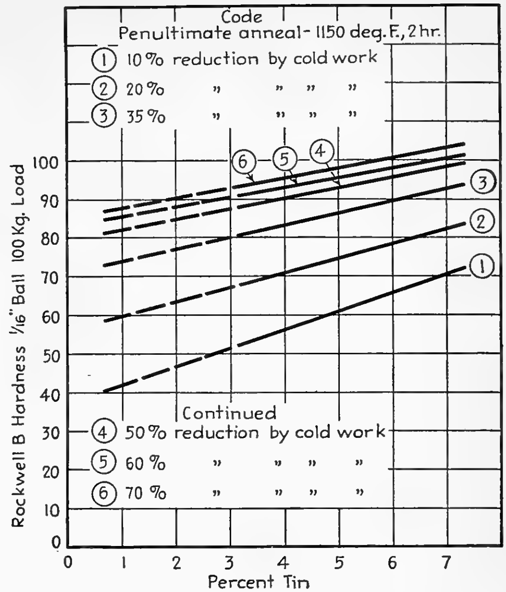

CHART 55.—The effect of tin on the Rockwell B hardness of copper containing 0.05 per cent phosphorus (cold-rolled varying amounts from a ready-to-finish anneal of 1150°F. for 2 hr.) based on data by Cook and Tallis.[30] (Solid line based on actual data; dotted line extrapolated.)

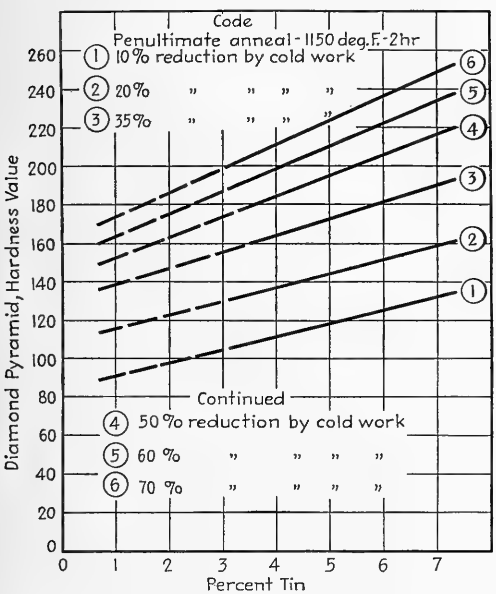

CHART 56.—The effect of tin on the diamond-pyramid hardness of copper containing 0.05 per cent phosphorus (cold-rolled varying amounts from a ready-to-finish anneal of 1150°F. for 2 hr.) based on data by Cook and Tallis.[30] (Solid line based on actual data; dotted line extrapolated.)

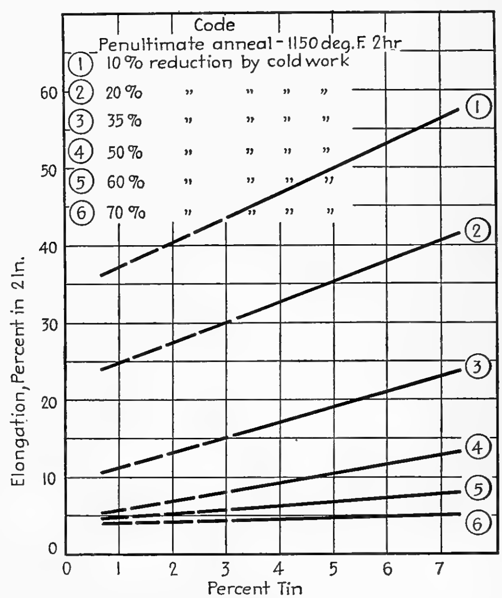

CHART 57.—The effect of tin on the percentage elongation in 2 in. of copper containing 0.05 per cent phosphorus (cold-rolled varying amounts from a ready-to-finish anneal of 1150°F. for 2 hr.) based on data by Cook and Tallis.[30] (Solid line based on actual data; dotted line extrapolated.)

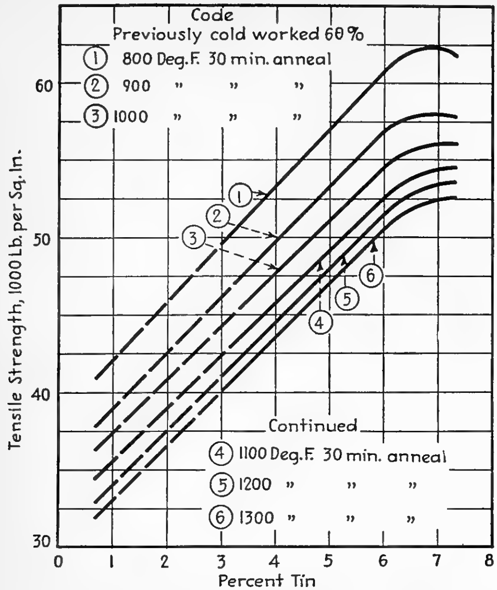

CHART 58.—The effect of tin on the tensile strength of copper containing 0.05 per cent phosphorus, annealed at various temperatures after having been cold-rolled 60 per cent (reduction of area) based on data by Cook and Tallis.(30) (Solid lines based on actual data; dotted lines extrapolated.)

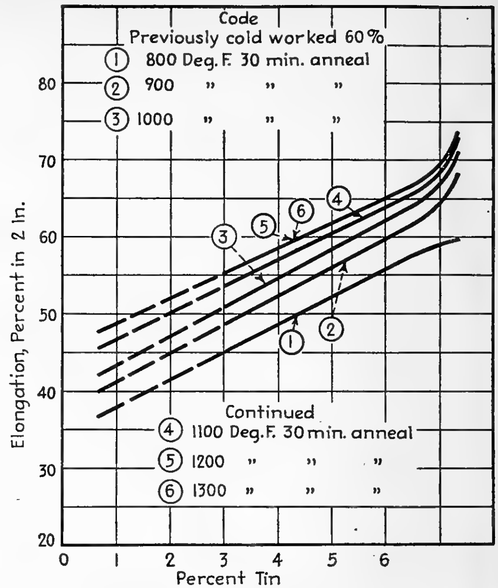

CHART 59.—The effect of tin on the percentage elongation in 2 in. of copper containing 0.05 per cent phosphorus, annealed at various temperatures after having been cold-rolled 60 per cent (reduction of area) based on data by Cook and Tallis.(30) (Solid lines based on actual data; dotted lines extrapolated.)

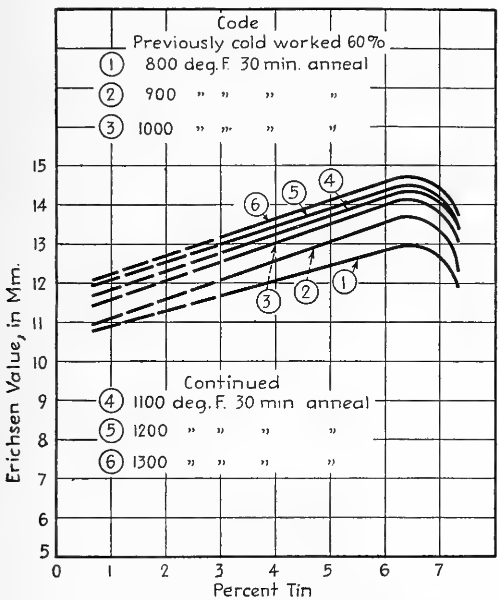

CHART 60.—The effect of tin on the Erichsen ductility value of copper containing 0.05 per cent phosphorus, annealed at various temperatures after having been cold-rolled 60 per cent (reduction of area) based on data by Cook and Tallis.(30) (Solid lines based on actual data; dotted lines extrapolated.)

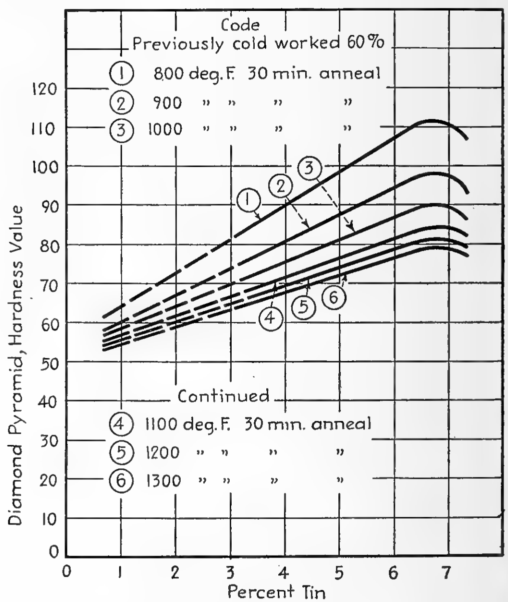

CHART 61.—The effect of tin on the hardness of copper containing 0.05 per cent phosphorus, annealed at various temperatures after having been cold-rolled 60 per cent (reduction of area) based on data by Cook and Tallis.(30) (Solid lines based on actual data; dotted lines extrapolated.)

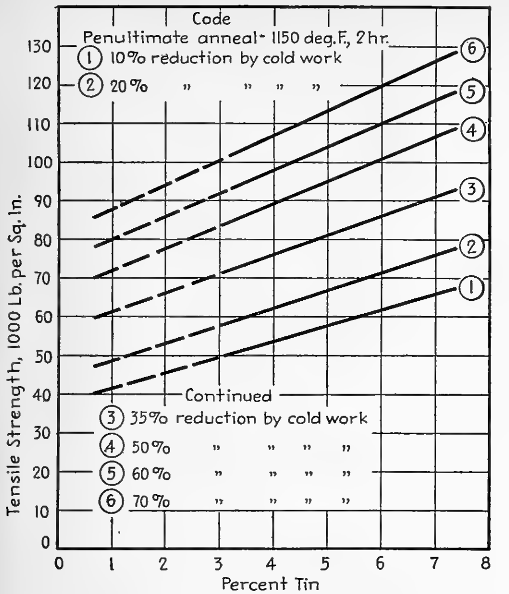

Chart 62.—The effect of tin on the tensile strength of copper containing 0.40 per cent phosphorus (cold-rolled varying amounts from a ready-to-finish anneal of 1150°F. for 2 hr.) based on data by Cook and Tallis.[30] (Solid lines based on data; dotted lines extrapolated.)

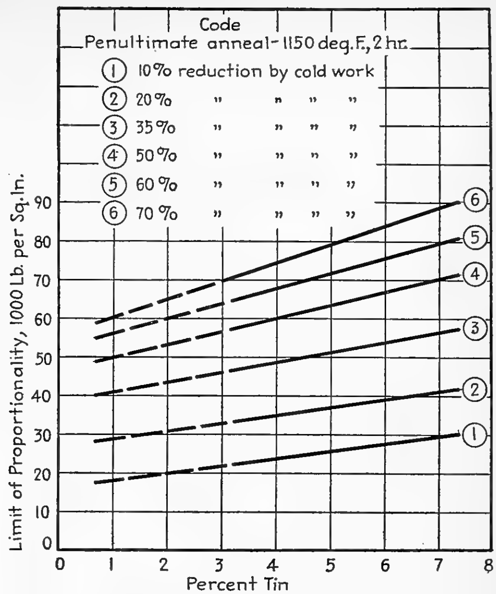

Chart 63.—The effect of tin on the proportional limit of copper containing 0.40 per cent phosphorus (cold-rolled varying amounts from a ready-to-finish anneal of 1150°F. for 2 hr.) based on data by Cook and Tallis.[30] (Solid lines based on data; dotted lines extrapolated.)

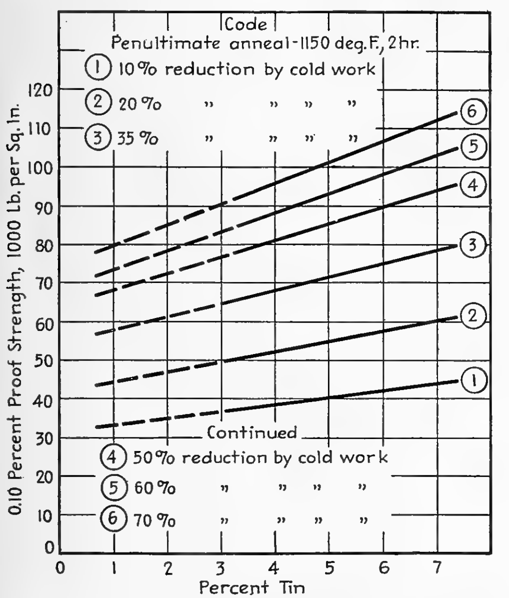

Chart 64.—The effect of tin on the proof strength of copper containing 0.40 per cent phosphorus (cold-rolled varying amounts from a ready-to-finish anneal of 1150°F. for 2 hr.) based on data by Cook and Tallis.[30] (Solid lines based on data; dotted lines extrapolated.)

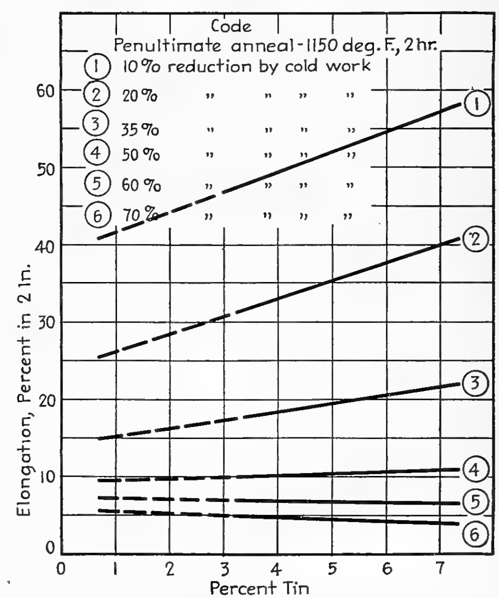

Chart 65.—The effect of tin on the percentage elongation in 2 in. of copper containing 0.40 per cent phosphorus (cold-rolled varying amounts from a ready-to-finish anneal of 1150°F. for 2 hr.) based on data by Cook and Tallis.[30] (Solid lines based on data; dotted lines extrapolated.)

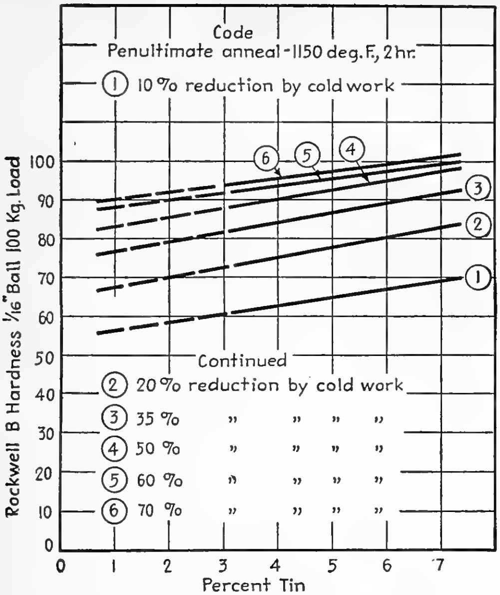

Chart 66.—The effect of tin on the Rockwell B hardness of copper containing 0.40 per cent phosphorus (cold-rolled varying amounts from a ready-to-finish anneal of 1150°F. for 2 hr.) based on data by Cook and Tallis.[30] (Solid lines based on data; dotted lines extrapolated.)

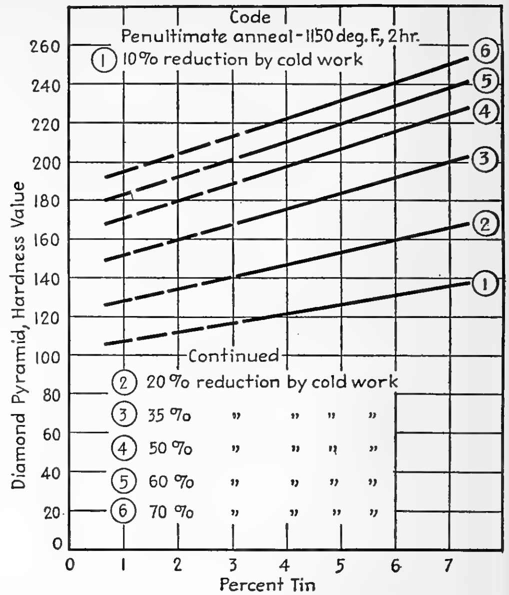

Chart 67.—The effect of tin on the diamond-pyramid hardness of copper containing 0.40 per cent phosphorus (cold-rolled varying amounts from a ready-to-finish anneal of 1150°F. for 2 hr.) based on data by Cook and Tallis.[30] (Solid lines based on data; dotted lines extrapolated.)

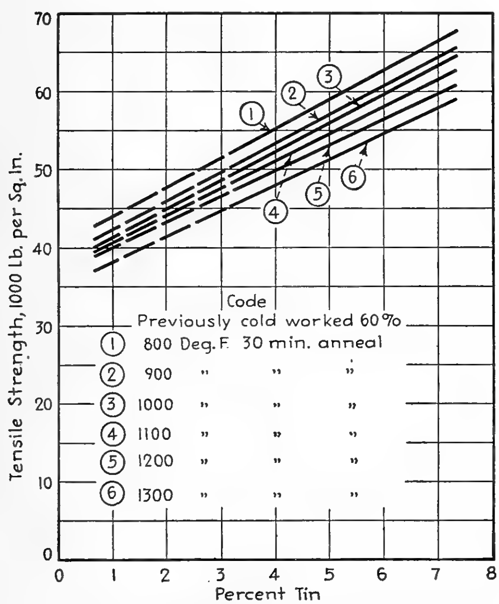

Chart 68.—The effect of tin on the tensile strength of copper containing 0.40 per cent phosphorus, annealed at various temperatures after having been cold-rolled 60 per cent (reduction of area) based on data by Cook and Tallis.[30] (Solid lines based on data; dotted lines extrapolated.)

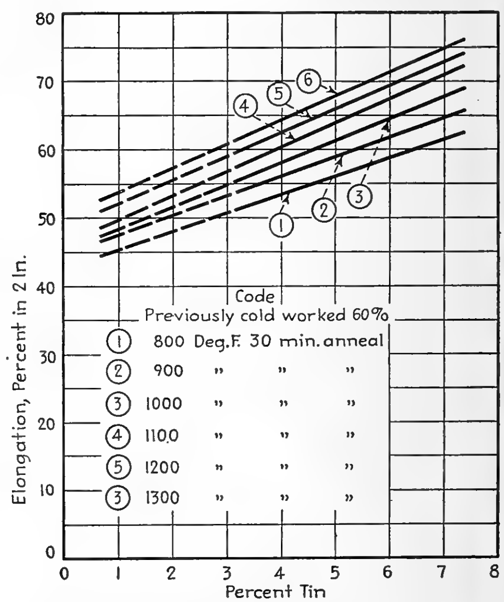

Chart 69.—The effect of tin on the percentage elongation in 2 in. of copper containing 0.40 per cent phosphorus, annealed at various temperatures after having been cold-rolled 60 per cent (reduction of area) based on data by Cook and Tallis.[30] (Solid lines based on data; dotted lines extrapolated.)

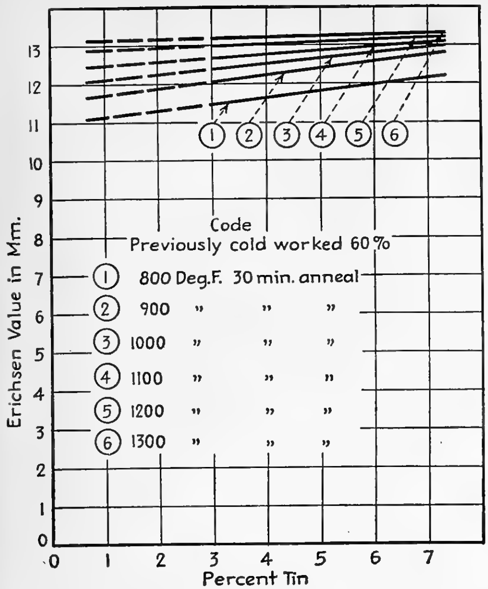

CHART 70.—The effect of tin on the Erichsen value of copper containing 0.40 per cent phosphorus, annealed at various temperatures after having been cold-rolled 60 per cent (reduction of area) based on data by Cook and Tallis.[30] (Solid lines based on data; dotted lines extrapolated.)

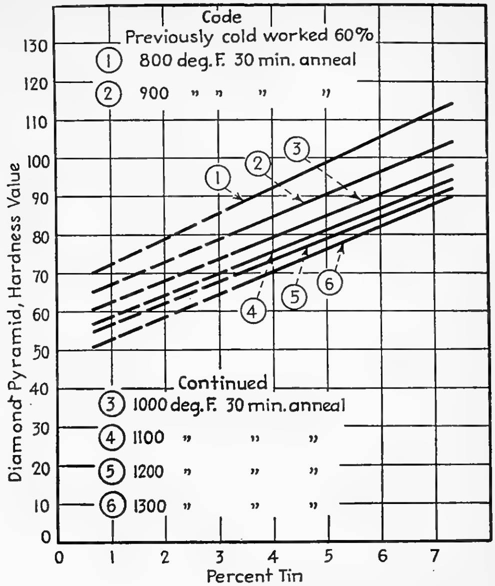

CHART 71.—The effect of tin on the hardness of copper containing 0.50 per cent phosphorus, annealed at various temperatures after having been cold-rolled 60 per cent (reduction of area) based on data by Cook and Tallis.[30] (Solid lines based on data; dotted lines extrapolated.)

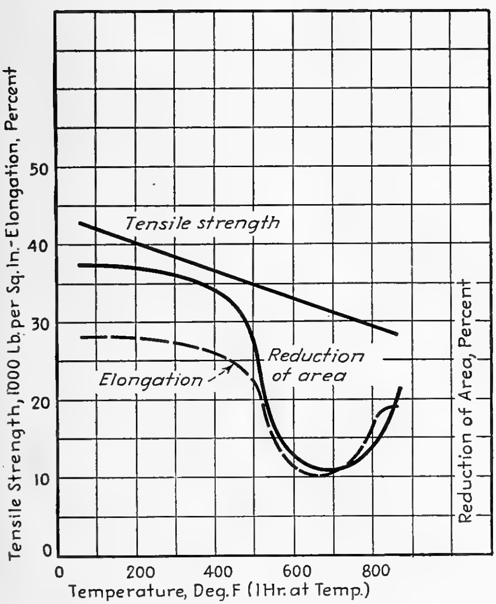

CHART 72.—The effect of elevated temperature on the tensile strength, percentage reduction of area, and percentage elongation of a phosphor bronze (2.41 % tin, 0.024 % phosphorus, balance copper) according to Huntington.[31,9]

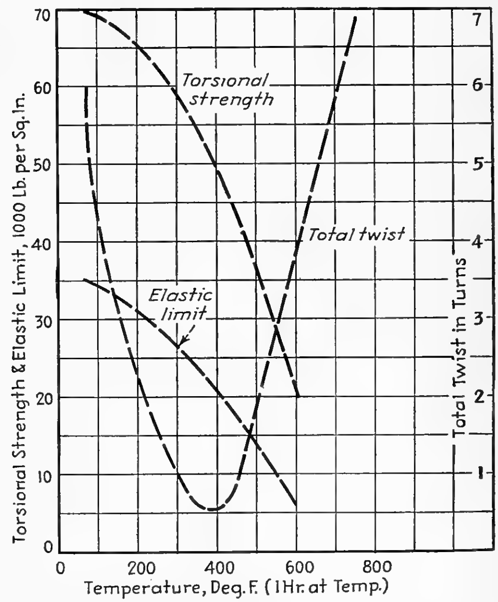

CHART 73.—The effect of elevated temperature on the torsional properties of a phosphor bronze (3.87 % tin, 0.307 % phosphorus, 0.16 % iron, balance copper) according to Bregousky and Spring.[22,9]

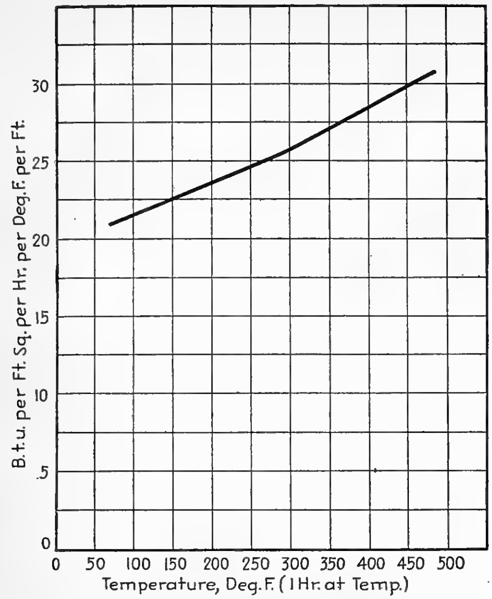

CHART 74.—The effect of temperature on the thermal conductivity of a phosphor bronze (12.4 % tin, 0.40 % phosphorus, balance copper) according to Griffiths and Schoefield.(23)

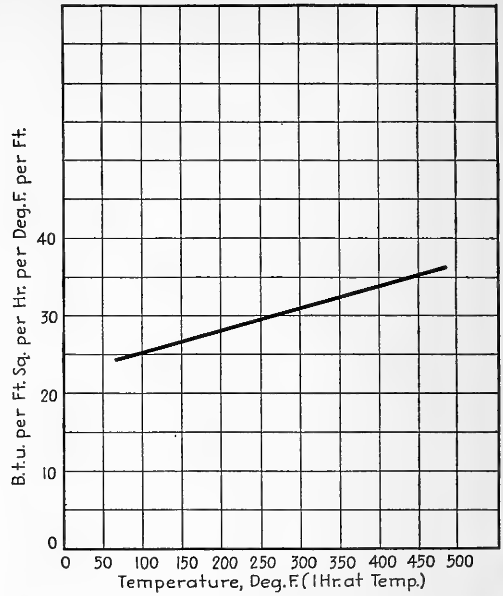

CHART 75.—The effect of elevated temperature on the thermal conductivity of a phosphor bronze (10.0 % tin, 2.0 % zinc, 0.15 % phosphorus, balance copper) according to Griffiths and Schoefield.(23)

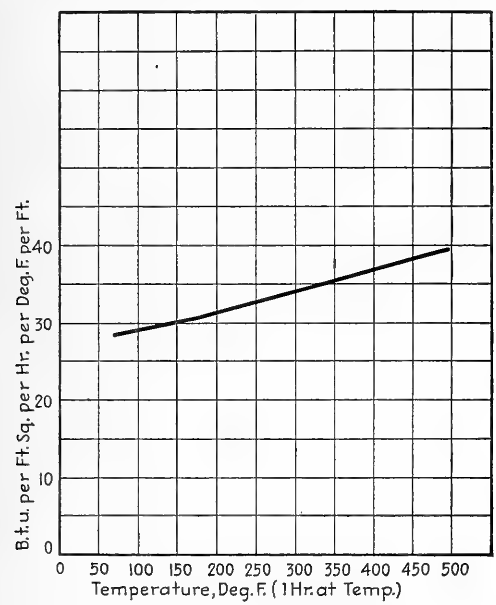

CHART 76.—The effect of elevated temperature on the thermal conductivity of a phosphor bronze (10.0 % tin, 2.0 % zinc, balance copper) according to Griffiths and Schoefield.(23)

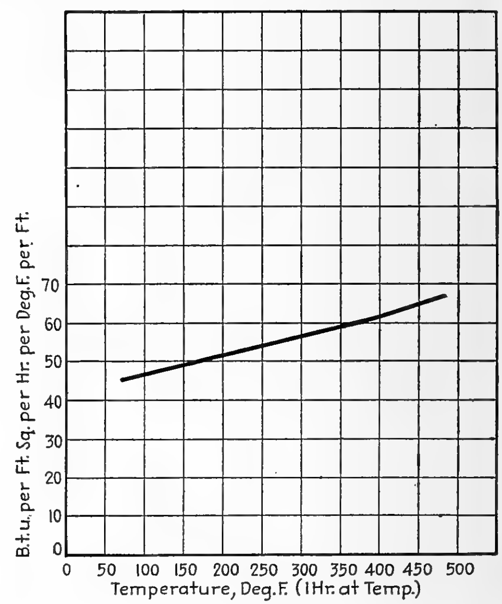

CHART 77.—The effect of elevated temperature on the thermal conductivity of a phosphor bronze (5.0 % tin, 2.10 % zinc, 0.15 % phosphorus, balance copper) according to Griffiths and Schoefield.(23)

CHAPTER XI

THE COPPER-BERYLLIUM ALLOYS

The copper-beryllium alloys are of some interest in spite of their high cost and certain difficulties experienced in their production because they exhibit, subsequent to heat-treatment, mechanical properties materially in excess of those attainable with other commercial alloys of copper. The particular property that in most instances prompts the industrial application of these alloys is their high endurance limit in fatigue.

The constitutional diagram for binary copper beryllium is shown in Fig. 1. As would be suggested by the diagram, these alloys are susceptible to heat-treatment or "age hardening" because of the limited solid solubility of the alpha phase at room temperature.

The commercial copper-beryllium alloys after a 2- or 3-hour heat-treatment at 1450 to 1500°F., followed by a water quench for the purpose of retaining the alpha structure, are malleable and can be drawn, stamped, or otherwise cold-worked. Subsequent to such forming or cold working and in order to establish phase equilibrium with attendant high mechanical properties, parts are subjected to an "aging" anneal at 525 to 575°F. for varying periods of time, dependent upon the physical dimensions of the part and the properties required.

It is common practice to add a third constituent to the binary alloys. In commercial practice cobalt is frequently added to obtain high temperature stability and nickel is introduced as a minor constituent for the purpose of retarding grain growth.

Physical constants of the more important copper-beryllium alloys are given in Table 1 on page 292. Charts 1 to 4 and Table 2 on pages 291 to 293 give in greater detail mechanical properties attainable.

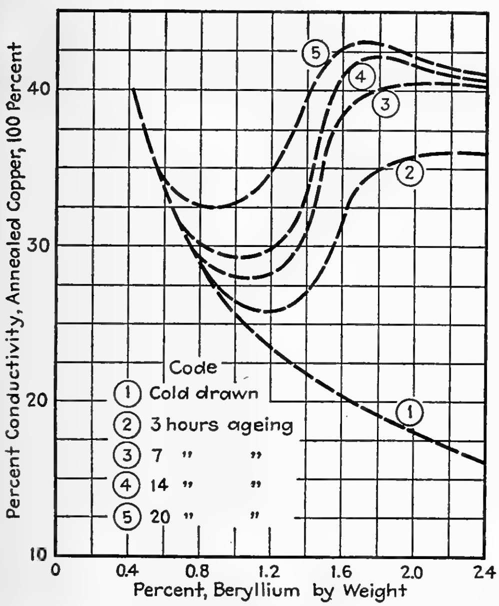

Chart 1.—The effect of aging time at an aging temperature of 575°F. on the electrical conductivity of copper-beryllium alloys according to Beryllium Corporation of American, Publications.(36)

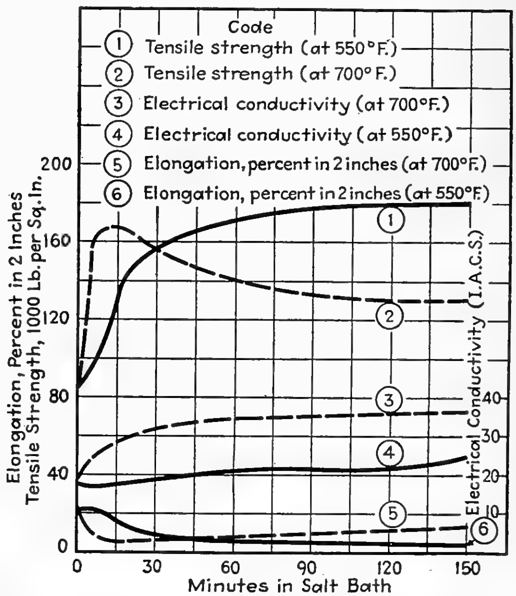

Chart 2.—The relationship of time and temperature of the age-hardening treatment to tensile strength, electrical conductivity, and percentage elongation in 2 in. of 2.25 per cent copper-beryllium strip, previously cold-worked 1 B. & S. No., hard, according to Riverside Metal Company.(35)

TABLE 1
MECHANICAL PROPERTIES OF BERYLLIUM COPPER
GENERAL DATA—STRIP[34,35,36]
Copper, 97.75%; Beryllium, 2.25%

Condition	Johnson's elastic limit, p.s.i. (000 omitted)	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Young's modulus, p.s.i. × 10^{-6}	Conductivity, % I.A.C.S.
Soft—annealed state	22	70	50.0	15	17.2
Soft—then heat-treated at 575°F., 1½ hr., salt bath	100	160	8.0	15	22.0
Soft—then rolled 2 B. & S. Nos., hard	55	90	15.0	15	17.3
Soft—rolled 2 B. & S. Nos., then heat-treated at 550°F., 1 hr., salt bath	110	180	4.0	15	23.0
Soft—rolled 2 B. & S. Nos., then heat-treated at 700°F., 1 hr., salt bath	75	140	7.0	15	34.5

PHYSICAL PROPERTIES OF BERYLLIUM COPPER

Density 0.297
Specific gravity 8.22
Melting range:
  Liquidus .... 1751°F.
  Solidus .... 1587°F.
Coefficient of expansion:
  20–100°C .... 16.5–16.7 × 10^{-6}
  20–200°C .... 16.6–17.1 × 10^{-6}
  20–300°C .... 17.5–18.0 × 10^{-6}

ELECTRICAL CONDUCTIVITY AT 20°C.

Condition	Beryllium copper, %	Beryllium copper + 0.40% nickel, %
Soft or hard-drawn	+17.5 I.A.C.S.	17.2
Heat-treated to maximum hardness	20–25% I.A.C.S.	18.0
Heat-treated to maximum conductivity	32–38% I.A.C.S.	20.25

THERMAL CONDUCTIVITY

Condition	B.t.u. per sq. ft. per in. per sec. (°F.) at 68°F.	Cal. per sq. cm. per cm. per sec. (°C.) at 20°C.
Soft-annealed	0.16	0.20
Soft-annealed, then heat-treated	0.20	0.25
Hard-drawn	0.14	0.18
Hard-drawn, then heat-treated	0.16	0.20

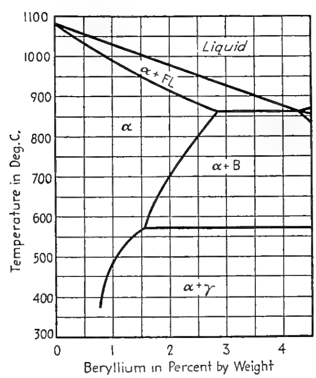

FIG. 1.—Constitutional diagram of Beryllium-copper alloys according to Masing and Dahl.

TABLE 2
PHYSICAL PROPERTIES[a]—BERYLLIUM-COPPER ALLOYS

No.	Copper, %	Beryllium, %	Nickel, %	Other, %	Thickness, in.	Temper, B. & S. Nos., hard	Heat-treatment	Tensile strength, p.s.i.	Proportional limit, p.s.i.	Modulus of elasticity, p.s.i.	Elongation, % in 2 in.	Rockwell hardness, B scale	Endurance limit 10^8 reversals, p.s.i.	Ratio endurance limit to tensile strength
1	Balance	2.25	....	....	......	..	Annealed at 1472°F., quenched in water, aged 2 hr. at 527°F.	171,200	......	19.1×10^6	5	111	31,000	0.181
2	97.44	2.15	0.31	0.06 Fe, 0.03 Si	0.040	..	Annealed at 1472°F., quenched in water, aged 2 hr. at 527°F.	175,000	46,000	18.9×10^6	6	102[b]	28,000	0.160
3	97.50	2.16	0.32	0.06 Fe, 0.03 Si	0.040	2	Annealed at 1472°F., quenched in water, cold-rolled, aged 2 hr. at 527°F.	173,000	48,000	18.5×10^6	5	102[b]	27,250	0.158
4	97.54	2.14	0.28	0.06 Fe, 0.03 Si	0.040	4	Annealed at 1472°F., quenched in water, cold-rolled, aged 2 hr. at 527°F.	193,000	55,000	18.4×10^6	2	105[b]	28,000	0.145
5	Balance	2.25	0.50	....	0.0201	4	Annealed at 1472°F., quenched in water, cold-rolled	118,000	39,000	17.2×10^6	4	84[b]	27,000	0.229
		Aged	....	....	0.0201	..	Aged 2 hr. at 527°F. after cold rolling	193,000	55,000	18.4×10^6	2	105[b]	36,000	0.187
6	Balance	2.25	0.50	....	0.0401	2	Annealed at 1472°F., quenched in water, cold-rolled	103,000	33,000	17.5×10^6	8	79[b]	23,250	0.226
		Aged	....	....	0.0401	2	Aged 2 hr. at 527°F. after cold rolling	173,000	48,000	18.5×10^6	5	102[b]	25,500	0.147
7	Balance	2.25	0.50	....	0.0201	2	Annealed at 1472°F. quenched in water, cold-rolled	84,000	25,900	19.4×10^6	19	36	23,000	0.274
		Aged	....	....	0.0201	2	Aged 2 hr. at 527°F. after cold rolling	171,000	49,500	19.8×10^6	4	108	26,500	0.155
		Aged	....	....	0.0201	2	Aged 1 hr. at 527°F. after cold rolling	....	......	....	..	....	30,000	

[a] According to Greenall and Gohn[1].
[b] Rockwell hardness, G scale.

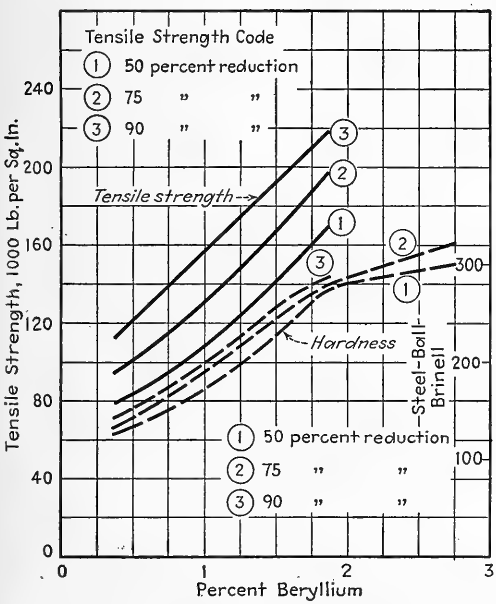

CHART 3.—The effect of cold working after aging at 575°F. for 3 hr. on the tensile strength and Monotron hardness of copper-beryllium alloys.(36)

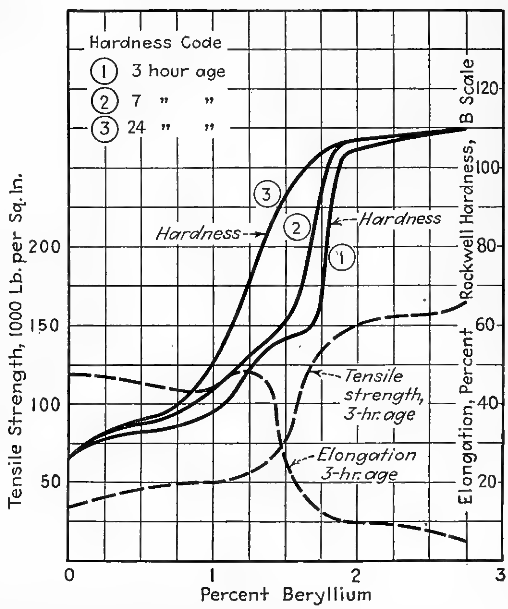

CHART 4.—The effect of age hardening at 575°F. on the tensile strength, percentage elongation in 2 in., and Rockwell B hardness of beryllium-copper alloys, previously quenched in water from a temperature of 1450°F. according to Beryllium Corporation of America.(36)

CHAPTER XII

LOW-TEMPERATURE MECHANICAL PROPERTIES OF WROUGHT COPPER AND COPPER-BASE ALLOYS

TABLE 1
COPPER

References	Condition	Temperature, °F.	Temperature, °C.	Tensile strength, p.s.i. (000 omitted)	Yield strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Impact, ft.-lb.	Rockwell hardness	Notes
(37)	Cold-rolled	68	20	45.8	43.3	16	56			
(50)		−310	−190	53	50.4	19	55			
	Annealed	68	20	32.6	12.7	58	44			
		−310	−190	50.4	18.3	63	68			
(37)	Annealed 99.75% Cu	64	18	32.8	7.3	52	70	62	...	a
(51)		32	0	33.7	7.3	52	69	66	...	a
		− 22	− 30	33.9	7.8	48	69	66	...	a
		−112	− 80	37.4	8.7	47	67	67	...	a
(38)	Annealed 99.985% Cu	68	20	31.4	8.6	48	76	43	...	b
(39)		14	− 10	32	8.9	40	78		...	b
		− 40	− 40	33.8	9.2	47	77	45	...	b
		−112	− 80	38.5	10.1	47	74	44	...	b
		−184	−120	41.2	10.8	45	70	45	...	b
		−292	−180	58.0	11.5	58	77	50	...	b
		68	20	33.1	....	53	75		...	c
		−292	−180	51.2	....	67	75		...	c
(38)	Electrolytic copper, annealed 1 hr. at 1290°F.	68	20	34.3	5.5	50.5	71.4	10	48	d
(40)		−110	− 78	41.6	14.2	50	73.6	9.5	62	d
		−295	−183	52	12.4	50.5	83.3	9.1	84	d
	Electrolytic copper, cold-worked	68	20	58.7	53.4	8.4	51.5	6.6	112	d
		−110	− 78	60.5	58.1	12	56.6	8.0	127	d
		−295	−183	64.8	59.7	11.2	61.2	7.4	152	d
(38)	Electrolytic copper 99.7%, quenched from 1380°F.	68	20	38.8	26.9	37.5	77	....	...	e
(42)		−423	−253	44.1	30.7	60.0	75	....	...	e
(38)	Electrolytic copper, hot-rolled to 1.56 in. (40 mm.)	68	20	31.3	7.1	55	70	....	...	f
(43)		− 4	− 20	33.8	7.1	56.2	70	....	...	f
		− 76	− 60	36.4	7.8	57.3	67	....	...	f
		−107	− 77	37.6	7.1	57.2	68	....	...	f
(38)	Cold-drawn 93% to 2.1 mm. (0.069 in.) from 6.35 mm. (0.268 in.)	68	20	66.8	....	1.1	57	....	...	g
(44)		32	0	69.1	....	1.8	56	....	...	g
		− 4	− 20	69.6	....	1.2	56	....	...	g
		− 22	− 30	70.4	....	1.9	54	....	...	g
		− 76	− 60	72	....	2.0	58	....	...	g
	Cold-drawn 83% to 2.8 mm. (0.109 in.) from 6.35 mm. (0.268 in.)	68	20	62.6	....	2.0	56	....	...	g
		32	0	64.1	....	2.5	57	....	...	g
		− 4	− 20	65.4	....	2.5	58	....	...	g
		− 22	− 30	65.8	....	2.8	58	....	...	g
		− 76	− 60	68.4	....	3.5	56	....	...	g

TABLE 1.—(*Continued*)

References	Condition	Temperature, °F.	Temperature, °C.	Tensile strength, p.s.i. (000 omitted)	Yield strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Impact, ft.-lb.	Rockwell hardness	Notes
	Cold-drawn 73%, 3.6 mm. (0.140 in.) from 6.35 mm. (0.268 in.)	68	20	58.7	....	2.0	57	....	...	g
		32	0	59.9	....	2.1	57	....	...	g
		− 4	− 20	61.3	....	2.0	57	....	...	g
		− 22	− 30	62.2	....	3.0	57	....	...	g
		− 76	− 60	64.1	....	4.0	57	....	...	g
(38) (45)	Sheet-quenched from 1475°F., 0.117 in. (3 mm.) thick	61	16	32	....	35	....	....	...	h
		− 75	− 60	35.5	....	37	....	....	...	h
		−112	− 80	37.7	....	37	....	....	...	h
		−185	−120	39.8	....	37	....	....	...	h
		−292	−180	45.5	....	36	....	....	...	h
	Copper wire, annealed, 0.195 in. (5 mm.) diameter	77	25	34.1	....	37	....	....	...	i
		− 75	− 60	37	....	32	....	....	...	i
		−185	−120	40.5	....	30	....	....	...	i
		−292	−180	45.9	....	31	....	....	...	i
(38)	Annealed condition, 0.025 P	70	20	32.6	8.3	58	....	46.8	43	j
		38	3	....	....	....	....	46.6	...	j
		0	− 18	....	....	....	....	43.9	...	j
		− 25	− 30	....	....	....	....	44.7	...	j
		− 60	− 50	....	....	....	....	43.7	...	j
		−110	− 80	....	....	....	....	46.3	...	j
		−175	−115	....	....	....	....	48.2	...	j

[a] Charpy impact tests were made on a 10-sq. mm. specimen with a sharp notch.

[b] All tests made on 0.25-in.-diameter specimens machined from 1-in.-diameter commercial rod; yield strength 0.10% offset; single test—Izod impact resistance, ft.-lb., all samples unfractured.

[c] Tests made on 0.504-in.-diameter specimens, machined from 1-in.-diameter commercial rod.

[d] Tests made on 4.5-mm. (0.1755-in.) diameter specimens; yield point determined on Amsler recorder; elongation measured on 50-mm. (1.95-in.) gage length; impact test values expressed as kilogram-meters per square centimeter on specimens (10 by 8 by 100 mm. having a 45-deg. sharp V notch); hardness—cone hardness in kilograms per square millimeter with 120-deg. cone, load of 25 kg. applied for 5 min.

[e] Yield point determined by drop of beam method. Elongation measured on 30-mm. (1.170-in.) gage length on specimen having a diameter of 3 mm. (0.117 in)..

[f] Yield strength 0.20% offset; elongation measured on 100-mm. (3.94-in.) gage length on specimen having a diameter of 20 mm. (0.788 in.).

[g] Elongation measured on 200-mm. (7.88-in.) gage length.

[h] Elongation measured on 20-mm. (0.788-in.) gage length on a 3 mm. (0.117 in.) by 5 mm. (0.195 in.) section.

[i] Elongation measured on a 150-mm. (5.85-in.) gage length on a specimen having a diameter of 5 mm. (0.195 in.).

[j] Impact tests made by Battelle Institute in 1936 for American Brass Company. Standard Charpy specimens (keyhole) (notch) cut from 0.750-in.-diameter rod. 120 ft.-lb. Amsler machine used. Specimens tested in standard time of 5 sec. after removal from bath at stated temperature. Specimens at −115°C. were frozen in ether with liquid air and allowed to heat to testing temperature. All others in bath 15 min. at testing temperature. Figures are average of three tests. All Charpy specimens were unfractured.

TABLE 2
BRASSES

References	Condition	Copper, %	Zinc, %	Temperature, °C.	Temperature, °F.	Tensile strength, p.s.i., (000 omitted)	Yield strength, p.s.i., (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Impact, ft.-lb.	Rockwell hardness	Notes
(51)	Annealed	71.60	Balance	18	64	41.5	9.5	82.6	76.4	85	...	a
(37)		71.60	Balance	0	32	42.8	9.8	79.7	78.7	86	...	a
		71.60	Balance	− 30	− 22	43.2	10.4	75.9	79.7	89.5	...	a
		71.60	Balance	− 80	−112	48.6	12.2	74.5	80.0	89	...	a
(39)	Annealed	69.56	Balance	20	68	51.1	28.2	49	77	66	...	b
(38)		69.56	Balance	− 10	14	53.1	28.6	49	77	....	...	b
		69.56	Balance	− 40	− 40	54.7	26.9	58	77	66	...	b
		69.56	Balance	− 80	−112	57.1	27.3	60	79	69	...	b
		69.56	Balance	−120	−184	61.2	28.0	55	78	71	...	b
		69.56	Balance	−180	−292	73.5	26.9	75	73	79	...	b
		69.56	Balance	20	68	54.1	36.5	58	75	....	...	c
		69.56	Balance	−180	−292	73.5	43.0	81	74	....	...	c
(41)	Annealed 2 hr. at	67.00	Balance	23	73	57	39.3	50.4	72	14.4	77	d
(38)	550°C. (1022°F.)	67.00	Balance	− 78	−110	61.2	43.7	49.8	76.6	16.9	86	d
		67.00	Balance	−183	−295	76.4	57.2	50.8	70.7	14.1	100	d
(41)	Cold-worked; 40%	67.00	Balance	23	73	85.4	84.6	6.3	66.5	8.1	142	d
(38)	reduction of area	67.00	Balance	− 78	−110	92.5	91.8	7.8	71.5	9.2	149	d
		67.00	Balance	−183	−295	102.9	101.7	10.1	66.5	9.4	172	d
(41)	Cold-worked; 25%	60.00	Balance	21	70	79.7	56.9	19.8	65.5	5.1	160	d
(38)	reduction of area	60.00	Balance	− 78	−110	83.0	59.9	21.0	67.7	5.3	160	d
		60.00	Balance	−183	−295	98.4	80.1	24.4	64.1	5.3	181	d
(41)	Annealed 2 hrs. at	60.00	Balance	20	68	57.6	19.9	51.3	75.5	8.6	95	d
(38)	550°C. (1022°F.)	60.00	Balance	− 78	−110	61.2	22.5	53.0	74.6	8.6	104	d
		60.00	Balance	−183	−295	75.8	28.5	55.3	71.0	8.3	142	d

[a] Impact Charpy tests made on 10-sq. mm. specimens with a sharp notch.

[b] Yield strength 0.10% offset; all tensile tests made on 0.25-in.-diameter rod machined from 1-in.-diameter commercial rod; impact-standard Izod specimen, all specimens unfractured.

[c] Yield strength—drop of beam method; all tensile tests made on 0.504-in.-diameter rod machined from 1-in.-diameter commercial rod; impact-standard Izod specimen, all specimens unfractured.

[d] All tensile tests on specimens 5 mm. (0.197 in.) in diameter; elongation measured on 50-mm. (1.97-in.) gage length; yield strength determined on Amsler Recorder; impact—kilogram-meters per square centimeter on specimen 10 × 8 × 100 mm. having a 45-deg. sharp V notch; hardness—cone hardness in kilograms per square millimeter with 120-deg. cone, load of 25 kg. applied for 5 min.

TABLE 3
LEADED BRASSES

References	Condition	Copper, %	Lead, %	Zinc, %	Temperature, °C.	Temperature, °F.	Tensile strength, p.s.i. (000 omitted)	Yield strength, p.s.i. (000 omitted)	Elongation % in 2 in.	Reduction, % of area	Impact, ft.-lb.	Rockwell hardness	Notes
(50)	Cold-rolled	.....	....	......	20	68	35.6	24.4	17	22	.....	...	a
(37)						−310	42.8	32.1	13	19	.....	...	a
(51)	Annealed	63.8	0.43	Balance	18	64	46.2	15.4	54.6	60.8	26.5	...	b
(37)		63.8	0.43	Balance	0	32	46.5	14.9	55.4	65.0	27	...	b
		63.8	0.43	Balance	− 30	− 22	46.7	14.7	65.1	68.5	27.5	...	b
		63.8	0.43	Balance	− 80	−112	49.8	15.6	65.8	64.0	28	...	b
(41)	Annealed 2 hrs.	58.7	1.3	Balance	20	68	52.8	20.6	50.2	62.5	4.4	...	c
(38)	at 550°C.	58.7	1.3	Balance	− 78	−110	54.6	24.6	49.8	64.0	4.9	...	c
	(1022°F.)	58.7	1.3	Balance	−183	−295	69.0	28.9	50.6	62.1	4.6	...	c
(41)	Cold-worked,	58.7	1.3	Balance	22	72	63.8	45.8	28.2	57	2.2	...	c
(38)	12% reduction	58.7	1.3	Balance	− 78	−110	70.4	54.1	27.0	59	2.5	...	c
	of area	58.7	1.3	Balance	−183	−295	86.6	69.9	30.8	57	2.2	...	c
(46)		58.9	1.5	Balance	20	68	60.4	....	25.7	47	5.95	94	d
(38)		58.9	1.5	Balance	−183	−297	82.5	...	36	32.4	5.32	124	d
(46)	0.90 iron	57.14	0.69	Balance	20	68	51.9	....	22.3	19.9	5.23	94	d
(38)					−183	−297	72.5	....	26.9	19.2	5.18	113	d

[a] Composition of alloy and previous history not available.
[b] Impact-Charpy on a 10-sq. mm. specimen with a sharp notch.
[c] All tensile tests on specimens 5 mm. (0.197 in.) in diameter; elongation measured on a 50-mm. (1.97-in.) gage length; yield strength determined on Amsler Recorder; impact—kilogram-meters per square centimeter on specimen 10 by 8 by 100 mm. having a 45-deg. sharp V notch.
[d] Previous history not available; impact—kilogram-meters per square centimeter. Hardness—brittle hardness.

TABLE 4
TIN BRASSES

References	Condition	Copper, %	Tin, %	Others, %	Zinc, %	Temperature, °C.	Temperature, °F.	Tensile strength, p.s.i. (000 omitted)	Yield strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Impact, ft.-lb.	Rockwell hardness	Notes
(50)	Rolled naval	.....	....	......	......	20	68	57.1	28.8	47.4	50.5	....	...	a
(37)	brass						−310	81.1	37.2	48.3	48.4	....	...	a
(39)	Annealed manganese bronze	56.45	0.90	1.25 Pb,	......	20	68	72.4	24	28	44	20	...	b
(38)				1.43 Mn,		− 10	14	70.3	22.5	33	41	..	...	b
				1.08 Fe		− 40	− 40	75.5	27	29	45	21	...	b
						− 80	−112	75.5	27	31	43	22	...	b
						−120	−184	80.9	27.8	35	45	21	...	b
						−180	−292	94.8	28.8	37	41	21	...	b
						20	68	71.7	35.0	36	41	..	...	c
						−180	−292	96.2	....	35	31	..	...	c
(38)	Annealed Tobin bronze	60.25	0.75	0.08 Fe	Balance	20	68	64.6	35.0	41	..	16.1	B61	d
						3	38	....	....	....	..	16.1	...	d
						− 18	0	....	....	....	..	17.6	...	d
						− 30	− 25	....	....	....	..	18.3	...	d
						− 50	− 60	....	....	....	..	18.1	...	d
						− 80	−110	....	....	....	..	17.9	...	d
						−115	−175	....	....	....	..	16.9	...	d
(38)	Annealed admiralty metal	70.57	0.95	0.03 Fe	Balance	20	68	46.5	13.3	83.5	....	60.8	F64	e
						3	38	....	....	....	....	60.6	...	e
						− 18	0	....	....	....	....	58.8	...	e
						− 30	− 25	....	....	....	....	60.8	...	e
						− 50	− 60	....	....	....	....	58.9	...	e
						− 80	−110	....	....	....	....	61.5	...	e
						−115	−175	....	....	....	....	59.2	...	e

[a] Composition of alloy and previous history not available.

[b] Yield strength 0.10% offset; impact—standard Izod specimens, all fractured. Specimens machined to 0.25 in. diameter from 1-in.-diameter commercial rod.

[c] Yield strength—drop of beam method; test specimens machined to diameter of 0.504 in. from 1-in.-diameter commercial rod.

[d] Tensile tests performed at room temperatures on specimens 0.7 in. in diameter. Impact tests at Battelle Institute in 1936 for American Brass Company. Tests made on annealed specimens. Standard Charpy specimens (keyhole) (notch) cut from 0.750-in.-diameter rods. 120-ft.-lb. Amsler machine used. Specimens in standard time of 5 sec. after removal from bath at stated temperatures. Specimens at −115°C. (−175°F.) were frozen in ether with liquid air and allowed to heat to testing temperature. All others in bath 15 min. at testing temperature. Figures are average of three tests. All Charpy specimens were fractured.

[e] Same as footnote *d*, except that all Charpy specimens were unfractured.

TABLE 5
NICKEL SILVERS

References	Condition	Copper, %	Nickel, %	Zinc, %	Temperature, °C.	Temperature, °F.	Tensile strength, p.s.i. (000 omitted)	Yield strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Impact, ft.-lb.	Rockwell hardness	Notes
(50)	Cold-rolled nickel	.....	.....	....	20	68	73.8	69.3	21.5	54.3	....	...	a
(37)	silver					−310	93.7	80.5	35.5	62.6	....	...	a
	Annealed nickel	.....	......	....	20	68	64.9	29.5	46.8	62.3	....	...	a
	silver					−310	83.0	38.2	56.8	69.5	....	...	a
(39)	Annealed	55.15	30.50	14.3	20	68	75.3	27.9	33	53	80	...	b
(38)					− 10	14	76.2	27.8	32	50	....	...	b
					− 40	− 40	78.2	28.6	34	52	87	...	b
					− 80	−112	83.1	27.5	39	52	83	...	b
					−120	−184	89.8	28.8	38	52	80	...	b
					−180	−292	104.2	28.4	41	55	87	...	b
					20	68	74.4	32.3	43	58	....	...	c
					−180	−292	102.2	45.1	48	58	....	...	c
(38)	Annealed Ambrac	74.28	19.49 (also 0.80Mn)	5.43	20	68	54.7	35.2	43	....	67.5	B49	d
					3	38	.....	....	....	....	69.6	...	d
					− 18	0	.....	....	....	....	61.0	...	d
					− 30	− 25	.....	....	....	....	56.4	...	d
					− 50	− 60	.....	....	....	....	55.5	...	d
					− 80	−110	.....	....	....	....	55.8	...	d
					−115	−175	.....	....	....	....	52.6	...	d

[a] Alloy composition and previous history not available.

[b] Yield strength 0.10% offset; all tensile tests on 0.25-in.-diameter specimens machined from 1-in.-diameter commercial rod; impact—standard Izod specimens, all specimens unfractured.

[c] Yield strength—drop of beam; all tensile tests on 0.504-in.-diameter specimens machined from 1-in.-diameter commercial rod.

[d] Impact tests made by Battelle Institute in 1936 for American Brass Company. Standard Charpy specimens (keyhole) (notch) cut from 0.750-in.-diameter rod. 120 ft.-lb. Amsler machine used. Specimens tested in standard time of 5 sec. after removal from bath at stated temperature. Specimens at −115°C. were frozen in ether with liquid air and allowed to heat to testing temperature. All others in bath 15 min. at testing temperature. Figures are average of three tests. All Charpy specimens were unfractured.

TABLE 6
CUPRO-NICKELS

References	Condition	Copper, %	Nickel, %	Manganese, %	Iron, %	Temperature, °C.	Temperature, °F.	Tensile strength, p.s.i. (000 omitted)	Yield strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Impact, ft.-lb.	Rockwell hardness	Notes
(39)	Annealed	79.71	20.58	. . .	. .	20	68	51.5	27.7	26	78	77	. . .	[a]
(38)						−10	14	56.2	28.7	28	77	. . . .	. . .	[a]
						−40	−40	59.6	29.0	29	77	81	. . .	[a]
						−80	−112	61.6	28.9	29	76	79	. . .	[a]
						−120	−184	66	29.2	28	75	84	. . .	[a]
						−180	−292	73.7	32.5	36	72	85	. . .	[a]
						20	68	59.0	45.2	35	72	. . . .	. . .	[b]
						−180	−298	81.4	48.5	44	71	. . . .	. . .	[b]
(39)	Annealed	54.36	45.78	. . .	. .	20	68	60.0	19.6	40	77	81	. . .	[a]
(38)						−10	14	66.1	18.4	47	78	. . . .	. . .	[a]
						−40	−40	67.6	21.0	43	78	85	. . .	[a]
						−80	−112	72.2	22.1	48	75	81	. . .	[a]
						−120	−184	77.1	24.1	48	74	83	. . .	[a]
						−180	−292	89.7	26.3	57	76	80	. . .	[a]
						20	68	65.7	44.2	39	72	. . . .	. . .	[b]
						−180	−292	88.2	53.8	60	74	. . . .	. . .	[b]
(39)	Annealed	28.86	69.58	. . .	. .	20	68	70.8	20.9	41	75	90	. . .	[a]
(38)						−10	14	77.5	25.5	48	77	. . . .	. . .	[a]
						−40	−40	80.0	24.9	47	76	93	. . .	[a]
						−80	−112	85.3	27.1	40	74	90	. . .	[a]
						−120	−184	91.7	28.6	41	74	93	. . .	[a]
						−180	−292	112.7	29.6	51	72	97	. . .	[a]
						20	68	66.5	28.6	48	71	. . . .	. . .	[b]
						−180	−292	98.2	38	59	69	. . . .	. . .	[b]
(38)	Annealed	69.27	29.54	.57	. .	20	68	57.6	34.2	53.5	. .	66.3	B55	[c]
						3	38	. . . . .	. . . .	. . . .	. .	63.9	. . .	[c]
						−18	0	. . . . .	. . . .	. . . .	. .	60.0	. . .	[c]
						−30	−25	. . . . .	. . . .	. . . .	. .	59.4	. . .	[c]
						−50	−60	. . . . .	. . . .	. . . .	. .	59.4	. . .	[c]
						−80	−110	. . . . .	. . . .	. . . .	. .	58.7	. . .	[c]
						−115	−175	. . . . .	. . . .	. . . .	. .	60.0	. . .	

[a] Yield strength 0.10% offset; all tensile specimens 0.25 in. in diameter machined from 1-in.-diameter commercial rod; impact—standard Izod specimens, all specimens unfractured.

[b] Yield strength—drop of beam method; all tensile specimens 0.504 in. in diameter machined from 1-in.-diameter commercial rod; impact—standard Izod specimens, all specimens unfractured.

[c] Impact tests made by Battelle Institute in 1936 for American Brass Company. Standard Charpy specimens (keyhole) (notch) cut from 0.750-in.-diameter rod. 120 ft.-lb. Amsler machine used. Specimens tested in standard time of 5 sec. after removal from bath at stated temperature. Specimens at −115°C. were frozen in ether with liquid air and allowed to heat to testing temperature. All others in bath 15 min. at testing temperature. Figures are average of three tests. All Charpy specimens were unfractured.

TABLE 7
ALUMINUM BRONZES

References	Condition	Copper, %	Aluminum, %	Nickel, %	Temperature, °C.	Temperature, °F.	Tensile strength, p.s.i. (000 omitted)	Yield strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Impact, ft.-lb.	Rockwell hardness	Notes
(50)	Cast aluminum	....	....	......	20	68	70.3	29.0	33.3	32.6	...	..	[a]
(37)	bronze	....	....	......	.....	−310	85.9	42.6	24.9	22.4	...	..	[a]
(50)	Forged aluminum	....	....	......	20	68	88.9	47.9	45.2	46.9	...	..	[a]
(37)	bronze	....	....	......	.....	−310	112.9	84.9	38.4	42.1	...	..	[a]
(39)	Annealed	91.1	7.31	0.44Mn									
(38)		....	.....	1.02Zn	20	68	77.2	26.6	26	29	24*	..	[b]
					−10	14	77.0	26.8	33	30	...	..	[b]
					−40	−40	78.9	26.9	35	36	24*	..	[b]
					−80	−112	82.6	27.1	31	30	24*	..	[b]
					−120	−184	88.0	27.6	32	31	21*	..	[b]
					−180	−292	96.0	29.2	29	30	21*	..	[b]
					20	68	77.6	39.0	33	34	...	..	[c]
					−180	−292	78.3	....	32	28	...	..	[c]
(39)	Quenched from	92.3	1.73	5.86	20	68	51.5	11.4	42	80	58	..	[b]
(38)	900°C. (1650°F.)				−10	14	49.5	13.6	40	80	...	..	[b]
					−40	−40	55.8	16.1	41	80	...	..	[b]
					−80	−112	57.4	16.3	43	79	...	..	[b]
					−120	−184	61.6	15.0	44	82	...	..	[b]
					−180	−292	67.2	22.9	49	82	67	..	[b]
(39)	Quenched from	92.3	1.73	5.86	20	68	91	....	24	50	40*	..	[b]
(38)	900°C.				−10	14	100.1	54.9	22	48	...	..	[b]
	(1650°F.), re-				−40	−40	103.7	61.6	25	57	...	..	[b]
	heated 2 hr. at				−80	−112	100.8	51.5	23	57	...	..	[b]
	550°C. (1022°F.)				−120	−184	108.0	63.4	26	63	...	..	[b]
					−180	−292	107.1	54.9	26	67	55	..	[b]

[a] Alloy composition and previous history not available.
[b] Yield strength 0.10% offset; all tensile tests on 0.25-in.-diameter specimens machined from 1-in.-diameter commercial rod; impact—standard Izod specimens, specimens marked * fractured, all other unfractured.
[c] Yield strength—drop of beam; all tensile tests on 0.504-in.-diameter specimens machined from 1-in.-diameter commercial rod.

TABLE 8
TIN BRONZES

References	Condition	Copper, %	Tin, %	Zinc, %	Temperature, °C.	Temperature, °F.	Tensile strength, p.s.i. (000 omitted)	Yield strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Impact, ft.-lb.	Notes
(50)	Rolled tin bronze	.....	....	....	20	68	61.6	57.0	36	65.4	......	[a]
(37)					−190	−310	93.2	71.8	56.3	58.0	......	[a]
(50)	Cast tin bronze	.....	....	....	20	68	40.2	18.6	31.3	36.7	......	[a]
(37)					−190	−310	45.3	30.5	15.3	24.6	......	[a]
(42)	As cast	88.38	10.0	1.61	20	68	45.5	29.4	30	36	......	[b]
(38)					−253	−423	58.0	46.4	18	38.5	......	[b]

[a] Alloy composition and previous history not available.
[b] Elongation measured on 30-mm. (1.182-in.) gage length, specimen diameter 3 mm. (0.118 in.); yield strength—drop of beam.

TABLE 9
SILICON BRONZES

References	Condition	Copper, %	Silicon, %	Manganese, %	Iron, %	Temperature, °C.	Temperature, °F.	Tensile strength, p.s.i. (000 omitted)	Yield strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Impact, ft.-lb.	Notes
(50)	Rolled silicon	.....	....	....	....	20	68	67.5	34.1	49	45.2	....	a
(37)	bronze						−310	88.1	39.7	51.3	41.3	....	a
(38)	Cold-drawn from 0.656-in. diameter to 0.500-in. diameter	96.13	2.75	0.97	0.15	25	77	74.2	....	39.8	75.1	....	b
						0	32	76.2	....	31.2	70.4	....	b
						− 80	−112	82.9	....	31.7	72.4	....	b
						−190	−310	100.5	....	36.2	72.5	....	b
(38)	Annealed	95.75	3.05	0.98	0.17	20	68	62.4	29.9	65.5	....	66.4	c
						3	38	.....	....	....	....	73.3	c
						− 18	0	.....	....	....	....	80.1	c
						− 30	− 25	.....	....	....	....	74.6	c
						− 50	− 60	.....	....	....	....	73.1	c
						− 80	−110	.....	....	....	....	69.2	c
						−115	−175	.....	....	....	....	64.5	c

[a] Alloy composition and previous history not available.
[b] Tests made in 1932 at the National Bureau of Standards for the American Brass Company. Amsler machine used. Speed of loading about 20,000 p.s.i. per minute. Room temperature tests made on 0.5-in.-diameter specimens, all other temperatures on specimens machined to 0.25 in. in diameter.
[c] Impact tests made by Battelle Institute in 1936 for American Brass Company. Standard Charpy specimens (keyhole) (notch) cut from 0.750-in.-diameter rod. 120-ft.-lb. Amsler machine used. Specimens tested in standard time of 5 sec. after removal from bath at stated temperature. Specimens at −115°C. were frozen in ether with liquid air and allowed to heat to testing temperature. All others in bath 15 min. at testing temperature. Figures are average of three tests. All Charpy specimens were unfractured.

TABLE 10
BERYLLIUM COPPERS

References	Condition	Copper, %	Beryllium, %	Temperature, °C.	Temperature, °F.	Tensile strength, p.s.i. (000 omitted)	Yield strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Impact, ft.-lb.	Notes
(39)	Quenched from 800°C.	97.44	2.56	20	68	76.2	24.9	36	50	41	a
(38)	(1472°F.)			− 10	14	.....	.....	...	...	..	a
				− 40	− 40	.....	.....	...	...	..	a
				− 80	−112	86.7	29.1	38	54	40	a
				−120	−184	.....	.....	...	...	..	a
				−180	−292	111.6	50.0	41	57	40	a
(39)	Quenched from 800°C.	97.44	2.56	20	68	186.6	125.4	2.6	5.0	2*	a
(38)	(1472°F.), reheated 2 hr.			− 10	14	189.5	126.6	0.8	9.0	..	a
	300°C. (572°F.)			− 40	− 40	188.8	118.5	0.4	5	3*	a
				− 80	−112	201.6	147.4	0.4	5	3*	a
				−120	−184	197.8	138.9	0.4	4	3*	a
				−180	−292	214.4	155.0	3.0	6	3*	a

[a] Yield strength 0.10% offset; all tensile tests on specimens 0.25 in. in diameter, machined from 1-in.-diameter commercial rod; impact—standard Izod specimens, specimens marked * fractured, all others unfractured.

CHAPTER XIII

FATIGUE AND CORROSION-FATIGUE PROPERTIES OF WROUGHT COPPER AND COPPER-BASE ALLOYS

TABLE 1
COPPER

References	Condition	Copper, %	Oxygen, %	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Hardness Rockwell B	Endurance limit, p.s.i. (000 omitted)	Cycles, 10^6	Form	Notes
(1)	Annealed soft	99.95	.....	31.4	35	..	..	11	100	Strip	
(1)	2 B. & S. Nos., hard	99.95	.....	44.4	8	..	33	13	100	Strip	
(1)	6 B. & S. Nos., hard	99.95	.....	52.6	2	..	55	14	100	Strip	
(52)	Cold-drawn 36% ready-to-finish grain size, 0.040 mm.	99.948	0.031	48.8	10	62	47	17	300	Rod	a
(52)	Cold-drawn 20%	99.997	0.000	51	14	88	37	17	300	Rod	b
(53)	Annealed 1290°F., 30 min	99.96	.....	29	60	..	..	12.5	30	Rod	
(53)	Annealed	99.96	.....	32.5	59	74	....	11.5	30	Rod	c
(54)	Annealed 1290°F.	99.98	.....	32.5	57	72	..	10	500	Rod	
(55)	Annealed 1200°F., 1 hr.	......	.....	31	53	74	..	10	500	Rod	
(56)	Annealed 1200°F., 1 hr.	......	.....	32	58	72	..	10.5	...	Rod	
(57)	Hot-rolled	......	.....	31.5	59	72	..	12.5	...	Rod	
(58)	Annealed	......	.....	32	51	70	48 Brinell	13	10	Rod	
(59)	Annealed 1100°F.	99.92	.....	31	60	69	47 Brinell	10	100	Rod	d
(56)	Cold-rolled	......	.....	52	12	53	..	16	...	Rod	
(55)	Light anneal	......	.....	46.5	14	56	..	16.5	...	Rod	
(57)	Cold-drawn	......	.....	40.5	27	67	..	13	...	Rod	
(56)	Cold-drawn	99.92	.....	36	32	84	..	17.5	30	Rod	e
(55)	Cold-drawn	99.95	0.036	37.5	30	73	..	18.5	50	Rod	
(55)	Cold-rolled	......	.....	40.5	25	66	..	....	...	Rod	f

[a] 0.50% extension yield strength 47,600 p.s.i.; 0.20% offset yield strength 46,600 p.s.i.; modulus of elasticity 17.77 × 10^6 p.s.i.
[b] 0.50% extension yield strength 49,400 p.s.i.; 0.20% offset yield strength 49,000 p.s.i.; modulus of elasticity 17.8 × 10^6 p.s.i.
[c] Trace of iron, nickel, and tin.
[d] 0.01% iron and tin.
[e] 0.01% phosphorus.
[f] Corrosion-fatigue limit, carbonated water, 17,000 p.s.i.; salt water (brackish), 16;500 p.s.i.

TABLE 2
EFFECT OF OXYGEN ON FATIGUE STRENGTH OF COPPER
According to Gough, Gillet, and Mack and Hanson and Ford

References	Oxygen, %	Condition	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Impact, ft.-lb.	Electrical conductivity, % I.A.C.S.	Specific gravity, gm. per cc.	Endurance limit p.s.i. (000 omitted)
(60)	0.04	Annealed	29	60	. .	. . .	. . . . .	. . . . .	12.5[a]
(60)	0.06	Annealed	29.3	56	. .	. . .	. . . . .	. . . . .	12.5[a]
(60)	0.09	Annealed	29.5	53	. .	. . .	. . . . .	. . . . .	12.5[a]
(61)	0.016	Annealed 1290°F., 30 min.	32.5	54	77	46[b]	101.4	8.91	11[a,c]
(61)	0.04	Annealed 1290°F., 30 min.	32	50	72	46[b]	101.6	8.905	13.5[a,c]
(61)	0.06	Annealed 1290°F., 30 min.	32.5	56	70	48[b]	101.5	8.90	13[a,c]
(61)	0.09	Annealed 1290°F., 30 min.	33	53	65	45[b]	100.6	8.88	12[a,c]
(61)	0.17	Annealed 1290°F., 30 min.	34.5	49	57	31[b]	99.0	8.84	11[a,c]
(61)	0.36	Annealed 1290°F., 30 min.	37	35	39	16	96.2	8.76	11[a,c]
(62)	0.036	Cold-drawn	37.5	30	73	. . .	99.6	. . . . .	18.5[d]
(62)	0.049	Cold-drawn	37.5	29	68	. . .	98.9	. . . . .	17.5[d]
(62)	0.094	Cold-drawn	38	27	63	. . .	97.9	. . . . .	19[d]
(62)	0.22	Cold-drawn	41	27	49	. . .	94.6	. . . . .	17[d]

[a] Approximate endurance limit, determined by a short-cut method.
[b] Izod, specimens unbroken.
[c] Specimens made in laboratory, not entirely sound.
[d] 5×10^7 reversals of stress.

TABLE 3
EFFECT OF PHOSPHORUS ON FATIGUE STRENGTH OF COPPER
According to Hanson, Archbutt, and Ford

References	Oxygen, %	Phosphorus %	Condition	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Impact, ft.-lb.	Electrical conductivity, % I.A.C.S.	Specific gravity, gm. per cc.	Endurance limit (at 2×10^7 cycles), p.s.i. (000 omitted)
(63)	0.019	0.014	Annealed 1290°F., 30 min.	34.5	32	73	39[a]	94.3	8.92	11
(63)	0.01	0.03	Annealed 1290°F., 30 min.	32	59	82	38[a]	78.2	8.91	12
(63)	0.009	0.045	Annealed 1290°F., 30 min.	32.5	50	86	41[a]	72.4	8.92	12.5
(63)	. . . . .	0.096	Annealed 1290°F., 30 min.	33	62	80	40[a]	55.5	8.92	14.25
(63)	. . . . .	0.148	Annealed 1290°F., 30 min.	34	63	85	41[a]	45.2	8.92	15
(63)	. . . . .	0.178	Annealed 1290°F., 30 min.	35	61	85	43[a]	42.5	8.90	13.25
(63)	. . . . .	0.254	Annealed 1290°F., 30 min.	35.5	63	84	41[a]	33.1	8.90	13.5
(63)	. . . . .	0.494	Annealed 1290°F., 30 min.	38.5	62	90	43[a]	19.7	8.87	15.5
(63)	. . . . .	0.69	Annealed 1290°F., 30 min.	38.5	63	84	44[a]	15.5	8.86	16.5
(63)	0.002	0.79	Annealed 1290°F., 30 min.	40	64	81	44[a]	14.0	8.84	17.5
(63)	. . . . .	0.95	Annealed 1290°F., 30 min.	40	66	85	44[a]	11.6	8.82	17

[a] Izod, not broken.

TABLE 4
EFFECT OF ARSENIC AND ARSENIC PLUS OXYGEN ON FATIGUE STRENGTH OF COPPER
According to Hanson and Marryat

References	Oxygen, %	Arsenic, %	Iron, %	Condition	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Impact, ft.-lb.	Electrical conductivity, % I.A.C.S.	Specific gravity, gm. per cc.	Endurance limit, p.s.i. (000 omitted)
(65)	0.016	0.053	0.008	Annealed 1290°F., 30 min.	31.5	57	72	46	85.5	8.91	14[a]
(65)	0.005	0.093	Trace	Annealed 1290°F., 30 min.	32	57	70	43	76.9	8.89	14.5[a]
(65)	0.003	0.36	Trace	Annealed 1290°F., 30 min.	32.5	60	79	46	45.3	8.92	13.5[a]
(65)	0.009	0.60	Trace	Annealed 1290°F., 30 min.	33.5	55	62	18[b]	33.7	8.85	14.5[a]
(65)	0.013	0.86	Trace	Annealed 1290°F., 30 min.	34	56	66	30	25.6	8.86	15[a]
(65)	0.006	1.04	Trace	Annealed 1290°F., 30 min.	34	59	79	47	22.5	8.91	15.5[a]
(65)	0.11	0.09	.....	Annealed 1290°F., 30 min.	....	..	58	39	73.9	8.87	15.5[c]
(65)	0.039	0.09	.....	Annealed 1290°F., 30 min.	32.5	62	70	44	75.3	8.90	13.5[c]
(65)	0.04	0.24	.....	Annealed 1290°F., 30 min.	33	57	71	43	55.1	8.89	15.5[c]
(65)	0.06	0.25	.....	Annealed 1290°F., 30 min.	32.5	58	67	40	54.8	8.88	15[c]
(65)	0.07	0.30	.....	Annealed 1290°F., 30 min.	33	55	66	39	49.9	8.88	15[c]
(65)	0.058	0.34	.....	Annealed 1290°F., 30 min.	33.5	56	64	38	46.4	8.88	14.5[c]
(65)	0.071	0.44	.....	Annealed 1290°F., 30 min.	33	59	67	39	40.8	8.88	15.5[c]
(65)	0.034	0.45	.....	Annealed 1290°F., 30 min.	34	62	72	42	37.9	8.90	16[c]
(65)	0.05	0.93	.....	Annealed 1290°F., 30 min.	35.5	61	72	44	24.0	8.90	15.5[c]
(65)	0.005	1.40	.....	Annealed 1290°F., 30 min.	....	..	67	40	19.2	8.87	15.5[c]
(65)	0.006	2.02	.....	Annealed 1290°F., 30 min.	36.5	59	64	42	14.5	8.86	17[c]

[a] Determined by short-cut method, not true endurance limit.
[b] Izod, broken.
[c] 2×10^7 cycles.

TABLE 5
EFFECT OF ANTIMONY ON FATIGUE STRENGTH OF COPPER
According to Archbutt and Prytherch

References	Oxygen, %	Antimony, %	Arsenic, %	Condition	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Impact, ft.-lb.	Electrical conductivity, % I.A.C.S.	Specific gravity gm. per cc.	Endurance limit, (2 × 10^7 cycles) p.s.i. (000 omitted)
(67)	0.008	0.0035	.....	Annealed 1290°F., 30 min.	31.5	63	75	40	101.0	8.91	12
(67)	0.013	0.021	.....	Annealed 1290°F., 30 min.	32	63	74	37	97.4	8.91	13
(67)	0.005	0.046	.....	Annealed 1290°F., 30 min.	32	60	72	39	94.8	8.90	13
(67)	0.015	0.092	.....	Annealed 1290°F., 30 min.	33.5	49	73	40	94.1	8.92	13
(67)	0.016	0.22	.....	Annealed 1290°F., 30 min.	33	67	77	35	75.6	8.92	15.5
(67)	0.014	0.47	.....	Annealed 1290°F., 30 min.	33.5	58	66	36	56.4	8.92	17.5
(67)	0.014	0.05	0.05	Annealed 1290°F., 30 min.	32	60	73	37	82.5	8.90	15
(67)	0.018	0.32	0.045	Annealed 1290°F., 30 min.	32	59	71	37	48.9	8.89	15
(67)	0.019	0.51	0.048	Annealed 1290°F., 30 min.	33	58	73	41	37.8	8.89	16
(67)	0.018	0.05	0.249	Annealed 1290°F., 30 min.	34	59	77	38	65.9	8.91	16
(67)	0.017	0.32	0.244	Annealed 1290°F., 30 min.	33.5	59	75	41	46.2	8.90	16
(67)	0.013	0.55	0.24	Annealed 1290°F., 30 min.	34	64	76	34	32.0	8.91	17.5
(67)	0.018	0.06	0.49	Annealed 1290°F., 30 min.	35	60	76	13	56.8	8.89	17
(67)	0.017	0.53	0.50	Annealed 1290°F., 30 min.	36	62	76	16	39.9	8.90	17.5

TABLE 6
EFFECT OF IRON ON FATIGUE STRENGTH OF COPPER
According to Hanson and Ford

References	Oxygen, %	Iron, %	Condition	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Impact, ft.-lb.	Electrical conductivity, % I.A.C.S.	Specific gravity, gm. per cc.	Endurance limit by short-cut method, p.s.i. (000 omitted)
(64)	0.014	0.06	Annealed 1290°F., 30 min.	32.5	57	73	44	101.0	8.90	14
(64)	0.003	0.20	Annealed 1290°F., 30 min	32.0	60	73	43	54.1	8.92	13.5
(64)	0.004	0.40	Annealed 1290°F., 30 min.	33.5	60	80	43	40.8	8.92	14.5
(64)	0.008	0.73	Annealed 1290°F., 30 min.	37.5	52	80	51	42.0	8.91	14.5
(64)	0.005	0.96	Annealed 1290°F., 30 min.	36	45	82	63	38.9	8.91	15
(64)	0.004	1.38	Annealed 1290°F., 30 min.	43	30	79	59	37.7	8.91	15.5
(64)	0.007	1.80	Annealed 1290°F., 30 min.	44.5	29	79	65	37.7	8.91	16
(64)	0.008	2.09	Annealed 1290°F., 30 min.	49.5	34	79	70	37.9	8.90	20

TABLE 7
EFFECT OF BISMUTH ON FATIGUE STRENGTH OF COPPER
According to Hanson and Ford

References	Oxygen, %	Bismuth, %	Condition	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Impact, ft.-lb.	Electrical conductivity, % I.A.C.S.	Specific gravity, gm. per cc.	Endurance limit, p.s.i. (000 omitted)
(66)	0.015	0.002	Annealed 1290°F., 30 min.	32	66	68	45	101.3	8.90	13.5[b]
(66)	0.016	0.006	Annealed 1290°F., 30 min.	33	62	72	45	101.0	8.92	13.5[b]
(66)	0.011	0.016	Annealed 1290°F., 30 min.	33.5	60	74	45	101.0	8.91	13.5[b]
(66)	0.015	0.015	Annealed 1290°F., 30 min.	33	64	72	47	99.5	8.89	15[b]
(66)	0.015	0.002	Cold-drawn, 50% reduction of area	52.5	17	62	41[a]	99.9	8.92	19[b]
(66)	0.016	0.006	Cold-drawn, 50% reduction of area	53.5	17	65	47[a]	99.8	8.92	19.5[b]
(66)	0.011	0.016	Cold-drawn, 50% reduction of area	51	17	60	42[a]	100.0	8.92	19.5[b]
(66)	0.015	0.015	Cold-drawn, 50% reduction of area	51	13	73	43[a]	98.9	8.93	19[b]

[a] Broken specimen (Izod).
[b] 2×10^7 cycles.

TABLE 8
85-15, RED BRASS OR RICH LOW BRASS

References	Condition	Copper, %	Iron, %	Lead, %	Zinc, %	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Rockwell B, 100 kg., 1/16-in. ball	Endurance limit, p.s.i. (000 omitted)	Cycles 10^6	Form	Notes
(52)	Cold-worked 4%, ready-to-finish grain size 0.025 mm.	84.53	0.02	0.01	Balance	44.7	40	81	51	20	300	Rod	a
(68)	Cold-drawn and annealed 450°F., 3 hr.	84.91	0.05	....	Balance	53	27	73	..	16	60	Rod	b
(68)	Cold-drawn and annealed 900°F., 3 hr.	84.91	0.05	....	Balance	40.5	57	79	..	15.5	100	Rod	c

[a] 0.5% extension yield strength 29,300 p.s.i.; 0.20% offset yield strength 29,200 p.s.i.; modulus of elasticity 17,200,000 p.s.i.
[b] Corrosion-fatigue limit, both salt and carbonated water, 15,500 p.s.i. for 2×10^7 cycles.
[c] Corrosion-fatigue limit, both salt and carbonated water, 15,500 p.s.i. for 2.5×10^7 cycles.

TABLE 9
80-20 BRASS

References	Condition	Copper, %	Iron, %	Lead, %	Zinc, %	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Rockwell B, 100 kg., 1/16-in. ball	Endurance limit, p.s.i. (000 omitted)	Cycles, 10^6	Form	Notes
(68)	Cold-drawn and annealed 450°F., 2 hr.	79.40	0.10	....	Balance	58	31	65	..	21	100	Rod	[a]
(68)	Cold-drawn and annealed 900°F., 2 hr.	79.40	0.10	....	Balance	45.5	62	72	..	17	40	Rod	[b]
(69)	Cold-worked	79.51	0.02	0.09	Balance	72.5	18	61	81	21.5	50	Rod	
(69)	Cold-worked and annealed 527°F.	79.51	0.02	0.09	Balance	70.5	22	65	81	25	50	Rod	
(69)	Cold-worked and annealed 1100°F.	79.51	0.02	0.09	Balance	45.5	51	73	17	22.5	50	Rod	
(69)	Full annealed and compressed 20%	79.51	0.02	0.09	Balance	48.5	51	73	67	25.5	50	Rod	
(68)	Cold-drawn	81.00	Trace	....	Balance	76.5	16	65	..	22.5	100	Rod	
(68)	Cold-drawn and annealed 450°F., 1 hr.	81.00	Trace	....	Balance	80.5	15	64	..	26	40	Rod	
(68)	Cold-drawn and annealed 1100°F., 1 hr.	81.00	Trace	....	Balance	44	64	80	..	17	90	Rod	

[a] Corrosion-fatigue limit, carbonated water, 15,000 p.s.i. for 6×10^7 cycles and 14,000 p.s.i. for 8×10^7 cycles in salt water (brackish).
[b] Corrosion-fatigue limit, salt water (brackish), 14,000 p.s.i. for 10^8 cycles.

TABLE 10
70-30 CARTRIDGE BRASS

References	Condition	Copper, %	Iron, %	Lead, %	Zinc, %	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Rockwell B, 100 kg., 1/16-in. ball	Endurance limit, (000 omitted)	Cycles, 10^6	Form	Notes
(69)	Cold-drawn	70.03	0.02	0.02	Balance	74	21	58	81	22	50	Rod	
(69)	Cold-drawn and annealed 527°F.	70.03	0.02	0.02	Balance	73.5	23	60	82	28	50	Rod	
(69)	Cold-drawn and annealed 1100°F.	70.03	0.02	0.02	Balance	47	55	75	11	22.5	50	Rod	
(69)	Annealed 1100°F., compressed 20% and annealed 527°F.	70.03	0.02	0.02	Balance	51.5	58	71	63	25	50	Rod	
(70)	Annealed	70.00	....	....	Balance	48.5	57	70	..	20	10	Rod	a
(70)	Cold-worked 20%	70.00	....	....	Balance	53	44	71	..	22.5	10	Rod	b
(53)	....	69.85	0.04	....	Balance	44.5	84	85	..	20	60	Rod	
(57)	Cold-drawn	73.28	0.13	0.03	Balance	50.5	57	73	..	17	20	Rod	
(71)	Annealed 1470°F.	72.00	....	....	Balance	38.5	55	81	..	12	20	Rod	
(6)	Annealed 1100°F., 1 hr.	71.73	0.03	0.02	Balance	46.5	61	..	16	13	100	Strip	
(6)	Cold-rolled, 4 B. & S. Nos., hard, 37%	71.73	0.03	0.02	Balance	81.5	6	..	84	20	100	Strip	
(6)	Cold-rolled, 10 B. & S. Nos., hard, 68%	71.73	0.03	0.02	Balance	98	2	..	92	20	100	Strip	
(57)	Cold-drawn	71.64	0.13	0.02	Balance	47.5	63	75	..	19	70	Rod	c
(68)	Cold-worked and annealed 425°F., 3 hr.	70.79	0.07	....	Balance	76.5	19	58	..	13.5	30	Rod	d
(68)	Cold-worked and annealed 450°F., 3 hr.	70.79	0.07	....	Balance	58.5	41	68	..	14	80	Rod	e
(68)	Cold-worked	70.08	0.05	....	Balance	73	20	47	..	17	100	Rod	
(68)	Cold-worked and annealed 400°F., 30 min.	70.08	0.05	....	Balance	74.5	15	42	..	20	80	Rod	
(68)	Cold-worked 450°F. for 1½ hr.	70.08	0.05	....	Balance	74	18	48	..	20	80	Rod	
(68)	Cold-worked and annealed 500°F. for 1½ hr.	70.08	0.05	....	Balance	73.5	18	49	..	22	70	Rod	
(68)	Annealed 1200°F., 1 hr.	70.08	0.05	....	Balance	45	73	66	..	15	100	Rod	

[a] Notched endurance limit, 20,000 p.s.i. for 10^7 cycles (notch 0.05-mm. radius, 0.2 mm. deep).
[b] Notched endurance limit, 22,500 p.s.i. for 10^7 cycles (notch 0.05-mm. radius, 0.2 mm. deep).
[c] Torsion strength 41,000 p.s.i.; angle of twist 575 deg.; torsion endurance limit 9,000 p.s.i. for 4×10^7 cycles; corrosion-fatigue limit, both fresh and salt (brackish) water, 13,000 p.s.i. for 10^8 cycles.
[d] Corrosion-fatigue limit, salt water (brackish), 9,000 p.s.i. for 5×10^7 cycles.
[e] Corrosion-fatigue limit, salt water (brackish), 12,500 p.s.i. for 6×10^7 cycles.

TABLE 11
65-35, 2 AND 1, OR COMMON HIGH BRASS

References	Condition	Copper, %	Iron, %	Lead, %	Zinc, %	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Rockwell B, 100 kg., 1/16-in. ball	Endurance limit, p.s.i. (000 omitted)	Cycles, 10^6	Form	Notes
(68)	Cold-worked and annealed 450°F., 3 hr.	65.15	0.08	....	Balance	54	43	67	..	13	20	Rod	a
(68)	Cold-worked and annealed 450°F., 3 hr.	65.14	0.08	....	Balance	71	22	59	..	17	5	Rod	b
(68)	Annealed 1200°F., 1 hr.	65.14	0.08	....	Balance	43.5	78	74	..	15	20	Rod	c
(68)	Cold-worked and annealed 450°F., 3 hr.	64.95	0.04	....	Balance	82.5	15	62	..	25	40	Rod	d
(68)	Annealed 1200°F., 1 hr.	64.95	0.04	....	Balance	47	71	73	..	18	10	Rod	e
(6)	Annealed 1100°F.	65.09	0.03	0.02	Balance	46	58	..	..	12	100	Strip	
(6)	Cold-rolled, 4 B. & S. Nos., hard, 37% reduction of area	65.09	0.03	0.02	Balance	77	6	..	..	13.5	100	Strip	
(6)	Cold-rolled, 10 B. & S. Nos., hard, 68% reduction of area	65.09	0.03	0.02	Balance	95.5	2	..	..	15	100	Strip	
(1)	Annealed 1100°F.	65.09	0.03	0.02	Balance	47	58	..	16	15	100	Strip	f
(1)	Cold-rolled, 4 B. & S. Nos., hard, 37% reduction of area	65.09	0.03	0.02	Balance	77	6	..	79	19.5	100	Strip	g
(1)	Cold-rolled, 10 B. & S. Nos., hard, 68% reduction of area	65.09	0.03	0.02	Balance	96	2	..	87	20	100	Strip	h
(52)	Cold-drawn 30% reduction of area, ready-to-finish grain size 0.060 mm.	63.00	0.01	0.03	Balance	72	18	62	82	22.7	300	Rod	i

[a] Corrosion-fatigue limit, carbonated water, 12,000 p.s.i. for 4 × 10^7 cycles.
[b] Corrosion-fatigue limit, carbonated water, 12,000 p.s.i. for 5 × 10^7 cycles.
[c] Corrosion-fatigue limit, carbonated water, 12,000 p.s.i. for 3 × 10^7 cycles.
[d] Corrosion-fatigue limit, salt water (brackish), 12,000 p.s.i. for 6 × 10^7 cycles.
[e] Corrosion-fatigue limit, salt water (brackish), 12,000 p.s.i. for 10^7 cycles.
[f] Proportional limit 13,000 p.s.i.; modulus of elasticity 14.5 × 10^6.
[g] Proportional limit 32,000 p.s.i.; modulus of elasticity 15.6 × 10^6.
[h] Proportional limit 30,000 p.s.i.; modulus of elasticity 14.9 × 10^6.
[i] 0.50% extension yield strength 54,000 p.s.i.; 0.20% offset yield strength 56,000 p.s.i.; modulus of elasticity 15.7 × 10^6 p.s.i.

TABLE 12
60-40 OR MUNTZ METAL

References	Condition	Copper, %	Iron, %	Lead, %	Zinc, %	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Rockwell B, 100 kg., 1/16-in. ball	Endurance limit, p.s.i. (000 omitted)	Cycles, 10^6	Form	Notes
(58)	....	60.00	....	....	40.00	57	48	69	..	25	10	Rod	a
(72)	Annealed 1020°F.	60.25	0.02	0.02	39.61	66	48	40	56	29	400	Rod	
(73)	Annealed 1000°F., ½ hr.	60.00	....	....	40.00	49	50	24	34	20.5	34	Rod	
(54)	Annealed 1200°F.	59.78	0.03	0.08	40.11	54	56	61	37	22	400	Rod	
(54)	Cold-drawn, 0.750 in. diameter to 0.500 in. diameter	59.78	0.03	0.08	40.11	97	13	52	96	26	500	Rod	
(62)	As received	61.60	0.03	0.06	38.31	60	41	73	..	20	50	Rod	
(69)	As received	58.84	0.03	0.09	40.03	76.5	24	52	82	27.5	50	Rod	
(69)	As received and annealed 527°F.	58.84	0.03	0.09	40.03	73.3	32	58	79	30.5	50	Rod	
(69)	Annealed 1300°F.	58.84	0.03	0.09	40.03	57.5	41	58	54	21.5	50	Rod	
(69)	Fully annealed and then compressed 20%	58.84	0.03	0.09	40.03	68.5	30	40	79	25.5	35	Rod	
(57)	Cold-worked and annealed 480°F., 1 hr.	59.65	0.16	0.20	40.11	76.5	2	5	..	16	100	Rod	b
(57)	Cold-worked and annealed 650°F., 1 hr.	59.65	0.16	0.20	40.11	79	15	17	..	18	100	Rod	c
(57)	Cold-worked and annealed 840°F.,1 hr.	59.65	0.16	0.20	40.11	65.5	35	43	..	18	100	Rod	d

[a] Corrosion-fatigue limit, salt water, 17,000 p.s.i. for 10^7 cycles.
[b] Torsion strength 55,000 p.s.i.; angle of twist 31 deg.; torsion endurance limit 5,500 p.s.i. for 5×10^8 cycles.
[c] Torsion strength 50,000 p.s.i.; angle of twist 99 deg.; torsion endurance limit 7,500 p.s.i. for 2×10^7 cycles.
[d] Torsion strength 45,500 p.s.i.; angle of twist 125 deg.; torsion endurance limit 8,500 p.s.i. for 5×10^7 cycles.

TABLE 13
LEADED BRASSES

References	Condition	Copper, %	Lead, %	Iron, %	Zinc, %	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % in area	Endurance limit, p.s.i. (000 omitted)	Cycles, 10^6	Form	Notes
(74)	....	58.00	2.3	....	Balance	62.5	25	..	28.5	?	Rod	
(75)	....	62.00	2.8	....	Balance	60.5	23	47	18	100	Rod	a
(62)	As received	61.60	0.06	0.03	Balance	60.0	41	73	20	50	Rod	
(62)	As received	61.54	0.53	0.03	Balance	59.0	39	66	23	50	Rod	
(62)	As received	61.03	1.58	0.03	Balance	58.0	39	60	23	50	Rod	
(62)	As received	59.88	2.61	0.03	Balance	59.0	38	53	21–24	50	Rod	
(62)	As received	59.40	3.43	0.03	Balance	58.0	37	51	19–23	50	Rod	
(47)	Cold-drawn	62.00	3.00	....	Balance	....	..	..	26 (80°F.) 27.5 (−20°F.) 27 (−40°F.)	50	Rod	
(47)	Cold-drawn	62.00	3.00	....	Balance	....	..	..	17 (80°F.) 16.5 (−20°F.) 17.5 (−40°F.)	50	Rod	b

[a] Torsion endurance limit 14,000 p.s.i. for 10^8 cycles.
[b] Specimens had a 45-deg. notch.

TABLE 14
TIN BRASSES

References	Condition	Copper %	Tin, %	Zinc, %	Others, %	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Rockwell B, 100 kg., 1/16-in. ball	Endurance limit, p.s.i. (000 omitted)	Cycles, 10^6	Form	Notes
(57)	Annealed 900°F., 3 hr.	90.75	1.10	8.62	0.13 Fe	49	62	76	..	16	60	Rod	a
(52)	Cold-worked 30%, ready-to-finish grain size 0.035 mm.	88.47	1.02	10.49	0.02 Fe	65.2	12	76	80	29.3	300	Rod	b
(52)	Cold-worked 30% ready-to-finish grain size 0.040 mm.	87.02	1.10	11.48	0.37 P	78.8	13	64	89	28.3	300	Rod	c
(83)	Annealed to grain size of 0.035 mm.	70.88	1.07	Balance	......	50.8	75	..	5	19	10	Rod	
(83)	Annealed to grain size of 0.035 mm.	70.11	1.08	Balance	0.03 As	47.8	85	..	0	17	10	Rod	
(83)	Annealed to grain size of 0.035 mm.	71.04	1.07	Balance	0.033 Sb	50.5	79	..	5	18	10	Rod	
(83)	Annealed to grain size of 0.035 mm.	70.25	1.05	Balance	0.034 P	53.5	69	..	10	17	10	Rod	
(68)	Cold-worked and annealed 450°F., 1 hr.	62.28	0.59	Balance	0.08 Fe	84.5	13	40	..	23	100	Rod	d
(68)	Cold-worked and annealed 850°F., 1 hr.	62.28	0.59	Balance	0.08 Fe	53.5	56	61	..	20	100	Rod	e
(76)	Annealed	61.20	0.43	Balance	0.10 Pb	68	27	53	..	21	100	Rod	
(57)	Hot-rolled	60.81	0.35	Balance	......	59.5	48	56	..	18.5	50	Rod	
(52)	Cold-worked 9.4% Tobin bronze	60.09	0.67	39.16	0.06 Pb	66.3	34	55	80	28	300	Rod	f,g
(52)	Cold-worked 11.5% Tobin bronze	59.97	0.89	39.08	0.03 Pb	69.6	25	51	77	23.7	300	Rod	h,i
(52)	Cold-worked 11.5% naval brass	60.00	0.82	39.13	0.04 Pb	69.9	24	47	76	15	300	Rod	i,j
(52)	Cold-worked 11.5% naval brass	60.05	0.87	39.02	0.04 Pb	72.3	23	47	82	15	300	Rod	i,k

[a] Corrosion-fatigue limit for both salt and carbonated water 17,000 p.s.i. for 4×10^7 cycles.

[b] 0.50% extension yield strength 59,500 p.s.i.; 0.20% offset yield strength 61,800 p.s.i.; modulus of elasticity 17.04×10^6 p.s.i.

[c] 0.5% extension yield strength 62,900 p.s.i.; 0.20% offset yield strength 69,200 p.s.i.; modulus of elasticity 15.75×10^6 p.s.i.

[d] Corrosion-fatigue limit for both carbonated and salt water 17,000 p.s.i. for 5×10^7 cycles.

[e] Corrosion-fatigue limit for salt water 17,000 p.s.i. for 5×10^7 cycles.

[f] 0.50% extension yield strength 39,300 p.s.i.; 0.20% offset yield strength 38,300 p.s.i.; modulus of elasticity 14.1×10^6 p.s.i.

[g] Tension specimens 0.313 in. in diameter, fatigue specimens 0.300 in. in minimum diameter; machined from 0.500-in.-diameter rod. Fatigue tests run at 3,500 r.p.m.

[h] 0.50% yield strength (extension) 49,000 p.s.i.; 0.20% offset yield strength 50,500 p.s.i.; modulus of elasticity 14.07×10^6 cycles.

[i] Tension specimens 0.313 in. in diameter; fatigue specimens 0.300 in. in minimum diameter; machined from 1.00-in.-diameter rod; specimen axes 1/4 in. from surface of rod. Fatigue tests run at 3,500 r.p.m.

[j] 0.50% extension yield strength 49,900 p.s.i.; 0.20% offset yield strength 53,700 p.s.i.; modulus of elasticity 13.44×10^6 p.s.i.

[k] 0.50% extension yield strength 53,500 p.s.i.; 0.20% offset yield strength 55,000 p.s.i.; modulus of elasticity 14.44×10^6 p.s.i.

TABLE 15
THE NICKEL SILVERS

References	Condition	Copper, %	Nickel, %	Zinc, %	Iron, %	Manganese, %	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Rockwell B	Endurance limit, p.s.i. (000 omitted)	Cycles, 10^6	Form	Notes
(57)	Hot-rolled	74.01	19.75	5.17	0.34	0.75	57	36	70	..	23	60	Rod	
(57)	Annealed 1400°F., 1 hr.	74.01	19.75	5.17	0.34	0.75	51	48	73	..	....	...	Rod	[a]
(57)	Cold-drawn as received	60.08	10.89	29.05	0.20	....	58.5	50	59	..	17	60	Rod	
(57)	Cold-drawn as received	65.30	17.63	17.15	0.23	....	62.5	28	50	..	22	50	Rod	
(6)	Annealed	55.23	18.38	26.22	0.06	0.11	67	42	..	..	14	100	Strip	
(6)	Cold-rolled, 4 B. & S. Nos., hard, 37% reduction of area	55.23	18.38	26.22	0.06	0.11	98.5	2	..	..	18.5	35	Strip	
(6)	Cold-rolled, 10 B. & S. Nos., hard, 68% reduction of area	55.23	18.38	26.22	0.06	0.11	116	1.5	..	..	22	45	Strip	
(1)	Annealed	54.99	18.55	26.30	0.04	0.11	60.5	48	..	53	16.5	100	Strip	[b]
(1)	Annealed	54.99	18.55	26.30	0.04	0.11	62.8	49	..	53	17.5	100	Strip	[c]
(1)	Annealed	54.99	18.55	26.30	0.04	0.11	60.5	48	..	53	14	100	Strip	[d]
(1)	Cold-rolled, 4 B. & S. Nos., hard, 37%	54.99	18.55	26.30	0.04	0.11	95.4	1.5	..	90	20.5	100	Strip	[b]
(1)	Cold-rolled, 4 B. & S. Nos., hard, 37%	54.99	18.55	26.30	0.04	0.11	94.4	2.5	..	90	22.0	100	Strip	[c]
(1)	Cold-rolled, 4 B. & S. Nos., hard, 37%	54.99	18.55	26.30	0.04	0.11	93.2	5.5	..	90	18.5	100	Strip	[d]
(1)	Cold-rolled, 10 B. & S. Nos., hard, 68% reduction	54.99	18.55	26.30	0.04	0.11	117.7	1.2	..	97	25.0	100	Strip	[b]
(1)	Cold-rolled, 10 B. & S. Nos., hard, 68% reduction of area	54.99	18.55	26.30	0.04	0.11	114.8	1.5	..	97	26.0	100	Strip	[c]
(1)	Cold-rolled, 10 B. & S. Nos.,hard, 68% reduction of area	54.99	18.55	26.30	0.04	0.11	124.6	2.0	..	97	28.0	100	Strip	[d]
(1)	Cold-rolled, 6 B. & S. Nos., hard, ready-to-finish grain size 0.017 mm.	55.18	17.60	27.08	0.03	0.14	106.6	...	..	..	25.5	100	Strip	
(1)	Cold-rolled 6 B. & S. Nos., hard, annealed 627°F., ½ hr., ready-to-finish grain size 0.017 mm.	55.18	17.60	27.08	0.03	0.14	110.0	...	..	..	26.5	100	Strip	
(1)	Cold-rolled, 6 B. & S. Nos., hard, ready-to-finish grain size 0.022 mm.	55.18	17.60	27.08	0.03	0.14	108.5	...	..	..	23.0	100	Strip	

[a] Torsion strength 44,000 p.s.i.; angle of twist 857 deg., torsion endurance limit 13,000 p.s.i.
[b] Specimens taken parallel to rolling direction.
[c] Specimen taken 45 deg. to rolling direction.
[d] Specimens taken 90 deg. to rolling direction.

TABLE 15.—(*Continued*)

References	Condition	Copper, %	Nickel, %	Zinc, %	Iron, %	Manganese, %	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Rockwell B	Endurance limit, p.s.i. (000 omitted)	Cycles, 10^6	Form	Notes
(1)	Cold-rolled 6 B. & S. Nos., hard, annealed 627°F., ½ hr., ready-to-finish grain size 0.022 mm.	55.18	17.60	27.08	0.03	0.14	114.3	...	..	..	24.0	100	Strip	
(1)	Cold-rolled, 6 B. & S. Nos., hard, ready-to-finish grain size 0.090 mm.	55.18	17.60	27.08	0.03	0.14	108.1	...	..	..	23.0	100	Strip	
(1)	Cold-rolled, 6 B. & S. Nos., hard, annealed 627°F., ½ hr., ready-to-finish grain size 0.090 mm.	55.18	17.60	27.08	0.03	0.14	110.9	...	..	..	22.5	100	Strip	
(1)	Cold-rolled, 8 B. & S. Nos., hard, ready-to-finish grain size 0.015 mm.	55.18	17.60	27.08	0.03	0.14	114.2	...	..	..	28.3	100	Strip	
(1)	Cold-rolled, 8 B. & S. Nos., hard, annealed 627°F., ½ hr. ready-to-finish grain size, 0.015 mm.	55.18	17.60	27.08	0.03	0.14	118.5	...	..	..	28.8	100	Strip	
(1)	Cold-rolled, 8 B. & S. Nos., hard, ready-to-finish grain size, 0.020 mm.	55.18	17.60	27.08	0.03	0.14	117.2	...	..	..	26.5	100	Strip	
(1)	Cold-rolled, 8 B. & S. Nos., hard, annealed 627°F., ½ hr., ready-to-finish grain size, 0.020 mm.	55.18	17.60	27.08	0.03	0.14	125.4	...	..	..	29.5	100	Strip	
(1)	Cold-rolled, 8 B. & S. Nos., hard, ready-to-finish grain size, 0.090 mm.	55.18	17.60	27.08	0.03	0.14	112.4	...	..	..	23.8	100	Strip	
(1)	Cold-rolled, 8 B. & S. Nos., hard, 627°F., ½ hr., annealed ready-to-finish grain size, 0.090 mm.	55.18	17.60	27.08	0.03	0.14	118.3	...	..	..	24.5	100	Strip	

TABLE 16
THE CUPRO-NICKELS

References	Condition	Copper, %	Nickel, %	Iron, %	Manganese, %	Carbon, %	Others, %	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Endurance limit, p.s.i. (000 omitted)	Cycles, 10^6	Form	Notes
(79)	Cold-rolled	48.37	48.33	....	1.90	0.23	0.05 Si	85	35	61	37	100	Rod	a
(79)	Annealed 1400°F., 1 hr.	48.37	48.33	....	1.90	0.23	0.05 Si	.....	46	62	32	69	Rod	
(79)	Cold-worked and annealed 750°F., 3 hr.	53.54	45.00	0.38	1.03	0.04	0.02 Si	96.5	22	71	41	100	Rod	b
(79)	Annealed 1200°F., 1 hr.	53.54	45.00	0.38	1.03	0.04	0.02 Si	66.5	47	78	30	4	Rod	c
(79)	Cold-worked	53.71	44.77	0.66	0.86	0.08	......	103.5	15	70	43	40	Rod	
(79)	Annealed 1450°F., 1 hr.	53.71	44.77	0.66	0.86	0.08	......	69.5	49	79	28	8	Rod	
(79)	Hot-rolled	53.77	44.68	0.52	1.14	0.11	......	70.5	49	79	34.5	?	Rod	d
(79)	Annealed 1500°F., 1 hr.	53.77	44.68	0.52	1.14	0.11	......	70.5	49	80	....	...	Rod	e
(79)	Hot-rolled	56.63	40.29	1.02	1.44	0.16	0.03 Si	78	33	60	37.5	?	Rod	
(79)	Annealed 1400°F., 1 hr.	56.63	40.29	1.02	1.44	0.16	0.03 Si	72	47	67	30	?	Rod	
(79)	Cold-worked and annealed 850°F., 3 hr.	67.11	28.66	2.82	1.35	0.04	0.006 Si	98	18	54	36	100	Rod	f
(79)	Annealed 1450°F., 1 hr.	67.11	28.66	2.82	1.35	0.04	0.006 Si	70.5	46	72	26.5	40	Rod	g
(79)	Cold-worked	69.82	29.08	0.27	....	.....	0.95 Sn	87.5	4	22	33.5	50	Rod	
(77)	Cold-rolled, 6 B. & S. Nos., hard, 50% reduction of area	68.47	29.58	0.25	0.32	0.048	1.33 Sn	97.9	2.5	..	27	50	Strip	
(79)	Cold-worked and annealed 400°F., 1 hr.	77.92	21.24	0.51	0.29	0.03	0.031 P, 0.011 S	62.5	23	68	25.5	100	Rod	h
(79)	Annealed 1400°F., 1 hr.	77.92	21.24	0.51	0.29	0.03	0.011 S, 0.031 P	47.5	50	75	18	100	Rod	i
(79)	Cold-worked	80.34	19.23	0.27	0.12	.....	......	50	36	68	17.5	50	Rod	

[a] Corrosion-fatigue limit, carbonated water, 24,000 p.s.i. for 5 × 10^7 cycles.
[b] Corrosion-fatigue limit, carbonated water, 20,000 p.s.i. for 7 × 10^7 cycles; salt water (brackish) 21,000 p.s.i. for 6 × 10^7 cycles.
[c] Corrosion-fatigue limit, carbonated water, 21,000 p.s.i. for 7 × 10^7 cycles; salt water (brackish) 22,000 p.s.i. for 2 × 10^7 cycles.
[d] Torsion strength 66,000 p.s.i.; angle of twist 976 deg.; torsion endurance limit 14,500 p.s.i.
[e] Torsion strength 60,000 p.s.i.; angle of twist 1,023 deg.; torsion endurance limit 17,000 p.s.i.
[f] Corrosion fatigue, carbonated water, 22,000 p.s.i. for 7 × 10^7 cycles (notched specimen).
[g] Corrosion fatigue, carbonated water, 20,000 p.s.i. for 6 × 10^7 cycles (notched specimen).
[h] Corrosion-fatigue limit, carbonated water, 20,000 p.s.i. for 7 × 10^7 cycles; salt water (brackish) 25,000 p.s.i. for 4 × 10^7 cycles.
[i] Corrosion-fatigue limit, carbonated water, 18,000 p.s.i. for 8 × 10^7 cycles; salt water (brackish) 18,000 p.s.i. for 5 × 10^7 cycles.

TABLE 17
ALUMINUM BRONZES

References	Condition	Copper, %	Aluminum %	Iron, %	Manganese, %	Others, %	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Brinell, 500 kg., 10-mm. ball	Endurance limit, p.s.i. (000 omitted)	Cycles, 10^6	Form	Notes
(80)	Hot-rolled 1 3/16-in.-diameter rod	99.90	0.10	....	....	......	32.5	66	91	66	13	0.5	Rod	
(80)	Hot-rolled 1 3/16-in.-diameter rod	97.01	2.99	....	....	......	44.5	57	86	102	22	0.5	Rod	
(80)	Hot-rolled 1 3/16-in.-diameter rod	94.93	5.07	....	....	......	57	69	78	124	24.5	1	Rod	
(68)	Rolled	94.85	5.62	0.07	....	......	72	43	66	...	19	100	Rod	a
(80)	Hot-rolled 1 3/16-in.-diameter rod	92.65	7.35	....	....	......	63	73	75	134	24.5	1	Rod	
(57)	Rolled	90.91	9.10	Trace	....	......	87	34	55	...	23	60	Rod	b
(80)	Hot-rolled 1 3/16-in.-diameter rod	90.10	9.90	....	....	......	84	29	31	210	29.5	1	Rod	
(57)	Rolled	90.52	10.01	Trace	....	......	83.5	38	39	...	28	80	Rod	c
(57)	Annealed 1200°F., 1 hr.	90.52	10.01	Trace	....	......	62.5	24	23	...	20	50	Rod	
(76)	Extruded quench in water from 1650°F., reannealed 1150°F.	89.91	10.06	0.13	....	......	77.5	36	34	128	34	70	Rod	
(82)	Annealed 600°F., 3 hr.	90.39	10.00	0.17	....	......	75	20	26	...	28	?	Rod	
(82)	Annealed 600°F., 3 hr.	87.69	10.50	2.64	....	......	100	17	18	...	31	?	Rod	
(57)	Rolled	87.12	10.40	2.92	....	......	99	31	40	...	35	50	Rod	d
(68)	Rolled	87.00	9.60	3.40	....	......	91.5	28	29	...	27	40	Rod	e
(81)	Rolled 1 3/16-in.-diameter rod	89.06	10.02	....	0.92	......	96	23	34	...	27.5	1	Rod	
(81)	Rolled 1 3/16-in.-diameter rod	88.30	9.82	....	1.88	......	91	29	32	...	27.5	1	Rod	
(81)	Rolled 1 3/16-in.-diameter rod	88.11	8.91	....	2.98	......	89.5	39	44	...	27.5	1	Rod	
(68)	As extruded	83.60	12.57	3.40	0.43	......	83.5	1	4	...	40	15	Rod	f
(68)	As extruded	86.71	9.93	3.10	....	0.26 Sn	88	12	15	...	42	20	Rod	g
(68)	As extruded	88.67	7.49	2.89	0.14	0.81 Ni	90.5	35	36	...	38	60	Rod	h
(78)	As hot-forged	79.83	9.73	5.42	....	4.97 Ni	116	8	19	226	51	50	Rod	i
(78)	Extruded and lightly cold-worked	89.50	8.89	0.15	....	1.40 Zn	80	30	42	150	32	50	Rod	j

[a] Torsion strength 52,500 p.s.i.; angle of twist 396 deg.; torsion endurance limit 12,000 p.s.i. for 4×10^7 cycles.
[b] Torsion strength 60,000 p.s.i.; angle of twist 217 deg.; torsion endurance limit 13,000 p.s.i. for 5×10^7 cycles.
[c] Torsion strength 44,500 p.s.i.; angle of twist 72 deg.; torsion endurance limit 14,000 p.s.i. for 5×10^7 cycles.
[d] Torsion strength 60,500 p.s.i.; angle of twist 60 deg.; torsion endurance limit 17,000 p.s.i. for 8×10^7 cycles; corrosion-fatigue limit, carbonated water, 25,000 p.s.i. for 3×10^7 cycles.
[e] Corrosion-fatigue limit, carbonated water, 24,000 p.s.i. for 3×10^7 cycles.
[f] Corrosion-fatigue limit, carbonated water, 30,000 p.s.i. for 10^7 cycles; salt water (brackish) 30,000 p.s.i. for 5×10^7 cycles.
[g] Corrosion-fatigue limit, carbonated water, 33,000 p.s.i. for 5×10^7 cycles; salt water (brackish) 29,000 p.s.i. for 2×10^7 cycles.
[h] Corrosion-fatigue limit, carbonated water, 23,000 p.s.i. for 5×10^7 cycles.
[i] Proportional limit 5,400 p.s.i.; modulus of elasticity 18.8×10^6 p.s.i.; corrosion-fatigue limit, salt spray, 32,800 p.s.i. for 5×10^7 cycles.
[j] Proportional limit 17,700 p.s.i.; modulus of elasticity 17.5×10^6 p.s.i.; corrosion-fatigue limit, salt spray, 22,000 p.s.i. for 5×10^7 cycles.

TABLE 18
TIN BRONZES

References	Condition	Copper, %	Tin, %	Phosphorus, %	Iron, %	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Rockwell B, 100 kg., 1/16-in. ball	Endurance limit, p.s.i. (000 omitted)	Cycles, 10^6	Form	Notes
(52)	Cold-rolled 37%, ready-to-finish grain size 0.015 mm.	98.68	1.25	0.05	....	59.2	14	75	70	31.3	300	Rod	a
(1)	Annealed	95.82	3.86	0.068	....	55.1	52	..	58	13.75	100	Strip	b
(1)	Cold-rolled, 4 B. & S. Nos., hard, 37% reduction of area	95.82	3.86	0.068	....	78.8	6	..	83	25.5	100	Strip	c
(1)	Cold-rolled, 8 B. & S. Nos., hard, 60% reduction of area	95.82	3.86	0.068	....	90.2	2	..	85	22	100	Strip	d
(57)	Cold-drawn	95.57	4.05	0.39	0.09	56	48	79	...	22.5	20	Rod	
(57)	Annealed 1200°F., 1 hr.	95.57	4.05	0.39	0.09	48	71	81	...	22.5	20	Rod	
(57)	Cold-rolled	95.74	4.20	0.05	....	66.5	22	59	...	29	50	Rod	
(78)	Rolled and drawn annealed 527°F., ½ hr.	95.56	4.23	0.13	....	62	25	78	75	22	50	Rod	e
(52)	Cold-rolled 30%, ready-to-finish grain size 0.090 mm.	95.27	4.32	0.38	0.03	69.8	23	79	92	29	300	Rod	f
(77)	Cold-rolled, 6 B. & S. Nos., hard, 50% reduction of area	95.16	4.66	0.032	....	97.9	2.5	..	91	36	50	Strip	
(77)	Cold-rolled, 6 B. & S. Nos., hard, 50% reduction of area	95.16	4.70	0.102	....	98.7	2	..	92	35.5	50	Strip	
(57)	Cold-rolled	95.61	4.66	0.06	0.03	58.5	32	71	...	....	...	Rod	g
(54)	Annealed 1290°F., 1 hr.	94.96	4.89	.....	....	45	67	84	39	23	100	Rod	
(54)	Cold-drawn	94.96	4.89	.....	....	85	12	67	93	27	40	Rod	
(54)	Cold-drawn	95.00	5.06	0.03	....	63	33	75	...	27	60	Rod	h
(55)	Cold-worked and annealed 375°F., 3 hr.	94.55	5.42	0.13	0.07	81.5	25	65	80	23	1.5	Rod	i
(55)	Cold-worked and annealed 400°F., 3 hr.	94.55	5.42	0.13	0.07	63	38	74	68	27	40	Rod	j
(55)	Annealed 1200°F., 1 hr.	94.55	5.42	0.13	0.07	48	72	80	7	20	100	Rod	
(77)	Cold-rolled, 6 B. & S. Nos., hard, 50% reduction of area	91.98	7.45	0.067	....	104	4.5	..	95	33.6	50	Strip	
(1)	Annealed	92.04	7.68	0.066	....	59.7	67	..	56	21	100	Strip	k
(1)	Cold-rolled, 4 B. & S. Nos., hard, 37% reduction of area	92.04	7.68	0.066	....	95.5	14	..	93	22	100	Strip	l
(1)	Cold-rolled, 8 B. & S. Nos., hard, 60% reduction of area	92.04	7.68	0.066	....	124.8	2	..	101	24.5	100	Strip	m
(6)	Annealed	91.84	8.08	0.03	0.02	59.5	67	..	...	21	100	Strip	
(6)	Cold-rolled, 4 B. & S. Nos., hard, 37% reduction of area	91.84	8.08	0.03	0.02	95.5	14	..	...	22	100	Strip	

[a] 0.50% extension yield strength 54,700 p.s.i.; 0.20% offset yield strength 54,800 p.s.i.; modulus of elasticity 19 × 10^6 p.s.i.
[b] Proportional limit 13,300 p.s.i.; modulus of elasticity 12.8 × 10^6 p.s.i.
[c] Proportional limit 52,500 p.s.i.; modulus of elasticity 15.5 × 10^6 p.s.i.
[d] Proportional limit 54,400 p.s.i.; modulus of elasticity 14.8 × 10^6 p.s.i.
[e] Corrosion-fatigue limit, salt spray, 26,200 p.s.i. for 5 × 10^7 cycles.
[f] 0.50% extension yield strength 60,000 p.s.i.; 0.20% offset yield strength 61,600 p.s.i.; modulus of elasticity 16.38 × 10^6 p.s.i.
[g] Torsion strength 52,500 p.s.i.; angle of twist 810 deg.; torsion endurance limit 12,000 p.s.i. for 7 × 10^7 cycles.
[h] Torsion strength 50,500 p.s.i.; angle of twist 618 deg.
[i] Corrosion-fatigue limit, carbonated water, 22,000 p.s.i. for 2 × 10^7 cycles.
[j] Corrosion-fatigue limit, carbonated water, 23,000 p.s.i. for 5 × 10^7 cycles.
[k] Proportional limit 26,000 p.s.i.; modulus of elasticity 15.5 × 10^6 p.s.i.
[l] Modulus of elasticity 14 × 10^6 p.s.i.
[m] Proportional limit 55,000 p.s.i.; modulus of elasticity 15 × 10^6.

TABLE 18.—(*Continued*)

References	Condition	Copper, %	Tin, %	Phosphorus, %	Iron, %	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Rockwell B, 100 kg., 1/16-in. ball	Endurance limit, p.s.i. (000 omitted)	Cycles, 10^6	Form	Notes
(6)	Cold-rolled, 10 B. & S. Nos., hard, 68% reduction of area	91.84	8.08	0.03	0.02	125	2	..	...	25	100	Strip	
(52)	Cold-rolled, 50% reduction of area, ready-to-finish grain size 0.100 mm.	91.78	8.10	0.08	0.043	110.3	10	69	98	30	300	Rod	n
(52)	Cold-rolled 30%, ready-to-finish grain size 0.100 mm.	91.78	8.10	0.08	0.043	81	27	77	97	34.7	300	Rod	o
(52)	Cold-rolled 15%, ready-to-finish grain size 0.100 mm.	91.78	8.10	0.08	0.043	66	48	81	80	30	300	Rod	p
(55)	Cold-worked and annealed 350°F., 4 hr.	91.71	8.20	0.13	0.07	94.5	26	59	...	17	20	Rod	q
(55)	Cold-worked and annealed 400°F., 4 hr.	91.71	8.20	0.13	0.07	81	38	74	75	22	20	Rod	r
(55)	Annealed 1200°F., 1 hr.	91.71	8.20	0.13	0.07	55.5	85	78	5	21	10	Rod	s
(52)	Cold-rolled 30%, ready-to-finish grain size 0.090 mm.	89.86	9.76	0.12	0.06	92.1	23	64	91	23	300	Rod	t
(55)	Cold-worked and annealed 400°F., 3 hr.	89.41	10.49	0.13	0.07	91.5	32	66	90	17	10	Rod	
(55)	Cold-worked and annealed 400°F., 3 hr.	89.41	10.49	0.13	0.07	86.5	36	56	75	17	20	Rod	v
(55)	Annealed 1200°F., 1 hr.	89.41	10.49	0.13	0.07	64.5	77	73	30	20	100	Rod	
(56)	Cold-rolled	89.39	10.60	0.13	0.08	83	38	63	...	27	15	Rod	
(56)	Annealed 1100°F., 1 hr.	89.39	10.60	0.13	0.08	67.5	70	72	...	27	30	Rod	

[n] 0.50% extension yield strength 65,300 p.s.i.; 0.20% offset yield strength 93,100 p.s.i.; modulus of elasticity 13.8 × 10^6 p.s.i.
[o] 0.50% extension yield strength 60,200 p.s.i.; 0.20% offset yield strength 64,500 p.s.i.; modulus of elasticity 15 × 10^6 p.s.i.
[p] 0.50% extension yield strength 49,100 p.s.i.; 0.20% offset yield strength 49,000 p.s.i.; modulus of elasticity 16.43 × 10^6 p.s.i.
[q] Corrosion-fatigue limit, carbonated water, 17,000 p.s.i. for 10^7 cycles.
[r] Corrosion-fatigue limit, carbonated water, 17,000 p.s.i. for 10^7 cycles.
[s] Corrosion-fatigue limit, salt water, 20,000 p.s.i. for 10^7 cycles.
[t] 0.50% extension yield strength 60,000 p.s.i.; 0.20% offset yield strength 70,400 p.s.i.; modulus of elasticity 14.07 × 10^6 p.s.i.
[v] Corrosion-fatigue limit, carbonated water, 16,000 p.s.i.

TABLE 19
SILICON BRONZES

References	Condition	Copper, %	Silicon, %	Manganese, %	Tin, %	Iron, %	Zinc, %	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Rockwell B	Endurance limit, p.s.i. (000 omitted)	Cycles, 10^6	Form	Notes
(77)	Cold-rolled, 6 B. & S. Nos., hard, 50% reduction of area	96.42	3.12	....	....	0.16	0.22	104.3	5	..	....	29	50	Strip	
(1)	Annealed	95.89	3.00	1.00	....	....	....	59.3	63	..	41	16	100	Strip	a
(1)	Cold-rolled, 4 B. & S. Nos., hard, 37% reduction of area	95.89	3.00	1.00	....	....	....	93.7	7	..	91	23	100	Strip	b
(1)	Cold-rolled, 8 B. & S. Nos., hard, 60% reduction of area	95.89	3.00	1.00	....	....	....	107.6	2	..	95	20.5	100	Strip	c
(52)	Cold-drawn, 39% reduction of area, ready-to-finish grain size 0.125 mm.	95.49	3.20	1.07	....	0.15	....	97.1	13	62	101	33.6	300	Rod	d
(52)	Cold-drawn 20%, ready-to-finish grain size 0.065 mm.	96.13	2.91	0.95	....	0.16	....	74.9	37	..	89	30.5	300	Rod	e
(52)	Cold-drawn, 8% reduction of area, ready-to-finish grain size 0.085 mm.	96.13	2.91	0.95	....	0.16	....	66.6	49	..	84	31.5	300	Rod	f
(52)	Annealed 1300°F. for ½ hr., ready-to-finish grain size 0.085 mm.	95.49	3.20	1.07	....	0.15	....	59.6	68	78	44	18.8	300	Rod	g
	Cold-drawn, 20% reduction of area, ready-to-finish grain size 0.100 mm.	96.29	3.19	....	0.42	0.10	....	73	26	65	....	30	100	Rod	
	Annealed 1300°F., 1 hr.	96.29	3.19	....	0.42	0.10	....	60	60	75	45	18	100	Rod	
(52)	Cold-drawn 72% reduction of area	98.17	1.41	0.21	....	0.06	....	88	10	74	86	30.4	300	Rod	h
	Extruded rod	97.97	1.74	....	0.21	0.08	....	47	64	84	26	19	50	Rod	i
	Extruded rod	97.97	1.74	....	0.21	0.08	....	47	64	84	26	20	50	Rod	j
	Hot-rolled rod	98.06	1.70	....	0.18	0.06	....	43	74	76	62F	16	50	Rod	k
	Hot-rolled rod	98.06	1.70	....	0.18	0.06	....	43	74	76	62F	19	60	Rod	l

[a] Proportional limit 9,400 p.s.i.; modulus of elasticity 16.6 × 10^6 p.s.i.
[b] Proportional limit 28,500 p.s.i.; modulus of elasticity 15.6 × 10^6 p.s.i.
[c] Proportional limit 31,600 p.s.i.; modulus of elasticity 15.4 × 10^6 p.s.i.
[d] 0.50% extension yield strength 64,200 p.s.i.; 0.20% offset yield strength 80,000 p.s.i.; modulus of elasticity 14.63 × 10^6 p.s.i.
[e] 0.50% extension yield strength 49,100 p.s.i.
[f] 0.50% extension yield strength 45,200 p.s.i.
[g] 0.50% extension yield strength 16,000 p.s.i.; 0.20% offset yield strength 14,500 p.s.i.; modulus of elasticity 16.94 × 10^6.
[h] 0.50% extension yield strength 68,500 p.s.i.; 0.20% offset yield strength 80,500 p.s.i.; modulus of elasticity 16.98 × 10^6 p.s.i. (Temper commercially furnished for use in the manufacture of bolts and screws by cold-upsetting or heading operations.)
[i] Specimen taken from 2.50-in. extruded rod: axis of specimen 0.750 in. from surface of rod.
[j] Specimen taken from 2.50-in. extruded rod: axis of specimen 0.325 in. from rod surface.
[k] Specimen taken from 2.50-in. hot-rolled rod: axis of specimen 0.750 in. from surface of rod.
[l] Specimen taken from 2.50-in. hot-rolled rod: axis of specimen 0.325 in. from surface of rod.

TABLE 20
BERYLLIUM COPPER

References	Condition	Copper, %	Beryllium, %	Others, %	Tensile strength, p.s.i. (000 omitted)	Elongation, % in 2 in.	Reduction, % of area	Rockwell B	Endurance limit, p.s.i. (000 omitted)	Cycles, 10^6	Form	Notes
(78)	Extruded and lightly cold-worked	97.26	2.25	0.30 Ni, 0.10 Fe	93.5	23	62	87	35.8	55	Rod	[a]
(1)	Annealed at 800°C. (1472°F.), quenched in water, aged 2 hr. at 275°C. (527°F.)	97.75	2.25	....	171.2	4.8	..	111	31	100	Strip	[b]
(1)	Annealed at 800°C. (1472°F.), quenched in water, cold-rolled 2 B. & S. Nos., hard, aged 2 hr. at 275°C. (527°F.)	97.50	2.16	0.32 Ni, 0.06 Fe	173	6.3	..	102G	27.25	100	Strip	[c]
(1)	Annealed at 800°C. (1472°F.), quenched in water, cold-rolled 4 B. & S. Nos., hard, aged 2 hr. at 275°C. (527°F.)	97.54	2.14	0.28 Ni, 0.06 Fe	193	2.0	..	104.50	28	100	Strip	[d]
(1)	Annealed 800°C. (1472°F.), quenched in water, cold-rolled, 4 B. & S. Nos., hard, 37% reduction of area	97.25	2.25	0.50 Ni	118	4.3	..	84G	27	100	Strip	[e]
(1)	Annealed 800°C. (1472°F.), quenched in water, cold-rolled, 2 B. & S. Nos., hard, 21% reduction of area	97.25	2.25	0.50 Ni	84.1	19.1	..	86	23	100	Strip	[f]
(1)	Cold-rolled 2 B. & S. Nos., hard, aged 2 hr. at 275°C. (527°F.)	97.25	2.75	0.50 Ni	171.0	4.0	..	108	26.5	100	Strip	[g]
(1)	Cold-rolled, 2 B. & S. Nos., hard, aged 1 hr. at 275°C. (527°F.)	97.25	2.75	0.50 Ni	.....	....	..	......	30	100	Strip	
(52)	Aged 1.5 hr. at 300°C. (572°F.)	97.54	2.12	0.31 Ni 0.07 Fe	.....	....	..	99G	61.5	300	Rod	[h]
(52)	Cold-drawn, 21% reduction of area, aged 1.5 hr. at 300°C. (572°F.)	97.42	2.12	0.40 Ni 0.09 Fe	186.9	5	19	98G	55	300	Rod	[i,h]
(52)	Cold-drawn, 21% reduction of area, aged 1.5 hr. at 300°C. (572°F.)	97.42	2.12	0.40 Ni 0.09 Fe	.....	....	..	102G	47.2	300	Rod	[h]

[a] Proportional limit 31,000 p.s.i.; 0.10% proof stress 68,500 p.s.i.; Young's modulus of elasticity 16.3×10^6 p.s.i.; corrosion- fatigue limit, salt spray, 40,000 p.s.i. for 6.3×10^7 cycles; elongation measured on $4\sqrt{\text{area}}$.

[b] Fatigue specimen taken parallel to direction of rolling; modulus of elasticity 19.1×10^6 p.s.i.

[c] Fatigue specimen taken parallel to direction of rolling; modulus of elasticity 18.5×10^6 p.s.i.; proportional limit 48,000 p.s.i.

[d] Fatigue specimen taken parallel to direction of rolling; proportional limit 55,000 p.s.i.; modulus of elasticity 18.4×10^6 p.s.i.

[e] Fatigue specimen taken parallel to direction of rolling; proportional limit 39,000 ps..i.; modulus of elasticity 17.2×10^6 p.s.i.

[f] Fatigue specimen taken parallel to direction of rolling; proportional limit 25,900 p.s.i.; modulus of elasticity 19.4×10^6 p.s.i.

[g] Fatigue specimens taken parallel to direction of rolling; proportional limit 49,500 p.s.i.; modulus of elasticity 19.8×10^6 p.s.i.

[h] Tension specimens 0.313 in. in diameter, fatigue specimens 0.300 in. in minimum diameter; machined from 0.500-in.-diameter rod. Fatigue tests run at 3,500 r.p.m.

[i] 0.50% extension yield strength 93,500 p.s.i.; modulus of elasticity 18.8×10^6 p.s.i.

CHAPTER XIV

BENDING PROPERTIES OF WROUGHT COPPER AND COPPER-BASE ALLOYS

TABLE 1
RECOMMENDED RADII FOR FORMING 90-DEG. BENDS IN SHEET COPPER
According to Gohn[85]

Condition	Tensile strength, p.s.i. (000 omitted)	Rockwell B	Nominal thickness		Minimum suitable radius of punch, in.					
			B. & S. gage No.	In.	Bend perpendicular to rolling direction		Bend 45 deg. to rolling direction		Bend parallel to rolling direction	
Cold-rolled, 2 B. & S. Nos., hard, 21% reduction of area	37–44	30–50	24	0.0201	1/32	0.0312	1/32	0.0312	3/64	0.0468
Cold-rolled, 6 B. & S. Nos., hard, 50% reduction of area	46–55	50–62	24	0.0201	1/64	0.0156	1/32	0.0312	1/32	0.0312

TABLE 2
RECOMMENDED RADII FOR FORMING 90-DEG. BENDS IN RED-BRASS SHEET
According to Gohn[85]
Copper, 83–86%; lead, max. 0.15%; iron, max. 0.05%

Condition	Tensile strength, p.s.i. (000 omitted)	Rockwell B	Nominal thickness: B. & S. gage No.	Nominal thickness: In.	Minimum suitable radius of punch, in.: Bend perpendicular to rolling direction		Bend 45 deg. to rolling direction		Bend parallel to rolling direction	
Drawing anneal	33.5–43.5	.....	36–14	0.005–0.0641	Sharp		Sharp		Sharp	
Cold-rolled, 2 B. & S. Nos., hard, 21% reduction of area	46.5–56.5	.....	36–26	0.005–0.0159	Sharp		Sharp		Sharp	
		43.71	24–16	0.0201–0.0508	Sharp		Sharp		Sharp	
		48–71	14	0.0641	1/32	0.0312	1/32	0.0312	1/32	0.0312
Cold-rolled, 4 B. & S. Nos., hard, 37% reduction of area	60.5–70.5	.....	36–28	0.005–0.0126	Sharp		Sharp		Sharp	
		.....	26	0.0159	Sharp		1/64	0.0156	1/64	0.0156
		66–78	24	0.0201	Sharp		1/64	0.0156	1/64	0.0156
		66–78	22	0.0253	Sharp		1/64	0.0156	1/32	0.0312
		66–78	20	0.0320	Sharp		1/64	0.0156	1/16	0.0625
		73–81	18	0.0403	1/64	0.0156	1/32	0.0312	3/32	0.0937
		73–81	16	0.0508	1/64	0.0156	1/32	0.0312	3/32	0.0937
		73–81	14	0.0641	1/32	0.0312	1/16	0.0625	1/8	0.125
Cold-rolled, 6 B. & S. Nos., hard, 50% reduction of area	70.0–79.5	.....	36	0.0050	Sharp		Sharp		1/64	0.0156
		.....	34	0.0063	Sharp		Sharp		1/64	0.0156
		.....	32	0.0080	Sharp		Sharp		1/32	0.0312
		.....	30	0.0100	Sharp		Sharp		1/32	0.0312
		.....	28	0.0126	Sharp		1/64	0.0156	1/16	0.0625
		.....	26	0.0159	Sharp		1/32	0.0312	3/32	0.0937
		74–84	24	0.0201	1/64	0.0156	1/32	0.0312	1/8	0.125
		74–84	22	0.0253	1/64	0.0156	1/16	0.0625	5/32	0.1562
		74–84	20	0.0320	1/64	0.0156	1/16	0.0625	3/16	0.1875
		79–85	18	0.0403	1/16	0.0625	3/32	0.0937	7/32	0.2187
		79–85	16	0.0508	1/16	0.0625	1/8	0.125	3/8	0.375
		79–85	14	0.0641	1/16	0.0625	3/16	0.1875	3/8	0.375
Cold-rolled, 8 B. & S. Nos., hard, 60% reduction of area	75–84	.....	36	0.0050	Sharp		1/64	0.0156	1/64	0.0156
		.....	34	0.0063	Sharp		1/64	0.0156	1/32	0.0312
		.....	32	0.0080	Sharp		1/64	0.0156	1/16	0.0625
		.....	30	0.0100	Sharp		1/64	0.0156	3/32	0.0937
		.....	28	0.0126	Sharp		1/32	0.0312	1/8	0.125
		.....	26	0.0159	1/64	0.0156	1/32	0.0312	3/16	0.1875
		79–88	24	0.0201	1/64	0.0156	3/32	0.0937	7/32	0.2187
		79–88	22	0.0253	1/32	0.0312	1/8	0.125	3/8	0.375
		79–88	20	0.0320	1/16	0.0625	1/8	0.125	3/8	0.375
		82–88	18	0.0403	1/16	0.0625	3/16	0.1875	1/2	0.500
		82–88	16	0.0508	1/16	0.0625	1/4	0.250	1/2	0.500
		82–88	14	0.0641	3/32	0.0937	3/8	0.375	1/2	0.500

TABLE 3
RECOMMENDED RADII FOR FORMING 90-DEG. BENDS IN LOW-BRASS SHEET
According to Gohn[85]
Copper, 80%; zinc, balance

Condition	Tensile strength, p.s.i. (000 omitted)	Rockwell B	Nominal thickness: B. & S. gage No.	Nominal thickness: In.	Minimum suitable radius of punch, in.: Bend perpendicular to rolling direction		Bend 45 deg. to rolling direction		Bend parallel to rolling direction	
Cold-rolled, 4 B. & S. Nos., hard, 37% reduction of area	68.0–77.0	76–84	24	0.0201	1/32	0.0312	3/64	0.0469	1/16	0.0625
Cold-rolled, 8 B. & S. Nos., hard, 60% reduction of area	85–93	87–92	24	0.0201	1/32	0.0312	1/8	0.125	3/16	0.1875

TABLE 4
RECOMMENDED RADII FOR FORMING 90-deg. BENDS IN 72-28 BRASS SHEET
According to Gohn[85]
Copper, 70.50–73.50%; lead, max. 0.10%; iron, max. 0.05%

Condition	Tensile strength, p.s.i. (000 omitted)	Rockwell B	Nominal thickness		Minimum suitable radius of punch, in.					
			B. & S. gage No.	In.	Bend perpendicular to rolling direction		Bend 45 deg. to rolling direction		Bend parallel to rolling direction	
Cold-rolled, 2 B. & S. Nos., hard, 21% reduction of area	56.5–66.5	.....	36–26	0.005–.0159	Sharp		Sharp		Sharp	
		57–73	24–20	0.0201–.0320	Sharp		Sharp		Sharp	
		63–76	18	0.0403	Sharp		Sharp		Sharp	
		63–76	16	0.0508	Sharp		Sharp		Sharp	
		63–76	14	0.0641	1/64	0.0156	N.D.[a]		N.D.	
Cold-rolled, 4 B. & S. Nos., hard, 37% reduction of area	71–81	.....	36–26	0.0050–.0159	Sharp		Sharp		Sharp	
		77–84	24–20	0.0201–0.0320	1/64	0.0156	1/32	0.0312	3/64	0.0469
		80–86	18	0.0403	1/64	0.0156	1/32[b]	0.0312	3/64	0.0469
		80–86	16	0.0508	1/32[b]	0.0312	1/32[b]	0.0312	1/8	0.125
		80–86	14	0.0641	1/32	0.0312	1/32	0.0312	1/8	0.125
Cold-rolled, 6 B. & S. Nos., hard, 50% reduction of area	82.5–91.5	.....	36	0.0050	Sharp		Sharp		Sharp	
		.....	34	0.0063	Sharp		Sharp		Sharp	
		.....	32	0.0080	Sharp		Sharp		1/64	0.0156
		.....	30	0.0100	Sharp		Sharp		1/32	0.0312
		.....	28	0.0126	Sharp		Sharp		1/32	0.0312
		.....	26	0.0159	Sharp		1/64	0.0156	1/16	0.0625
		85–89	24	0.0201	1/64	0.0156	3/64	0.0469	1/8	0.125
		85–89	22	0.0253	1/64	0.0156	1/16	0.0625	5/32	0.1562
		85–89	20	0.0320	1/32	0.0312	3/32	0.0937	5/32	0.1562
		87–91	18	0.0403	1/32	0.0312	5/32	0.1562	7/32	0.2187
		87–91	16	0.0508	3/64	0.0469	3/16	0.1875	>1/4	>0.250
		87–91	14	0.0641	1/16	0.0625	>1/4	>0.250	>1/4	>0.250
Cold-rolled, 8 B. & S. Nos., hard, 60% reduction of area	90.5–99.5	.....	36	0.0050	Sharp		Sharp		1/64[b]	0.0156
		.....	34	0.0063	Sharp		Sharp		1/64	0.0156
		.....	32	0.0080	Sharp		1/64	0.0156	1/32	0.0312
		.....	30	0.0100	Sharp		1/64	0.0156	3/32	0.0937
		.....	28	0.0126	Sharp		1/16	0.0625	3/32	0.0937
		.....	26	0.0159	Sharp		1/16[b]	0.0625	1/8	0.125
		88–92	24	0.0201	1/32	0.0312	1/8	0.125	7/32	0.2187
		88–92	22	0.0253	1/32	0.0312	1/8	0.125	7/32	0.2187
		88–92	20	0.0320	3/64	0.0469	N.D.		N.D.	
		90–94	18	0.0403	1/16	0.0625	>1/4	>0.250	>1/4	>0.250
		90–94	16	0.0508	1/8	0.125	>1/4	>0.250	>1/4	>0.250
		90–94	14	0.0641	1/8	0.125	>1/4	>0.250	>1/4	>0.250
Cold-rolled, 10 B. & S. Nos., hard, 68% reduction of area	95–104	.....	36	0.0050	Sharp		Sharp		1/32	0.0312
		.....	34	0.0063	Sharp		Sharp		1/32	0.0312
		.....	32	0.0080	Sharp[b]		3/64	0.0469	1/16	0.0625
		.....	30	0.0100	Sharp		1/16	0.0625	3/32	0.0937
		.....	28	0.0126	Sharp		1/16	0.0625	N.D.	
		.....	26	0.0159	Sharp		1/16	0.0625	7/32	0.2187
		90–94	22	0.0253	3/64	0.0469	5/32	0.1562	>1/4	>0.250
		90–94	20	0.0320	3/64	0.0469	3/16	0.1875	>1/4	>0.250
		92–96	18–14	0.0403–0.0641	1/8	0.125	>1/4	>0.250	>1/4	>0.250

[a] Value not determined.
[b] Interpolated from forming data on other gages.

TABLE 5

RECOMMENDED RADII FOR FORMING 90-DEG. BENDS IN COMMON HIGH-BRASS SHEET

According to Gohn[85]

Copper, 64.50–67.50%; lead, max. 0.30%; iron, max. 0.05%; zinc, balance

Condition	Tensile strength, p.s.i. (000 omitted)	Rockwell B	Nominal thickness: B. & S. gage No.	Nominal thickness: In.	Minimum suitable radius of punch, in.: Bend perpendicular to rolling direction		Bend 45 deg. to rolling direction		Bend parallel to rolling direction	
Cold-rolled, 21% reduction of area, 2 B. & S. Nos., hard	53.5–63.5	49–73[a]	36–11	0.005–0.0907	Sharp		Sharp		Sharp	
Cold-rolled, 3 B. & S. Nos., hard	61–71	67–80[a]	36–17	0.005–0.0453	Sharp		Sharp		Sharp	
		70–80	16	0.0508	Sharp		Sharp		1/64	
		70–80	15	0.0571	Sharp		Sharp		1/64	
		70–80	14	0.0641	1/64	0.0156	1/64	0.0156	1/32	0.0312
		70–80	12	0.0808	1/64[b]	0.0156	1/32[b]	0.0312	3/32[b]	0.0937
		70–80	11	0.0907	1/64	0.0156	1/32	0.0312	3/32	0.0937
Cold-rolled, 4 B. & S. Nos., hard, 37% reduction of area	68–78	75–83[a]	36–22	0.005–0.0253	Sharp		Sharp		Sharp	
		75–83	20	0.0320	Sharp		Sharp		1/64	0.0156
		78–85	18	0.0403	Sharp		Sharp		1/32	0.0312
		78–85	17	0.0453	Sharp		1/64	0.0156	1/16	0.0625
		78–85	16	0.0508	Sharp		1/64	0.0156	3/32	0.0937
		78–85	15	0.0571	1/64	0.0156	1/32	0.0312	3/32	0.0937
		78–85	14	0.0641	1/32	0.0312	1/32	0.0312	3/32	0.0937
		78–85	12	0.0808	1/32	0.0312	1/16	0.0625	3/32	0.0937
		78–85	11	0.0907	3/32	0.0937	1/8	0.125	1/4	0.250
		78–85	10	0.1019	1/4	0.250	1/4	0.250	1/4	0.250
		78–85	9	0.1144	1/4	0.250	1/4	0.250	1/4	0.250
Cold-rolled, 6 B. & S. Nos., hard, 50% reduction of area	79–88.5	83–87	24	0.0201	1/64	0.0156	1/32	0.0312	3/32	0.0937
		83–87	20	0.0320	1/32	0.0312	1/16	0.0625	3/16	0.187
		83–87	19	0.0359	3/64[b]	0.0468	3/32	0.0937	3/16	0.187
		85–89	18	0.0403	3/64	0.0468	1/8	0.125	3/16	0.187
		85–89	17	0.0453	1/16	0.0625	1/8[b]	0.125	3/16[b]	0.187
		85–89	16	0.0508	1/16	0.0625	1/8	0.125	3/16	0.187
		85–89	15	0.0571	3/32	0.0937	5/32	0.156	1/4	0.250
		85–89	14	0.0641	1/8	0.125	5/32	0.156	3/8	0.375
		85–89	13	0.0720	1/8	0.125	1/4	0.250	3/8	0.375
Cold-rolled, 6 B. & S. Nos., hard	79–88.5	85–89	11	0.0907	1/4	0.250	3/8	0.375	1/2	0.500
Cold-rolled, 8 B. & S. Nos., hard, 60% reduction of area	86–95	.....	31	0.0089	Sharp		1/64	0.0156	3/32	0.0937
		.....	30	0.0100	Sharp		1/64	0.0156	3/32	0.0937
		.....	26	0.0159	1/64	0.0156	1/16	0.0625	5/32	0.156
		85–89	24	0.0201	1/32	0.0312	3/32	0.0937	7/32	0.218
		85–89	22	0.0253	1/32	0.0312	5/32	0.156	>1/4	>0.250
		85–89	20	0.0320	1/32	0.0312	5/32	0.156	>1/4	>0.250
		88–92	18	0.0403	3/64	0.0468	7/32	0.218	>1/4	>0.250
		88–91	16	0.0508	3/32	0.0937	7/32	0.218	>1/4	>0.250
		88–92	14	0.0641	1/8	0.125	1/4	0.250	>1/4	>0.250
Cold-rolled, 10 B. & S. Nos., hard, 68% reduction of area	89.5–98.5	86–90	22	0.0253	3/64	0.0468	5/32	0.156	>1/4	>0.250

[a] Rockwell hardness limits do not apply to material less than 0.0201 in. thick.

[b] Interpolated from forming data on other gages.

TABLE 6

RECOMMENDED RADII FOR FORMING 90-DEG. BENDS IN LEADED HIGH-BRASS SHEET

According to Straw, Helfrick, and Fischrupp[84]

Copper, 64.0–67.0%; lead, 0.80–1.10%; zinc, balance

Condition	Tensile strength, p.s.i. (000 omitted)	Rockwell B	Nominal thickness		Minimum suitable radius of punch, in.					
			B. & S. gage No.	In.	Bend perpendicular to rolling direction		Bend 45 deg. to rolling direction		Bend parallel to rolling direction	
Cold-rolled, 1 B. & S. Nos., hard, 10.9% reduction of area	49.0–59.0	59.0	14	0.0641	Sharp		Sharp		Sharp	
Cold-rolled, 2 B. & S. Nos., hard, 21% reduction of area	55.0–65.0	63	18	0.0403	Sharp		Sharp		Sharp	
		71	16	0.0508	Sharp		1/64	0.0156	1/32	0.0312
		65	14	0.0641	Sharp		1/64	0.0156	1/32	0.0312
		71	12	0.0808	1/16	0.0625	1/16	0.0625	3/32	0.0312
Cold-rolled, 4 B. & S. Nos., hard, 37% reduction of area	68.0–78.0	75–83	24	0.0201	3/64[a]	0.0469	3/64[a]	0.0469	1/16[a]	0.0625
Cold-rolled, 8 B. & S. Nos., 60% reduction of area	86.0–95.0	87–92	24	0.0201	1/16[a]	0.0625	5/32[a]	0.1562	1/4[a]	0.250

[a] Based on data by Gohn[85].

TABLE 7

RECOMMENDED RADII FOR FORMING 90-DEG. BENDS IN CLOCK BRASS (ENGRAVER'S BRASS)

According to Straw, Helfrick, and Fischrupp[84]

Copper, 61 to 64%; lead, 1.25–2.0%; zinc, balance

Condition	Tensile strength, p.s.i. (000 omitted)	Rockwell B	Nominal thickness		Minimum suitable radius of punch, in.					
			B. & S. gage No.	In.	Bend perpendicular to rolling direction		Bend 45 deg. to rolling direction		Bend parallel to rolling direction	
Cold-rolled, 2 B. & S. Nos., hard, 21% reduction of area	55.0–65.0	71	11	0.0907	1/16	0.0625	3/32	0.0937	3/32	0.0937
Cold-rolled, 4 B. & S. Nos., hard, 37% reduction of area	68.0–78.0	76	24	0.0201	Sharp		1/32	0.0312	1/16	0.0625
		81	22	0.0253	1/32	0.0312	1/16	0.0625	3/32	0.0937
		80	20	0.0319	1/32	0.0312	1/16	0.0625	3/32	0.0937
		83	19	0.0359	1/16	0.0625	3/32	0.0937	[a]	
		80	17	0.0451	1/16	0.0625	3/32	0.0937	[a]	
		84	16	0.0508	1/16	0.0625	3/32	0.0937	[a]	
		82	14	0.0641	3/32	0.0937	1/8	0.125	[a]	
		83	13	0.0719	1/8	0.125	[a]	......	[a]	
		82	12	0.0808	1/8	0.125	[a]	......	[a]	
Cold-rolled, 8 B. & S. Nos., hard, 60% reduction of area	86.0–95.0	87	24	0.0201	1/16	0.0625	5/32[b]	0.1562	>1/4[b]	>0.250

[a] None of radii tested was suitable.

[b] Based on data by Gohn[85].

TABLE 8

RECOMMENDED RADII FOR FORMING 90-DEG. BENDS IN GRADE A (DEEP-DRAWING) NICKEL-SILVER SHEET

According to Gohn[85]

Copper, 70.5–73.5%; nickel, 16.5–19.5%; zinc, 8.5–11.5%; iron, max. 0.35%

Condition	Tensile strength, p.s.i. (000 omitted)	Rockwell B	Nominal thickness: B. & S. gage No.	Nominal thickness: In.	Minimum suitable radius of punch, in.: Bend perpendicular to rolling direction		Bend 45 deg. to rolling direction		Bend parallel to rolling direction	
Cold-rolled, 2 B. & S. Nos., hard, 21% reduction of area	65.5–73.5	.....	36–19	0.0050–0.0359	Sharp		Sharp		Sharp	
		38–54	18	0.0403	N.D.[a]		1/64	0.0156	1/32	0.0312
		38–54	16	0.0508	Sharp		1/64	0.0156	N.D.	
		38–54	14	0.0641	N.D.		N.D.	....	3/32	0.0937
		38–54	13	0.0720	3/32	0.0937	3/32	0.0937	3/32	0.0937
		38–54	11	0.0907	3/32	0.0937	3/32	0.0937	1/8	0.250
Cold-rolled, 4 B. & S. Nos., hard, 37% reduction of area	75.0–82.0	.....	36–26	0.0050–0.0159	Sharp		Sharp		Sharp	
		51–61	24	0.0201	Sharp		Sharp		1/64	0.0156
		51–61	22	0.0253	Sharp		Sharp		N.D.	
		51–61	20	0.0320	1/16	0.0625	1/16	0.0625	1/16	0.0625
		51–61	18	0.0403	1/16	0.0625	1/16	0.0625	1/16	0.0625
		51–61	16	0.0508	1/16	0.0625	1/16	0.0625	3/32	0.0937
		51–61	15	0.0571	3/32[b]	0.0937	3/32[b]	0.0937	1/8[b]	0.1250
		51–61	10	0.1019	1/8[b]	0.1250	1/8[b]	0.125		
Cold-rolled, 6 B. & S. Nos., hard, 50% reduction of area	81.0–88.0	.....	36–26	0.0050–0.0159	Sharp		Sharp		N.D.	
		57–65	22	0.0253	1/64	0.0156	1/32	0.0312	N.D.	
		57–65	20	0.0320	1/8	0.125	1/8	0.125	1/8	0.125
		57–65	18	0.0403	1/8	0.1250	1/8	0.125	3/16	0.1875
		57–65	16	0.0508	5/32	0.1562	5/32	0.1562	7/32	0.2187
Cold-rolled, 8 B. & S. Nos., hard, 60% reduction of area	....	.....	36–32	0.0050–0.0080	Sharp		Sharp		N.D.[a]	
			30	0.0100	Sharp		1/64	0.0156	N.D.	
			28	0.0126	1/64	0.0156	1/64	0.0156	N.D.	
			26	0.0159	1/64	0.0156	1/64	0.0156	N.D.	
			24	0.0201	3/64	0.0469	3/32	0.0937	3/16	0.1875
			22	0.0253	3/64	0.0469	3/16[c]	0.1875	N.D.	
			20	0.0320	5/32	0.1562	3/16	0.1875	N.D.	
			18	0.0403	5/32	0.1562	3/16	0.1875	7/32	0.2187
			16	0.0508	5/32	0.1562	7/32	0.2187	N.D.	
			14	0.0641	>1/4	>0.250	>1/4[c]	>0.250	>1/4	>0.250
Cold-rolled, 10 B. & S. Nos., hard, 67% reduction of area	....	.....	36	0.0050	Sharp[c]		Sharp		N.D.	
			34	0.0063	Sharp		Sharp		N.D.	
			32	0.0080	Sharp		1/64	0.0156	N.D.	
			30	0.0100	Sharp		1/64	0.0156	N.D.	
			28	0.0126	1/64	0.0156	N.D.		N.D.	
			26	0.0159	1/64	0.0156	1/32	0.0312	N.D.	
			22	0.0253	3/64	0.0469	1/8	0.125	N.D.	
			20	0.0320	5/32	0.1562	7/32	0.2187	N.D.	
			18	0.0403	5/32	0.1562	7/32	0.2187	1/4	0.250
			16	0.0508	5/32	0.1562	1/4	0.250	N.D.	

[a] Value not determined.
[b] Based on data by Straw, Helfrick, and Fischrupp[84].
[c] Interpolated from forming data on other gages.

TABLE 9

RECOMMENDED RADII FOR FORMING 90-DEG. BENDS IN GRADE B (SPRING STOCK) NICKEL SILVER

According to Gohn[85] and Straw, Helfrick, and Fischrupp[84]

Copper, 53.5–56.5%; nickel, 16.5–19.5%; zinc, 25.5–28.5%; manganese, max. 0.50%; iron, max. 0.35%

Condition	Tensile strength, p.s.i. (000 omitted)	Rockwell B	Nominal thickness		Minimum suitable radius of punch, in.					
			B. & S. gage No.	In.	Bend perpendicular to rolling direction		Bend 45 deg. to rolling direction		Bend parallel to rolling direction	
Cold-rolled, 2 B. & S. Nos., hard, 21% reduction of area	78.0–93.0	.....	36–26	0.0050–0.0159	Sharp		Sharp		Sharp	
		48–67	24	0.0201	Sharp		Sharp		Sharp	
		62[a]	20	0.0319	Sharp[a]		Sharp[a]		Sharp[a]	
		65[a]	18	0.0403	1/16[a]	0.0625	1/16[a]	0.0625	1/16[a]	0.0625
		70[a]	16	0.0508	1/16[a]	0.0625	1/16[a]	0.0625	1/16[a]	0.0625
		70[a]	15	0.0571	1/16[a]	0.0625	1/16[a]	0.0625	3/32[a]	0.0937
		66[a]	14	0.0641	1/16[a]	0.0625	1/16[a]	0.0625	3/32[a]	0.0937
		69[a]	9	0.1144	1/8[a]	0.125	1/8[a]	0.125	[a,b]	
Cold-rolled, 4 B. & S. Nos., hard, 37% reduction of area	92.0–106.5	.....	30	0.0100	Sharp[a]		Sharp[a]		1/64[a]	0.0156
		66–75	24	0.0201	1/32	0.0312	1/32	0.0312	1/32	0.0312
		70[a]	20	0.0319	1/16[a]	0.0625	1/16[a]	0.0625	3/32[a]	0.0937
		73[a]	17	0.0452	1/16[a]	0.0625	1/16[a]	0.0625	3/32[a]	0.0937
		73[a]	14	0.0641	3/32[a]	0.0937	3/32[a]	0.0937	[a,b]	
Cold-rolled, 6 B. & S. Nos., hard, 50% reduction of area	102.0–115.0	.....	36	0.0050	Sharp		Sharp		Sharp	
		.....	34	0.0063	Sharp		Sharp		Sharp	
		.....	32	0.0080	1/64	0.0156	1/64	0.0156	1/64	0.0156
		.....	30	0.0100	1/64	0.0156	1/64	0.0156	1/64	0.0156
		69–78	28	0.0126	1/64	0.0156	1/64	0.0156	1/64	0.0156
		69–78	27	0.0142	1/64	0.0156	1/64	0.0156	1/32	0.0312
		69–78	26	0.0159	1/32	0.0312	3/64	0.0469	1/8	0.1250
		69–78	25	0.0179	1/32	0.0312	3/64	0.0469	1/8	0.1250
		72–79	24	0.0201	3/64	0.0469	3/32	0.0937	1/8	0.1250
		72–79	23	0.0226	1/16	0.0625	3/32	0.0937	1/8	0.1250
		72–79	22	0.0253	3/32	0.0937	3/32	0.0937	1/8	0.1250
		72–79	21	0.0285	3/32	0.0937	3/32	0.0937	3/16	0.1875
		72–79	20	0.0320	3/32	0.0937	3/32	0.0937	3/16	0.1875
		72–79	19	0.0359	1/8	0.125	1/8	0.125	3/16	0.1875
		75–82	18	0.0403	1/8	0.125	5/32	0.1562	3/16	0.1875
		75–82	16	0.0508	1/8	0.125	5/32	0.1562	7/32	0.2187
		75–82	14	0.0641	5/32	0.1562	3/16	0.1875	3/8	0.375
		75–82	12	0.0808	1/4	0.250	1/4	0.250	3/8	0.375
		75–82	11	0.0907	3/8	0.375	3/8	0.375	3/8	0.375
		75–82	..	0.125	>1/4	>0.250	>1/4	>0.250	>1/4	>0.250

[a] Based on data by Straw, Helfrick, and Fischrupp[84].

[b] None of the radii tested were suitable.

TABLE 10

RECOMMENDED RADII FOR FORMING 90-DEG. BENDS IN 5% (GRADE A) PHOSPHOR BRONZE SHEET

According to Straw, Helfrick, and Fischrupp[84]

Copper, 95.7%; tin, 4.3%; phosphorus, 0.20%; iron, max. 0.10%

Condition	Tensile strength, p.s.i. (000 omitted)	Rockwell B	Nominal thickness		Minimum suitable radius of punch, in.					
			B. & S. gage No.	In.	Bend perpendicular to rolling direction		Bend 45 deg. to rolling direction		Bend parallel to rolling direction	
Cold-rolled, 2 B. & S. Nos., hard, 20% reduction of area	55.0–70.0	26	24	0.0201	Sharp		Sharp		Sharp	
		38	20	0.0319	Sharp		Sharp		Sharp	
		37	14	0.0641	Sharp		Sharp		Sharp	
		42	13	0.0719	Sharp		Sharp		Sharp	
		47	12	0.0808	1/16	0.0625	1/16	0.0625	1/16	0.0625
		42	11	0.0907	1/16	0.0625	1/16	0.0625	1/16	0.0625
		42	..	0.1250	3/32	0.0937	3/32	0.0937	3/32	0.0937
Cold-rolled, 4 B. & S. Nos., hard, 37% reduction of area	72.0–87.0	59	24	0.0201	Sharp		1/32	0.0312	1/16	0.0625
		64	20	0.0319	1/64	0.0156	1/16	0.0625	1/8	0.1250
		59	18	0.0403	1/16	0.0625	1/16	0.0625	1/8	0.1250
		66	16	0.0508	1/16	0.0625	3/32	0.0937	[a]	
Cold-rolled, 6 B. & S. Nos., hard, 50% reduction of area	84.0–98.5	69	17	0.0453	1/16	0.0625	1/8	0.1250	[a]	
Cold-rolled, 8 B. & S. Nos., hard, 60% reduction of area	91.0–105.0	..	28	0.0126	Sharp		1/16	0.0625	[a]	
		..	27	0.0140	Sharp		1/16	0.0625	[a]	
		..	26	0.0159	1/64	0.0156	3/32	0.0937	[a]	
		..	25	0.0179	1/32	0.0312	1/8	0.125	[a]	
		72	23	0.0226	1/32	0.0312	1/8	0.125	[a]	
		72	22	0.0253	1/32	0.0312	1/8	0.125	[a]	
		67	21	0.0285	1/16	0.0625	[a]		[a]	
		71	20	0.0319	1/16	0.0625	[a]		[a]	
		74	18	0.0403	3/32	0.0937	[a]		[a]	
		75	17	0.0452	3/32	0.0937	[a]		[a]	
		75	16	0.0508	3/32	0.0937	[a]		[a]	
		74	14	0.0641	1/8	0.125	[a]		[a]	

[a] None of the radii tested were suitable.

TABLE 11

RECOMMENDED RADII FOR FORMING 90-DEG. BENDS IN 8% PHOSPHOR BRONZE

According to Gohn[85]

Copper, min. 91.0%; tin, 7.5–8.5%; phosphorus, .05–.25%; iron, max. 0.10%; zinc, max. 0.20%; nickel, max. 0.15%; lead, max. 0.02%

Condition	Tensile strength, p.s.i. (000 omitted)	Rockwell B	Nominal thickness		Minimum suitable radius of punch, in.					
			B. & S. gage No.	In.	Bend perpendicular to rolling direction		Bend 45 deg. to rolling direction		Bend parallel to rolling direction	
Cold-rolled, 2 B. & S. Nos., hard, 21% reduction of area	69–84	.....	36–14	0.005–0.0641	Sharp		Sharp		Sharp	
		47–68	13	0.0720	Sharp		Sharp		1/16[a]	0.0625
		47–68		0.1250	1/8	0.1250	1/8	0.1250	N.D.[b]	
Cold-rolled, 4 B. & S. Nos., hard, 37% reduction of area	85.0–100.0	.....	36	0.0050	Sharp		1/64	0.0156	1/64	0.0156
		.....	34	0.0063	Sharp		N.D.	....	1/64	0.0156
		.....	32	0.0080	Sharp		N.D.	....	1/64	0.0156
		.....	30	0.010	Sharp		N.D.	....	1/32	0.0312
		.....	28	0.0126	Sharp		N.D.	....	1/32	0.0312
		.....	26	0.0159	Sharp		1/64[a]	0.0156	1/64[a]	0.0156
		65–74	24	0.0201	Sharp		N.D.	....	1/16	0.0625
		65–74	22	0.0253	Sharp		N.D.	....	N.D.	
		69–77	18	0.0403	1/32	0.0312	1/8[c]	0.1250	N.D.	
		69–77	16	0.0508	3/32	0.0937	1/8	0.1250	3/16	0.1875
		69–77	14	0.0641	1/8[a]	0.1250	1/8	0.1250	1/4	0.250
Cold-rolled, 6 B. & S. Nos., hard, 50% reduction of area	97.0–111.5	.....	36	0.0050	Sharp		N.D.	....	1/32	0.0312
		.....	34	0.0063	Sharp		N.D.	....	1/32	0.0312
		.....	32	0.0080	Sharp		N.D.	....	3/64	0.0469
		.....	30	0.0100	Sharp		N.D.	....	N.D.	
		.....	28	0.0126	Sharp		N.D.	....	N.D.	
		.....	26	0.0159	Sharp		N.D.	....	N.D.	
		73–79	24	0.0201	Sharp		N.D.	....	1/4	0.250
		73–79	22	0.0253	1/32	0.0312	N.D.	....	N.D.	
		73–79	20	0.0320	1/32	0.0312	N.D.	....	N.D.	
		76–82	18	0.0403	3/64	0.0469	5/32	0.01562	>1/4	>0.250
		76–82	16	0.0508	N.D.	......	3/16	0.1875	>1/4	>0.250
		76–82	14	0.0641	5/32	0.1562	>1/4	>0.250	>1/4	>0.250
Cold-rolled, 8 B. & S. Nos., hard, 60% reduction of area	105.0–118.5	.....	36	0.0050	Sharp		1/64	0.0156	3/64	0.0469
		.....	34	0.0063	Sharp		1/32	0.0312	3/32	0.0937
		.....	32	0.0080	Sharp		3/64[c]	0.0469	3/32	0.0937
		.....	30	0.010	1/64	0.0156	1/16	0.0625	1/8	0.1250
		.....	28	0.0126	1/64	0.0156	3/32	0.0937	5/32	0.1562
		.....	26	0.0159	1/32	0.0312	3/32	0.0937	5/32	0.1562
		.....	25	0.0179	1/32	0.0312	1/8	0.1250	7/32	0.2187
		76–82	24	0.0201	1/32	0.0312	1/8	0.1250	1/4	0.250
		76–82	22	0.0253	1/32	0.0312	5/32	0.1562	3/8	0.375
		76–82	20	0.0320	3/32	0.0937	3/16	0.1875	1/2	0.500
		76–82	19	0.0359	3/32[c]	0.0937	7/32	0.2187	1/2	0.500
		79–85	18	0.0403	3/32	0.0937	1/4	0.250	1/2	0.500
		79–85	17	0.0453	1/8	0.250	3/8	0.375	1/2	0.500
		79–85	16	0.0508	3/32[a]	0.0937	3/8	0.375	1/2	0.500
		79–85	14	0.0641	5/32	0.1562	3/8	0.375	3/4	0.750
		79–85	11	0.0907	7/32	0.2187	1/2	0.500	3/4	0.750
Cold-rolled, 10 B. & S. Nos., hard, 67% reduction of area	109.5–122.0	.....	36	0.0050	Sharp		N.D.		1/16	0.0625
		.....	32	0.0080	1/64	0.0156	N.D.		3/32	0.0937
		.....	28	0.0126	1/64	0.0156	N.D.		N.D.	
		.....	26	0.0159	1/64	0.0156	3/32[a]	0.0937	N.D.	
		78–83	24	0.0201	1/32	0.0312	1/8[a]	0.125	N.D.	
		83	22	0.0253	1/16[a]	0.0625				
		81–86	14	0.0641	5/32	0.1562	>1/4	>0.250	>1/4	>0.250

[a] Based on data by Straw, Helfrick, and Fischrupp[84].

[b] Values not determined.

[c] Interpolated from forming data on other gages.

TABLE 12
RECOMMENDED RADII FOR FORMING 90-DEG. BENDS IN SHEET SILICON BRONZE (TYPE A)
According to Gohn[85]

Condition	Tensile strength, p.s.i. (000 omitted)	Rockwell B	Nominal thickness		Minimum suitable radius of punch, in.					
			B. & S. gage No.	In.	Bend perpendicular to rolling direction		Bend 45 deg. to rolling direction		Bend parallel to rolling direction	
Cold-rolled, 4 B. & S. Nos., hard, 37% reduction of area	87–97	88–96	24	0.0201	1/32	0.0312	1/32	0.0312	1/16	0.0625
Cold-rolled, 8 B. & S. Nos., hard, 60% reduction of area	105–113	94–99	24	0.0201	3/64	0.0468	3/32	0.0937	3/16	0.187

TABLE 13
RECOMMENDED RADII FOR FORMING 90-DEG. BENDS IN COPPER-BERYLLIUM SHEET
According to Gohn[85]
Heated 1 hr. at 800°C. (1472°F.); quenched in water

Condition	Tensile strength, p.s.i. (000 omitted)	Rockwell B	Nominal thickness		Minimum suitable radius of punch, in.					
			B. & S. gage No.	In.	Bend perpendicular to rolling direction		Bend 45 deg. to rolling direction		Bend parallel to rolling direction	
Soft..................	..	....	18	0.0403	Sharp		Sharp		Sharp	
Cold-rolled, 2 B. & S. Nos., hard, 21% reduction of area	..	....	18	0.0403	1/16	0.0625	3/32	0.0937	1/8	0.125
Cold-rolled, 4 B. & S. Nos., hard, 37% reduction of area	..	....	18	0.0403	3/16	0.187	7/32	0.218	>1/4	>0.250
Copper-nickel Beryllium										
Soft annealed	..	....	26	0.0159	1/64	0.0156	1/64	0.0156	1/64	0.0156
Cold-rolled, 1 B. & S. No., hard, 10% reduction of area	..	....	26	0.0159	1/32	0.0312	1/32	0.0312	1/32	0.0312
			18	0.0403	3/32	0.0937	1/16	0.0625	1/8	0.125
Cold-rolled, 2 B. & S. Nos., hard, 21% reduction of area	..	....	26	0.0159	1/32	0.0312	1/32	0.0312	1/32	0.0312
Cold-rolled, 1 B. & S. No., hard, 10% reduction of area, aged after rolling	..	....	18	0.0403	1/4	0.250	>1/4	>0.250	>1/4	>0.250

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APPENDIX A

TEST METHODS

Tensile strength in accordance with American Society for Testing Materials Specification E8-40T.

Yield strength in accordance with American Society for Testing Materials Specification E8-40T.

Percentage of elongation in 2 inches in accordance with American Society for Testing Materials Specification E8-36.

Percentage of reduction of area in accordance with American Society for Testing Materials Specification E8-36.

Brinell hardness in accordance with American Society for Testing Materials Specification E10-27.

Rockwell hardness in accordance with American Society for Testing Materials Specifications E18-36 and E18-39T.

Apparent elastic limit.[1] The value of the apparent elastic limit as given in the text was determined by the method illustrated in Fig. 1. Briefly, that method consists in plotting from the stress-strain curve equal increments of stress against corresponding increments of strain. The strain corresponding to the point at which the graph so obtained shows a marked change of slope is considered the apparent elastic limit of the material. The soundness of this method is indicated by Fig. 1, in which are included load-unload curves. It will be noted that specimens of the silicon bronze, stressed to below, and up to, the value of the apparent elastic limit, have no permanent set when the stress is released, while specimens stressed in excess of that value have a permanent set upon release of the stress. These tests were made on a 100,000-pound capacity Southwark-Emery hydraulic machine equipped with a Templin automatic stress-strain recorder. The gage length of the specimen used was 2 inches and strain was measured to an accuracy of 1 part in 100,000.

[1] WILKINS, R. A., Copper and Copper Base Alloy in the Construction of Corrosion Resisting Equipment and Structures, *Mech. Eng.*, vol. 58, p. 809, 1936.

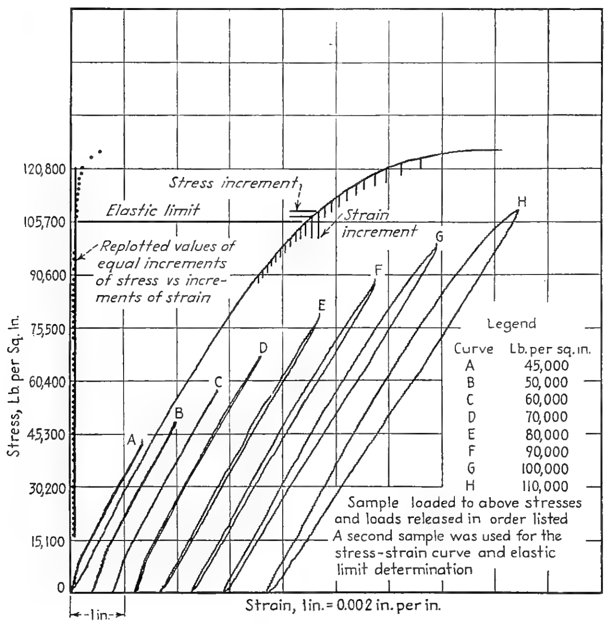

FIG. 1.

APPENDIX B

DEFINITION OF TERMS

1. Apparent Elastic Limit.—See Test Methods, Appendix A.

2. B. & S. Numbers Hard.—In the fabrication of wrought copper-base alloy sheet and strip, it is common practice to refer to the amount of cold work performed as the B. & S. Nos., hard, *e.g.*, sheet and strip thicknesses are based on Brown and Sharpe gage units. If a copper-base alloy is cold-rolled from 12 B. & S. gage (0.0808 in.) to 13 B. & S. gage (0.0720 in.), it is said to be 1 No., hard; if from 12 B. & S. gage (0.0808 in.) to 16 B. & S. gage (0.0508 in.), 4 Nos. hard. The relation between numbers hard, percentage reduction of area by cold working, and commercial temper designations is given in the following table:

Commercial temper cold-rolled sheet and strip	B. & S. Nos., Hard	Reduction of area, %
Quarter hard	1	10.9
Half hard	2	20.7
Three-quarters hard	3	29.4
Hard	4	37.1
Extra hard	6	50.0
Spring	8	60.5
Extra spring	10	68.7

3. Ready-to-finish Anneal and Ready-to-finish Grain Size.—In the cold-working as well as in the annealing charts for wrought copper-base alloy strip, it will be observed that complete mechanical properties are given for two different "ready-to-finish' grain sizes. In brass mill terminology it is common practice to refer to the anneal before the final cold working as the "ready-to-finish" anneal and the grain or crystal size of the metal obtained as the "ready-to-finish" grain size. Others have referred to it as the penultimate anneal or grain size. In all cases where properties are given for two different "ready-to-finish" grain sizes, the values selected have been those commonly encountered in the commercial production of the material in question.

4. Relief Anneal or Stress Reliefing.—It is common practice with certain of the wrought copper-base alloys to anneal them at a temperature below the recrystallization or equicohesive temperature to distribute or normalize residual internal stresses produced by previous cold-working operations. Relief annealing usually has very little influence on mechanical properties produced by previous cold work, though in some cases a definite improvement in elastic properties is effected. Copper-base alloys that have been properly relief-annealed offer much greater resistance to stress-corrosion cracking (season cracking) than do untreated materials.

INDEX OF ALLOY PROPERTIES