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Report No. 342/210

COPPER-SILICON BRONZES

A Compilation of Technical Data

by S. E. Conner

Watertown Arsenal

May 11, 1933.

-- Introduction --

This information has been compiled in the study of the problem of bronzes containing no or little strategic metals. It represents information collected from various sources and to a small extent information obtained in the Arsenal Laboratory.

S. E. Conner

Watertown Arsenal

May 11, 1933.

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1. Brief History and Reasons for Development -- Sources, etc. -- An alloy of copper, silicon and manganese of the solid solution type was developed by Mr. Charles B. Jacobs while at the du Pont Company. It was patented May 26, 1925 and manufacture was started by the du Ponts.

In 1927, the American Brass Company purchased the patents and took over its manufacture.

During the war, the du Pont Chemical Company was faced with the problem of finding a metal which would show high strength and, at the same time, withstand acid corrosion in order to make quick repairs of acid works which they had taken over at that period.

At that time, tin was very expensive and difficult to obtain, and tin bronzes were out of the question. Silicon was being produced in commercial quantities but was not being used for alloying or hardening copper.

The plain copper-silicon bronze had been known for some time but seems to be rather difficult to handle and no one was successful with its fabrication. Mr. Jacobs found that the addition of manganese to the copper-silicon alloy gave very favorable results and the resulting material had high strength as well as acid-resisting properties.[12]

It is a high-strength engineering material with a strength equal to medium carbon steel when hot rolled into sheets and exceeding that of medium carbon steel when cold rolled or drawn into sheets and rods. It is non-rusting, non-magnetic and highly resistant to corrosive gases and saline fogs encountered in industrial and seacoast communities.[4]

This metal is produced by the American Brass Company and can also be obtained in fabricated form from leading manufacturers.

Nearly all tin used in the United States is imported from foreign sources;over 70% of the ore comes from Malay,and the greater portion of the remainder from Australia, China, Bolivia, Nigeria Dutch East Indies, and the United States uses half of the world's total output. Metal Mkt & P.M.G. Report

This alloy is non-magnetic.

Tin in 1930

United States Bureau of Mines, Part 1, January 15, 1932,
Pages 355 to 385

Imports in 1930 exceeded $60,000,000 in value

Domestic Mine Production $10,500 in value

(15 long tons). Alaska furnished 13.1 tons of this.

(Alaska furnished 54.5 tons in 1929).

The remainder (1.9 tons) came from North Carolina and South Dakota.

In 1930, 23,393 long tons of secondary Sn were recovered, a decline of 24% from 1929.[25] This secondary Sn is 29% of the virgin Sn imported in 1930. Imports of 80,734 long tons (87,127 in 1929) were more than the previous year except 1929, but less in value than any year since 1922. This was imported as follows:-

British Malaya	69%
United Kingdom	15%
Netherlands	9%
Hong Kong	6%
Total	99%

Australia, Netherland East Indies, Germany, China, Canada, and Haiti furnished the remainder. World production of Sn in 1930 (174,000 long tons) decreased 9% from 1929.

P.M.G. Metal

It might be well to make mention of another patented tinless bronze known as P.M.G. metal, a substitute for phosphor bronze, manganese bronze, and gun metal which was brought to the attention of the War Department by the P.M.G. Metal Trust Ltd. of England. This substitute is an 88-10-2 alloy-copper, silicon, iron and also contains zinc. It is covered by Frankford Arsenal report No. 12 in which it has been, to some extent, compared with Everdur,[15] a copper, silicon, bronze alloy. See Section 10.

2. Composition -- General for Castings and Wrought Material. -- This alloy is furnished in two compositions, one being that used for castings and the other used in wrought form.

The composition of this alloy for castings is:

Copper	94.0%
Silicon	4.5%
Manganese	1.5%

For use in wrought forms the composition is:

Copper	96.00%
Silicon	3.00%
Manganese	1.00% [12]

Patent of the American Brass Company on Everdur

Copper	82 to 96.5%
Silicon	3 to 15 %
Manganese	0.5 to 3% [15]

3. Physical Characteristics of Various Forms. -- The wrought forms of these alloys are sheet, rods, tubes, wire and forgings. When annealed soft, the various forms of the metal have a tensile strength -- 52,000 to 56,000 lbs. per square inch; yield point about 15,000 lbs. per square inch; elongation 60% to 90% in 2; reduction of area 60% or above.[12]

Drawing or rolling hardens the material and increases tensile strength considerably and small rods have a

Tensile strength	90,000 to 100,000 lbs. per sq.in.
Yield point	75,000 to 85,000 lbs.per sq.in.
Elongation	In hard condition about 15%
Reduction of Area	Upwards of 50% [12]

In spring wire, the tensile strength is 140,000 to 150,000 lbs. per square inch with a yield point approaching 100,000 lbs.

The modulas of elasticity is 15,000,000.

The density 8.46 and a cubic inch weighs 0.306 pounds.[12]

Copper-Silicon-Manganese Bronze and Copper

In order to understand the general properties of these alloys, a comparison in tank sheet thickness is made to those of copper, which metal is generally known.

Property	Copper	Copper-Silicon-Manganese Bronze
Color	Copper red	Distinctive bronze
Density	8.90	8.46
Ten.Str.lbs.per sq.in.annealed	32,000	52,000
Ten.Str.lbs.per sq.in.cold rolled	45,000	75,000
El.in 2 in.per cent -- annealed	35.0	50.0
El.in 2 in.per cent -- cold rolled	15.0	35.0
Corrosion resistance	Good	In general better than copper

Property	Copper	Copper-Silicon-Manganese Bronze
Heat conductivity, Cal./CM3/SEC/ Deg. C	0.91 to 0.94	0.078
Elect.conduct., per cent of I.A.C.S. 20 deg. C	97 to 101	6.5
Melting Point deg. F	1981	1866
Melting Point deg. C	1083	1019
Machinability	Difficult drags with tool	Excellent
Weldability	Good in thickness 1/8 or less. Difficult in tank sheet thickness, 3/16 in. or above	Excellent by any method

These alloys are not subject to corrosion cracking or so-called "season cracking". This feature is extremely important in connection with non-ferrous alloys to be used under corrosive conditions in a strained state. Many non-ferrous metals usually classed as high strength materials give satisfactory service indoors or in the absence of corroding agents, but are likely to fail by corrosion cracking under some of the exacting demands of outdoor service. This type of failure is more prevalent with alloys of high zinc content, and experience has shown that alloys with a copper content of 80% or over are practically immune to this type of failure. This alloy may be used in the hard drawn or strained condition, under severe corrosive conditions, without the least danger of "season cracking".[12]

Machining Qualities

The machining qualities of the wrought alloy are comparable to those of steel as used for automatic screw machine work. A refrigerant base oil and high speed tools are essential.

Forging

This alloy flows readily under the hammer and may be hot forged without difficulty.

The heat should be brought to a dull red "750°C"; working should be rapid with blows not too heavy. At higher temperatures, it may become hot short and break under the hammer. A few trials on the part of the operator with test pieces will soon enable him to determine the correct forging temperature.[2]

Ingots for Castings

Ingots for foundry use contain approximately 94.4% copper, 4.5% silicon and 1.1% manganese. It is supplied in small notched ingots weighing approximately 25 pounds each, case in iron molds. The use of deoxidizing agents or hardening alloys is not necessary during the melting to produce good castings.

The metal comes to the foundry man ready for use and can be melted and cast with the regular equipment of brass and bronze foundries.

Due to the ease of handling in the foundry, and the dense, close-grained castings produced, the percentage of rejected castings on the foundry floor and in the machine shop is reduced to a minimum. It also casts well by the centrifugal process and in chilled molds. Under either of these methods greater density and a closer grain structure are obtained than when the metal is cast in green sand or baked molds. The castings may be heat treated (annealed) at 1200° - 1300°F (650° - 700°C) to further toughen the metal, improve its machining qualities and remove casting strains from certain types of castings. Annealing also increases the resistance to pressure.

When blow-holes resulting from improperly vented cores or molds, or scabs, occur in castings they can frequently be chiseled or bored out, and then filled up by welding with a similar composition welding rod or electrode. After machining the salvaged casting will be as sound as if the defect had not occurred, and the weld will have the same strength as the cast metal.[1]

Melting and Pouring

When melted the metal is very fluid and searching, which makes it possible to run it into small castings of thin sections, producing sharp and well defined castings.

Melting

The metal should be melted in a quick fire and not exposed to contact with the flame any more than necessary. Keep well covered with a gasless flux, such as ordinary bottle glas. The use of charcoal as a cover should be avoided. Always have enough molds prepared in advance to insure taking the metal from the furnace as soon as the proper temperature is reached. The metal should not be allowed to remain in the furnace too long after reaching the pouring temperature.

Melt with the least possible disturbance.

Avoid excessive stirring or puddling during the melting, as this is not necessary and tends to disturb the protecting cover and may cause gas pockets in the castings as a result of contamination of the metal by furnace gases. When stirring is necessary, it is better to use a graphite stirrer. Iron stirring rods are liable to introduce iron and injure the metal for certain uses.

Molding, Gating, Pouring

Molds for heavy castings should be prepared carefully, as any agitation of the metal by wet or hard sand, improperly vented cores and molds or pouring the metal too rapidly, will cause a drossy and dirty condition.

The casting may be made in a similar manner to high-grade phosphor bronze or gun metal castings, but careful attention should always be paid to the gating. For some castings, a good method is to pour through a strainer gate that can be choked quickly. When risers are on the side of the casting, cut the sprue leading from the strainer considerably larger than the combined area of the holes in the strainer. This will prevent the metal from squirting into the mold, which would defeat the desired object of having the metal flow quietly.

Where it is possible, pour from the bottom, always remembering to reduce the pressure between the strainer and the casting. These alloys require a little more generous treatment as to risers than red brass alloys, but experience will demonstrate that an excessive number of risers is not required.

Some foundry men prefer to use a by-pass and runner in pouring these alloys. The by-pass is placed in the drag of the mould and cut deeper than the runner. The runner may be placed entirely in the cope or at the parting of the flask, half in the drag and half in the cope.

The by-pass checks the velocity of the metal and being cut deep, acts as a strainer, insuring clean metal entering the runner. The sprues from the runner to the mold proper are cut either at right angles or staggered back. This acts as a further check to the velocity of the metal and assures its flowing into the mold with the least possible disturbance. It is desirable to have the metal enter the mold as quietly as manganese bronze.

When the character of the casting permits, it is requently advantageous to pour under pressure in order to avoid shrinkage and the resulting porosity, rather than to feed the shrinkage of the metal by using heavy risers.

In making patterns, allow for same shrinkage as for brass. Shrinkage 3/16 inch per foot.

Pouring Temperature

The metal should not be poured at a higher temperature than is necessary for it to run satisfactorily, as castings poured at too high a temperature are subject to porosity due to shrinkage. The metal flows very freely and no trouble is experienced in running thin sections. Heavy castings should be poured at lower temperature than smaller or lighter castings. For the average run of castings the best results have been obtained by pouring at temperatures of from 1960° to 2050°F (1071° to 1121°C). Some castings may require a pouring temperature slightly above 2100°F (1149°C) in order to have the metal run properly in the mold. Pour the metal as slowly as is consistent with the run of the castings to be made, especially in the case of large castings. The slower the metal is poured, the less will be the possibility of scruff.

Remelting Scrap

In routine foundry practice it is necessary to remelt gates and risers from previous castings. The scrap from this source, if entirely free from foreign scrap, can be added in the usual amounts to furnace charges without detriment to the castings produced.[1]

Copper-Silicon-Manganese Bronze Pipes and Tubes

They are supplied in the form of seamless cold drawn pipe and tubes in all sizes up to 6 inches in diameter and in lengths up to 20 feet depending on diameter and gauge required.

The tubes can be bent, flanged, flattened threaded and otherwise worked into the usual forms required.

Under identical conditions of test the comparative resistance offered by these tubes to fatigue by vibration was as follows:

Annealed -- 350% more resistant than annealed brass
Annealed -- 252% more resistant than annealed copper
Annealed -- 237% more resistant than annealed aluminum[2]

The following tables show in general the range of these alloys in various forms:

	Tensile Strength, lbs. per sq. in.	Elong. % in 2	BHN
Green Sand Castings	55,000-62,000	22-28	103-107
Hot Forging	60,000-65,000	45-65	---
Rolled Sheet	65,000-92,000	8-38	175
Annealed Sheet (.385 Ga.)	53,700	84	69
Drawn Wire (.120 Dia.)	148,000	46	---
Drawn Tubing (15/16 to 2 O.D.)	63,000/87,000	27-67	92-170
Cold Drawn Rod (1/4 dia.)	101,800	67	189[15]

Tests as Made on Test Bar Cast to Size by Frankford Arsenal

Type	No.	T.S.	El.% in 2	Brinell (500-10)	Rockwell "B" Scale 1/16" Ball
As cast	1	61,850	27.5	107	54.5
To size	2	62,850	28.5	107	57
Machined	1	41,350	7.5	116	55.5
	2	43,500	8.5	116	54[15]

3. Physical Properties. --

Melting Point 1,019 Deg. C (1867 Deg. F)

Density, grams per cm^3, Wrought 8.539 Cast 8.15

Sheet	Soft	Hot Rolled (Tank Stock)	Hard Rolled
T.S.	50,000	55,000-65,000	85,000
Y.P.	20,000	27,500-32,500	65,000
El.in 2 in per cent	50	30-40 in 8	6

Hard Rod

Diameter	Up to 1	Over 1 to 1½	Over 1½ to 3
T.S. lbs. per sq.in.	90,000	80,000	70,000
Y.P. lbs. per sq.in.	65,000	60,000	50,000
El. in 2.,per cent	15 5	25	25

Wire	Soft	Med. Hard	Hard	Spring
T.S. lbs. per sq.in.	50,000	90,000	120,000	145,000
Y.P. lbs. per sq.in.	20,000	60,000	80,000	95,000
El.in 10 inches per cent	50	4	2	1

	Hard Tube	Cast Ingot	
Outside diameter	Up to 2 in.	Size tested dia.,in.	0.722
T.S.lbs.per sq.in.	80,000		50,000
Y.P.lbs.per sq.in.	65,000		25,000
El.in 2 in.per cent	15		15

Hot Rolled Copper-Silicon-Manganese Bronze Tank Plate

T.S. = 55000-65000

Y.P. = 27500-32500

El.in 8 30-40%

Cold drawn seamless shells (Copper-silicon-manganese bronze)

T.S. = 80000-85000

Y.P. = 65000-70000

El. 2 = 20%

Tank Construction

Hot rolled tank plates can be furnished in widths up to 160 inches x 300 inches and in thicknesses of from .032 to 1 inch.

Cold drawn seamless shells of this metal, with the head left in are available in diameters up to 26 inches and 60 inches in length.

Comparative Physical Data

Hot rolled alloy tank plates with the physical properties for steel boiler plates as specified in the A.S.M.E. Code and cold rolled annealed copper plate.

Tank Plate	Tensile Strength, lbs.per sq.in.	Yield Point, lbs.per sq.in.	Elongation in 8 inches
Copper-Silicon-Manganese Bronze	55,000-65,000	27,500-32,500	30-40%
Steel	55,000-65,000	27,500-32,500	25% (min.)
Copper	30,000-31,000	10,000-12,000	30-35% [7]

Tensile Strength of 3/8-inch dia. Rod (Light Tempered) at Elev. Temperatures

Temperature Deg. F	Ultimate lbs.per sq.in.	Elong. in 2 in. Gauge Length %	Reduction of Area %
80	72,650	43.5	51.0
500	60,200	33.0	67.4
750	35,930	25.5	69.4
1,000	14,480	18.0	71.4

This alloy is non-magnetic	
Weight wrought, lbs. per cubic inch	0.308
Weight cast lbs. per cubic inch	.294
Thermal conductivity, B.T.U. per sq.ft. per hour 1 ft. thickness, per 1 deg.F	19
Electrical resistivity ohms per cir mil-foot at 20 degrees C (annealed)	155
Coefficient of linear expansion per deg. C	0.0000170
Coefficient of linear expansion per deg. F	0.0000095
Modulus of elasticity	15,000,000

*Yield point is taken as the load producing an extension under stress of 0.75%

NOTE:- The above values are not actual tests, but the minimum values that may be expected in practice.

Comparative Physical Constants

Thermal Conductivity Per 1°F

Temperature Difference	B.T.U. Sq. Ft. Hr. 1 Ft. Thickness
Copper	220
Copper-Silicon-Manganese Bronze	19
Brass (65 copper-35 zinc)	70
Iron (wrought)	34.9
Nickel	34.4
Steel	26
Lead	20

Electrical Conductivity

(International Annealed Copper Std. at 20 C)

Copper (Annealed)	100%
Copper-Silicon-Manganese Bronze	
Annealed	6.7%
Hard Drawn	6.2%
Aluminum	60.5%
Nickel	12.6%
Iron	7.8%

Electrical Resistivity (Ohms per Cir.Mil-foot at 20°C)	
Copper (annealed)	10.37
Copper-Silicon-Manganese Bronze (annealed)	155
hard drawn	167
Nickel (Pure)	70
Constantan	296
Nichrome	660
Nickel Silver	190
Steel, Soft	80

Coefficient of Linear Expan. (Pes 1°C at 25-100°C)	
Copper	0.0000168
Copper-Silicon-Manganese Bronze	0.0000170
Nickel	0.0000127
Steel	0.0000121
Iron Wrought	0.0000116

N.B. Except in the case of the bronze and copper, the above data are taken from Engineering Hand Book. Tables and the figures should be regarded as approximate.[5]

Tests of Copper-Silicon-Manganese Bronze at Watertown Arsenal Received from American Brass Company

On two samples, consisting of one 1. diameter rod and one 3. diameter rod the following results were obtained.

Original Size Dia.	Size Tested Dia.	Proportional Limit Lbs. per sq.in.	Yield Point Lbs. per sq.in	Tensile Strength Lbs. per sq.in	Elong. in 2 %	Reduction of Area %	Brinell and Rockwell Hardness	Test Piece Mark
1	.505	28000	76000	92500	17.5	59.8	Brinell 185 Rockwell B93	E1-1
1	.505	33000	79000	93500	17.5	59.8		E1-2
1	.505	38000	80500	91500	19.5	62.9		E1-3
3	.505	32000	63500	77500	25.0	69.2	Brinell 140 at center to 200 at edge. Rockwell B65 at center to B90 at edge	E3-O-1
*3	.505	12000	39000	50500	8.5	34.0		E3-C-1
**3	.252	40000	56000	68000	26.0	54.6		E-1-T
**3	.252	38000	51400	64000	--	37.2		E-2-T

Brinell 1000Kg. Load **Transverse tests

Rockwell 100 Kg. Load

*Test piece taken from center of bar

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Charpy Tests (Std.tensile notched impact specimen)

Mark	Charpy Ft.Lbs.	
E1-1	33.3	Taken from 1. dia. bar
E1-2	29.5	Taken from 1. dia. bar
E1-3	30.9	Taken from 1. dia. bar
E1-4	32.5	Taken from 1. dia. bar
E3-1	33.0	Taken from 3. dia. bar
E3-2	34.2	Taken from 3. dia. bar
E3-3	34.4	Taken from 3. dia. bar
E3-4	31.2	Taken from 3. dia. bar
E-1-T	24.2	Taken from 3. dia. bar; Transverse
E-2-T	7.0	Taken from 3. dia. bar; Transverse
E-3-T	25.3	Taken from 3. dia. bar; Transverse

Chemical Composition of Rods Tested

Chem.	E1 1. Rods	E3 3. Rods
Cu	95.75	95.60
Si	3.02	3.10
Mn	.88	.88
Fe	.35	.42

Tests Made by American Brass Company

These tests were made on samples retained from the shipment made to Watertown Arsenal for testing purposes. Note difference in results obtained which may be due in part to method and details of the test.

Original Size Diam.	Size Tested Diam.	Yield Point lbs. per sq.in. .75 Div.	Tensile Strength lbs. per sq.in.	Reduction of Area %	Elong. in 2 in. %	Brinell Hardness No. 1000 Kg.	Rockwell Hardness 100 Kg.
1	.880	73300	104300	58.7	18	208	B101
3	1.095	54100	71700	64.1	44	185	B94

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Physical Tests of Copper-Silicon-Manganese Bronze
(Copper 96%, Silicon 3%, Manganese 1%) approx.

Fabricated Forms	Size Inch	*Yield Point Lbs. per sq.in.	Tensile Strength Lbs. per sq.in.	Elong. in 2 in. %	Reduction of Area %	Brinell Hardness No.
Rods Cold Drawn	1/4	83,200	101800	15.5	67	189
	1/2	80,000	98700	18.8	57.5	183
	3/4	73,000	92800	28.0	68.0	177
	1	76,000	96400	20.5	44.0	179
	1 1/4	69,800	96600	35.5	67.0	180
	1 1/2	63,200	80300	36.0	55.0	162
	2	56,500	71800	42.0	56.0	141
Rods, Soft	1/2	14,800	54300	87.5	83.0	60
	2 3/16	24,700	56100	81.0	75.0	87
Tubes, Hard	15/16 O.D.	77,400	87600	26.0	45.0	170
	1.O.D.	25,100	62900	67.0	60.0	90
	2 3/8 O.D.	29,300	65200	67.0	48.0	92
Tubes, Soft	1.O.D.	18,100	54600	59.5	63.0	71
	2.O.D.	14,100	52800	92.0	66.0	59
Sheet, Hard	.188	75,000	91500	21.0	47.0	** 175
Soft	.385	20,700	53700	84.0	69.0	** 69
Sheet ¼ Hard	.040	50,300	65630	38.0	63.0	** 77
½ Hard	.042	58,330	69730	32.0	56.0	** 86
Hard	.041	87,500	92870	8.3	41.0	** 95
Extra Hard	.041	[illegible]	103870	5.5	33.0	** 97
Spring	.042	97,400	109330	4.3	33.0	** 99

2

*Yield Point taken as the load producing an extension under stress of 0.75%.
**Rockwell Hardness "B" scale, 1/16 in. Ball 100 Kg. Load.

Physical Tests of Copper-silicon-manganese Bronze (Copper 96%, Silicon 3%, Manganese 1%) Approx.

Fabricated Forms	Size Inch	*Yield Point, Lbs.per sq. in.	Tensile Strength, Lbs. per sq. inch	Elongation in 10 inches %	Reduction of Area %	Conductivity I.A.C.S. %
Wire, Soft	.367	25,000	58,800	49.7	---	6.7
1/2 Hard	.288	65,000	99,800	3.6	---	---
Hard	.230	85,000	125,170	2.4	---	6.2
Extra Hard	.184	92,000	142,100	1.2	---	---
Spring	.123	95,000	148,550	4.6	---	Brinell Hardness
Hot Press	.244	49,000	77,450	49.5 △	66.0	124
	.370	51,020	67,100	57.0 △	55.0	96
Cast Ingots	.722	30,500	55,810	22.5 ∅	22.6	103

*Yield Point taken as the load producing an extension under stress of 0.75%

△ Elongation in 1 inch %

∅ Elongation in 2 inches %

Comparison of Standard Bolt Material tables No. 25 and 26, page 715, Mark's Mechanical Engineering Hand Book, 1924 Edition with Copper-Silicon-Manganese Bronze Bolts.

Material For Bolts

Class	Material	Treatment	Min. T.S. lbs. per sq. in.	Min. Elastic Limit lbs. per sq. in.	Min. Elong. in 2 in. %	Maximum Percentage of		Cold Bend About an Inner Diameter of
						Phos-phorus	Sulphur	
High Grade	Open Hearth Nickel Steel	Anneal and Oil Temper	95,000	65,000	21	.06	0.04	1 in. through 180 degrees
A	Open Hearth Nickel or Carbon Steel	Anneal; Oil Tempering Optional	80,000	50,000	25	.06	0.04	1 in. through 180 degrees
B	Open Hearth Carbon Steel	Anneal	60,000	30,000	30	.06	0.04	1/2 in. through 180 degrees
C	Copper-Silicon-Manganese Bronze	Hard Drawn	80,000	60,000	25	---	----	1 in. through 180 degrees

Safe Loads for United States Standard Bolts

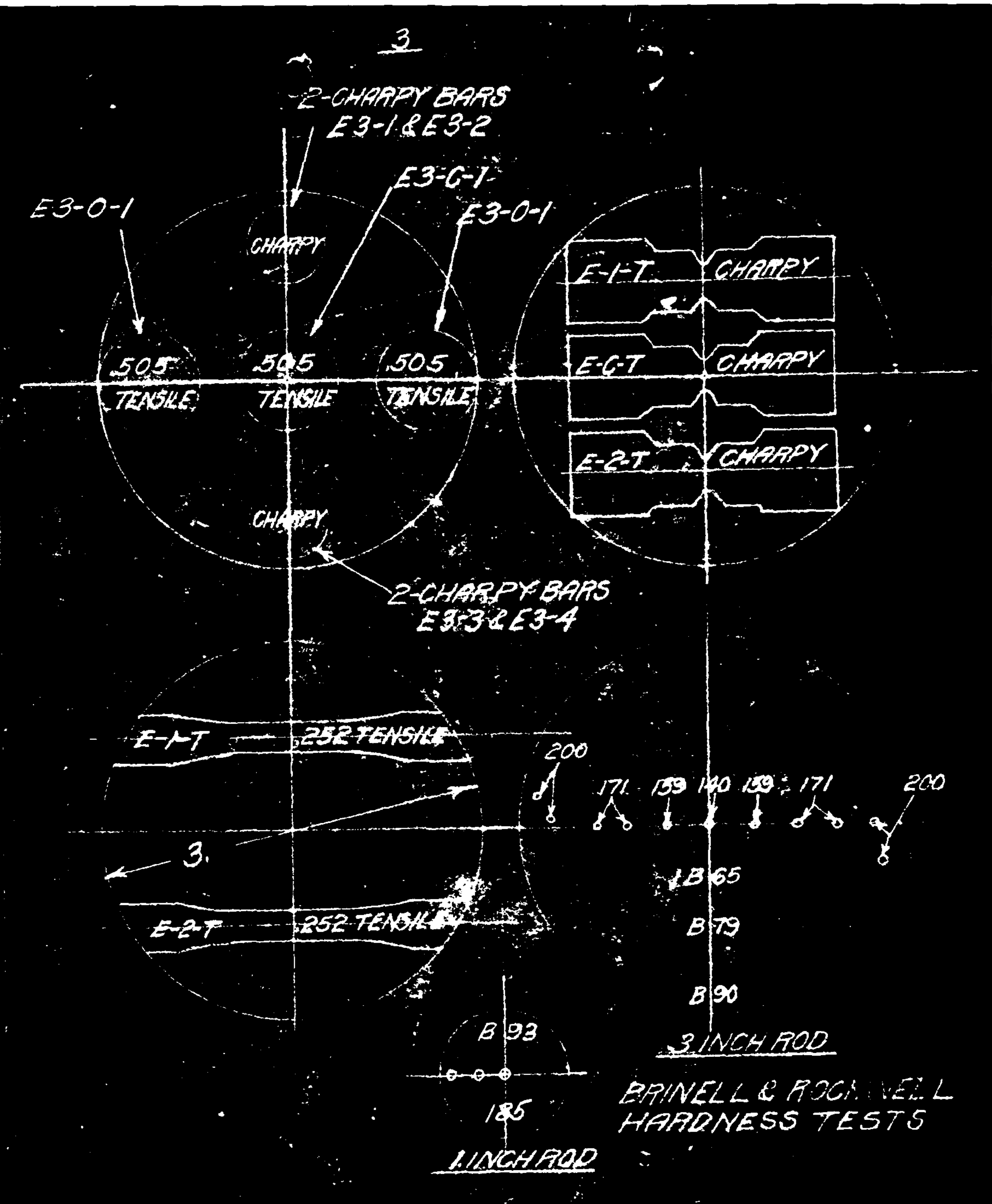
Nominal Diameter Inches	No. Threads Per Inch	Ultimate Strength, lbs. Per Square Inch							
		20,000	40,000	50,000	60,000	65,000	80,000	95,000	80,000
		Alloy Cu 88% Sn 10% Zn 2%	Phosphor Bronze	Wrought Iron and Best Rolled Bronze	Class B Bolt Material	Class A Bolt Material	Class A No. 1 & 2 Mach. Forgings	High Grade Mach. Forgings	Copper-Silicon-Manganese Bronze
1/4	20	57	115	143	172	186	229	272	229
5/16	18	99	198	247	297	322	396	470	396
3/8	16	150	301	376	451	488	601	714	601
7/16	14	207	415	519	623	675	830	986	830
1/2	13	282	564	704	845	915	1,125	1,340	1,125
9/16	12	365	730	912	1,095	1,186	1,460	1,730	1,460
5/8	11	456	913	1,140	1,370	1,480	1,820	2,170	1,820
3/4	10	690	1,380	1,725	2,070	2,240	2,760	3,280	2,760

Bronze Castings - Spec. 57-70D

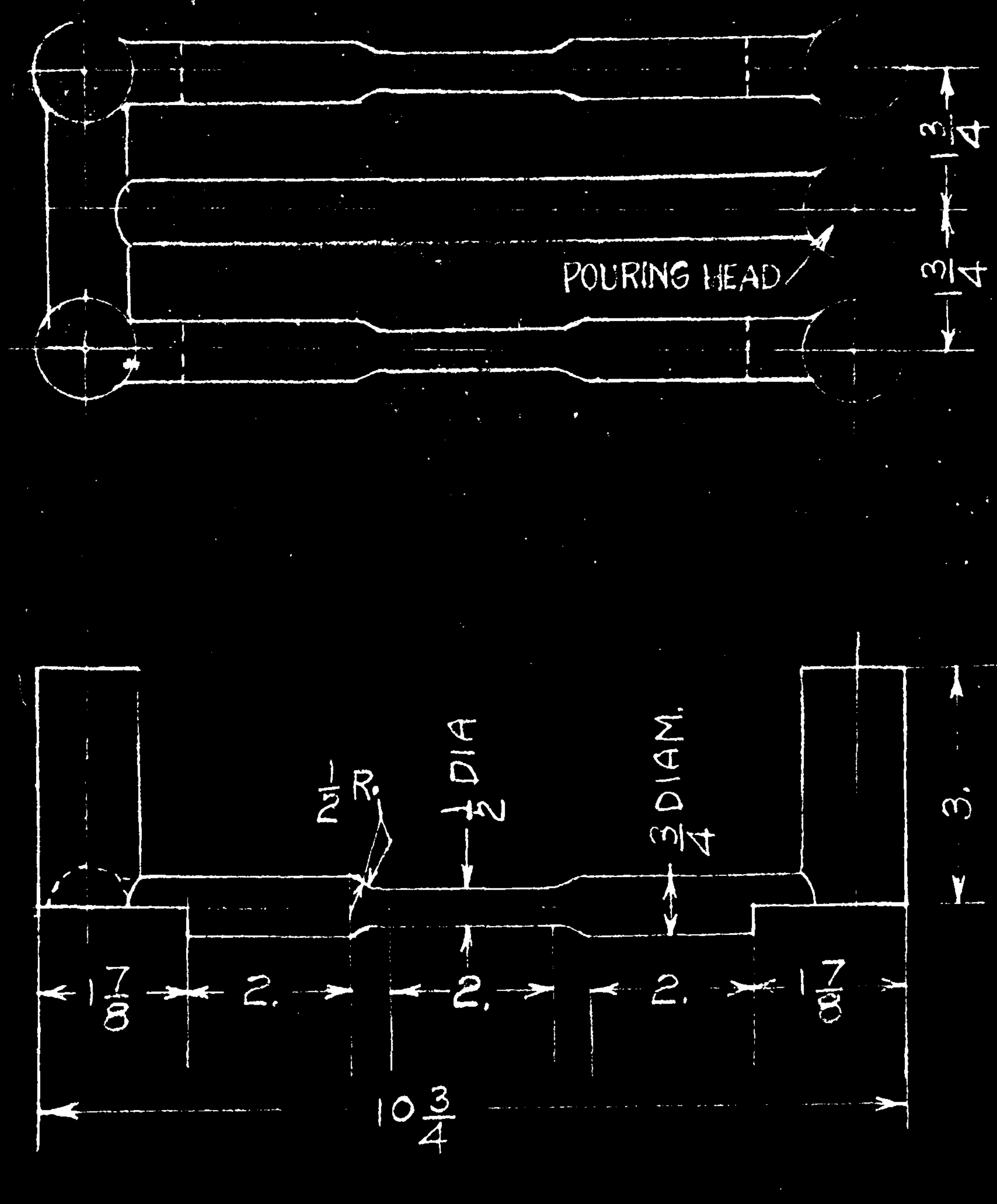
For which Copper-Silicon-Manganese Bronze may be used to obtain similar physical properties and without considering resistance to wear and corrosion

No.	Tensile Strength, Lbs. per Sq. In.	Elongation in 2 Inches -- Minimum	Brinell Hardness Number -- Min.
1	32,000	17%	
2	27,000	15	
3	28,000	15	
4	25,000	12	
5	40,000	20	
6	35,000	18	
7			
8	25,000	8	
9	30,000	1.0-8.0	
10	45,000		160
11	45,000	10	

No. 11 is a copper-silicon-manganese bronze. See Spec. 57-70D for complete specifications and chemical composition of above bronzes.[15] See F.A. Report No. 12, pages 39 to 43, inclusive, for actual analysis and tests run on Ordnance bronzes as in Spec. No. 57-70D.



LOCATION FROM WHICH TEST SPECIMENS WERE TAKEN, FROM THE 3 INCH ROD FURNISH BY THE AMERICAN BRASS CO. AND TESTED BY WATERTOWN ARSENAL.



CAST-TO-SIZE TEST BAR

Table of Weights

Copper-Silicon-Manganese Bronze
Plates and Sheets, U.S. Std. Gauge

(Copper 96%, Silicon 3%, Manganese 1%) Approx.

Size		Pounds Per
Gauge	Inches	Square Foot
0,000,000	.500	22.032
000	.375	16.524
0	.313	13.792
3	.250	11.016
4	.234	10.311
5	.219	9.650
6	.203	8.945
7	.188	8.284
8	.172	7.579
9	.156	6.874
10	.141	6.213
11	.125	5.508
12	.109	4.803
13	.094	4.142
14	.078	3.437
15	.070	3.084
16	.063	2.776
18	.050	2.203
19	.044	1.939
20	.038	1.674
21	.034	1.498
22	.031	1.366
23	.028	1.234
24	.025	1.102
25	.022	0.969
26	.019	0.837

Table of Weights (Cont'd.)

Copper-Silicon-Manganese Bronze Wire

(Copper 96%, Silicon 3%, Manganese 1%) Approx.

Size		Pounds Per Linear Foot
Gauge	Inches	
9/16	.5625	.9125
7/16	.4375	.5519
3/8	.375	.4054
5/16	.3125	.2816
1/4	.25	.1803
8	.1285	.04759
9	.1144	.03775
10	.1019	.029945
11	.0907	.023747
12	.0808	.018894
13	.0720	.014934
14	.0641	.011842
16	.0508	.007447
18	.0403	.004685
20	.0320	.002949
22	.0254	.001853
24	.0201	.001165
26	.0159	.000733
30	.0100	.000290

2

Copper-Silicon-Manganese Bronze Pipe -- Table of Weights

Std. Pipe Size	Standard Pipe Sizes Regular				Extra Heavy			
	Dia. Inches		Wall	Pounds Per	Dia. Inches		Wall	Pounds Per
	Outside	Inside	Inches	Linear Ft.	Outside	Inside	Inches	Linear Ft.
1/8	.405	.281	.0620	.245	.540	.294	.123	.592
1/4	.540	.375	.0825	.405				
3/8	.675	.494	.0905	.610	.675	.421	.127	.803
1/2	.840	.625	.1075	.908	.840	.542	.149	1.186
3/4	1.050	.822	.1140	1.251	1.050	.736	.157	1.618
1	1.315	1.062	.1265	1.754	1.315	.951	.182	2.579
1¼	1.660	1.368	.1460	2.550	1.660	1.272	.194	3.281
1½	1.900	1.600	.1500	3.028	1.900	1.494	.203	3.974
2	2.375	2.062	.1565	4.005	2.375	1.933	.221	5.491
2½	2.875	2.500	.1875	5.815	2.875	2.315	.280	8.382
3	3.500	3.062	.2190	8.289	3.500	2,892	.304	11.308
3½	4.000	3.500	.2500	10.815	4.000	3.358	.321	13.625
4	4.500	4.000	.2500	12.257	4.500	3.818	.341	16.361

2

(Copper 96%, Silicon 3%, Manganese 1% approx.

Copper-Silicon-Manganese Bronze Hexagons

Table of Weights

Diameter Across Flat	Pounds Per Linear Foot	Diameter Across Flat	Pounds Per Linear Foot
1/4	.1986	1	3.180
5/16	.3107	1¼	4.969
3/8	.4471	1½	7.155
1/2	.7950	1 3/4	9.739
5/8	1.242	2	12.720
3/4	1.789		

(Copper 96%, Silicon 3%, Manganese 1%) Approx. [2]

Copper-Silicon-Manganese Bronze

Table of Weights

Rounds

Diameter Inches	Pounds Per Linear Ft.	Diameter Inches	Pounds Per Linear Ft.
1/16	.01138	3/4	1.622
1/8	.04517	7/8	2.208
3/16	.1013	1	2.884
1/4	.1803	1 1/4	4.506
5/16	.2816	1 1/2	6.489
3/8	.4054	1 3/4	8.832
7/16	.5519	2	11.536
1/2	.7212	2 1/4	14.600
9/16	.9125	2 1/2	18.025
5/8	1.127	2 3/4	21.810
11/16	1.363		

(Copper 96%, Silicon 3%, Manganese 1%) Approx. [2]

Rectangulars

Width	1	2	3	4	6
Thickness		Pounds	Per Linear Foot		
1/4	.918	1.836	2.754	3.672	5.508
3/8	1.377	2.754	4.131	5.508	8.262
1/2	1.836	3.672	5.508	7.344	11.016
3/4	2.754	5.508	8.262	11.016	16.524
1	3.672	7.344	11.016	14.688	22.032

(Copper 96%, Silicon 3%, Manganese 1%) Approx. [2]

4. Corrosion Resistance. --

Copper-Silicon-Manganese Bronze

This alloy offers good corrosion resistance to such agents as:-

Sulphuric acid	- Cold up to 95%. Hot up to 50% in the absence of oxidizing agents.
Alum solutions	- All strengths hot or cold.
Alkaline sulphates	- Neutral or acid - hot or cold.
Zinc sulphate	- All strengths hot or cold.
Copper sulphates	- Neutral or acidified - cold.
Hydrobromic acid	- Cold up to 6% hot.
Hydrochloric acid	- All strengths - cold in the absence of air - hot up to 20% at 70°C in the absence of steam and air.
Brine solution	- All strengths hot or cold neutral or acidified with hydrocloric acid.
Sea water	- Hot or cold.
Sulphite solution	- Hot or cold as used in sulphite pulp mills.
Dry chlorine	- Cold.
Calcium chloride	- All strengths hot or cold. [12]

Zinc chloric	- All strengths up to 70°Be hot or cold.
Hydrofluoric acid	- Up to 18% cold.
Oxalic acid	- Cold and in saturated solution at 100°C
Phosphoric acid	- Up to 50 Be hot or cold (Not recommended for crude acid at boiling point)
Corrosive industrial and natural waters	
Citric and Tartaric acids	- Hot or cold
Latic acid edible or dark	- Hot or cold [12]

This alloy is not recommended for service in:-

Nitric Acid
Aqua Ammonia
Ferric Chloride - Hot
Hydrogen Sulphides
Ferric Sulphate - Hot
Aniline Hydrochloride
Crude Phosphoric Acid - At boiling point
Hydrochloric Acid - Mixed with excess of steam and air
Mixtures of Chromic and Sulphuric Acid [1]
Mixtures of Bichromates and Sulphuric Acid

Sulphuric Acid Test

-- 2 1/2% Sulphuric Acid --

Temperature	Length of Test	Est. Penetration Inches Per Year
C	Hours	
25	37	0.01
-- 10% Sulphuric Acid --		
60	96	0.5

Specimens were immersed 1 1/2 minutes and exposed to the air 1 1/2 minutes this cycle being repeated for various lengths of time.[14]

Copper-manganese-silicon alloys were prepared containing from 0.5 to 4.0% silicon with manganese content approximately three times that of silicon. These were drawn into wire 0.183 inch in diameter and corrosion tests in both hard and annealed (1/2 hour at 750°C followed by air cooling) conditions, were carried out in solution of 10% hydrochloric acid at room temperature and 10% sulphuric acid at 60°C. The specimens were raised and lowered so that immersion period of 1 1/2 minutes was followed by 1 1/2 minutes in air; the process being repeated for 216 hours. Both loss in weight and loss in tensile strength were measured. Addition of silicon up to 1% materially increases the resistance to corrosion but further additions confer little additional benefit. With two silicon hard drawn wires are more corroded than annealed wires, but with smaller amounts of silicon the difference is much less. With hard drawn wires the corrodibility becomes greater as the silicon content increases from 3 to 4 per cent, but this is not so for annealed wires.[26]

5. Wear and Fatigue, Micrograph Properties. -- Wear

With regard to wear resistance, laboratory and service tests have shown that these alloys exhibit good resistance to abrasion against steel -- for instance a steel shaft in a copper-silicon-manganese bearing. This allowance shows good abrasion resistance in contact with bronzes at low speeds and with good lubrication but is not recommended for higher speeds against bronze.[12] It should not be used for gears.[15]

Fatigue

An outstanding feature of this alloy is its resistance to failure by fatigue.

The Naval Aircraft Factory at Philadelphia has tested tubes of this composition to determine their suitability for aircraft fuel lines in a vibration machine designed for such tests. These tests were carried out with fibre stresses ranging from 9,000 to 30,000 pounds per square inch. The tubes showed average life seven times that of copper tubes.[12]

In the soft annealed state the fatigue limit rolled or drawn at 200,000,000 cycles is 25,000 pounds per square inch. That is, if the material is not stressed more than 25,000 pounds per square inch, it will withstand 200,000,000 or more reversals before fracturing under this load. When finished hard the fatigue limit approaches 30,000 pounds per square inch. The fatigue limit of rolled or drawn Tobin Bronze and Manganese Bronze in the annealed state is approximately 18,000 pounds per square inch.[2]

See Section 3 under "Pipe and Tubes" for comparative resistance of tubes to fatigue.

Some of the special manganese-silicon-copper alloys which have good static properties are disappointing in their endurance properties. The silicide alloys that are given high tensile strength by a precipitation-hardening heat treatment are prone to have a low endurance ratio so that their endurance limits lie pretty much in the same range as those of the ordinary brasses. On account of their high copper content, they may be good under corrosion-fatigue, but data on this, as well as on notched endurance tests and on cast alloys of this type, are lacking.

However, preliminary reports state that a copper beryllium alloy of about 2 1/2 per cent Be, given a precipitation hardening treatment, has the unusual tensile strength of 192,000 lbs. per square inch and stands 13 million cycles when stressed at nearly 100,000 pounds per square inch, while in a comparable test, phosphor bronze broke in less than half a million cycles at 57,000 pounds per square inch. It is also claimed that such an alloy stood 25 million cycles without failure at a stress at which a phosphor bronze spring alloy failed in .4 million cycles. Also in comparison with a standard spring steel which failed a certain stress in two million cycles, the Cu-Be alloy had not failed at three million.

Indications are that the Cu-Be alloy may not be sensitive to the notch effect, since that in the case of the spring-plate material repeated bend tests have indicated that any deleterious effect of the surface on "as rolled" plates, is small. It would seem probable that the Cu-Be alloys will be found capable of being given the highest endurance limits of any known copper-base alloy. Their high copper content should give them good corrosion-fatigue properties, though this, of course, needs experimental verification.[25]

6. Welding Characteristics. -- These alloys possess good welding characteristics and are readily welded by the oxy-acetylene metal or carbon arc and resistance methods. By using the alloy as a filler rod for oxy-acetylene or carbon arc welding and for electrodes for metal arc welding, all the types of welded joints usually made in steel can be made in these alloys with the same favorable comparison between the strength of the weld and that of the parent metal.

The sheet metal is also adaptable for continuous seam welding or spot welding on automatic welding machines. Sheets from .010 thick to .125 thick can be seam welded at approximately the same speeds as those obtained when welding steel sheets of the same thickness.

The alloy welding rods show good penetration when used on steel and for this reason it is possible to weld

Special High-Copper Alloys 25

Static												Endurance				
Composition																
Cu	Ni	Si	Zn	Mn	Te	Be	Condition	Tensile Strength Lbs. per Square Inch	Elong. %	Red. Area %	Rockwell B	Stress For Million Cycles Lbs. per Sq. in.	Endurance Limit Lbs. per Square Inch	No. Cycles Millions	Endurance Ratio	Surface Condition
96.4				3.6			Annealed	40,000					17,000	10	.42	Axial loading Haigh Mach.
95.96	3.27	.82					Heat Treated Final 800°F 2 hrs.	122,500	6	12			25,000		.20	
87.22	2.52	.57	9.89				Heat Treated	90,000	14		86	17,000	14,000	100	.16	
77.17	[illegible]	.57	19.89				1470°F Water then 930°F 1 hr. draw	86,000	21½		85	16,000	12,500	100	.15	
[illegible].90	[illegible]	.66	30.12				(750°F 1 hr. draw)	85,500	28		79	26,000	16,000	100	.19	
96.00		3.00		1.0			Spring Temper	80,000	22		91	32,000	24,000	100	.30	
96.00		3.00		1.0			8 Nos. Hard	90,000	5				23,500	100	.26	
95.71		3.92		.98	.22		Somewhat Cold Worked	67,000	49			27,000	24,000	100	.36	Polished inside & out
95.71		3.92		.98	.22		Somewhat Cold Worked	67,000	49				18,000	100	.29	Comm. Finish
95.71		3.92		.98	.22		Annealed	52,000	52½			17,000	11,000	100	.21	"
94.95			4.11	.86	.08		Cold Worked	45,000	45½		107	19,000	14,000	100	.[illegible]9	Extra Smooth [illegible]

Special High-Copper Alloys 25

Static | Endurance

tion					Tensile Strength Lbs. per Square Inch	Elong. %	Red. Area %	Rockwell B	Stress For Million Cycles Lbs. per Sq. in.	Endurance Limit Lbs. per Square Inch	No. Cycles Millions	Endurance Ratio	Surface Condition	Form of Material
Zn	Mn	Te	Be	Condition										
	3.6			Annealed	40,000					17,000	10	.42	Axial loading Haigh Mach.	
				Heat Treated Final 800°F 2 hrs.	122,500	6	12			25,000		.20		
9.89				Heat Treated	90,000	14		86	17,000	14,000	100	.16		No.24 B&S .02 thick
19.89				1470°F Water then 930°F 1 hr. draw	86,000	21½		85	16,000	12,500	100	.15		"
30.12				(750°F 1 hr. draw)	35,500	28		79	26,000	16,000	100	.19		"
	1.0			Spring Temper	80,000	22		91	32,000	24,000	100	.30		"
	1.0			8 Nos. Hard	90,000	5				23,500	100	.26		"
	.98	.22		Somewhat Cold Worked	67,000	49			27,000	24,000	100	.36	Polished inside & out	Tubing 3/8" O.D. .05 thick
	.98	.22		Somewhat Cold Worked	67,000	49				18,000	100	.29	Comm. Finish	"
	.98	.22		Annealed	52,000	52½			17,000	11,000	100	.21	"	"
4.11	.80	.08		Cold Worked	45,000	45½		107	19,000	13,000	100	.29	Extra Smooth Outside	"

Special High-Copper Alloys (Cont.) 25

Composition							Condition	Tensile Strength Lbs. per Square Inch	Elong. %	Red. Area %	Rockwell B	Stress For Million Cycles Lbs. per Sq. In.	Endurance Limit Lbs. per Square Inch	No. Cycles Millions	Endurance Ratio	Surface Condition
Cu	Ni	Si	Zn	Mn	Te	Be										
94.95			4.11	.86	.08		Cold Worked	42,500	52½		103	17,000	10,000	100	.24	Comm. finish
97.4						2.6	Heat treated quenched, rolled annealed, cold stretched, then tempered 1 hr. at 660°F	192,000	3/4		Br. 375		99,500	16	.52	

Special High-Copper Alloys (Cont.) 25

Composition Ni	Si	Zn	Mn	Te	Be	Condition	Tensile Strength Lbs. per Square Inch	Elong. %	Red. Area %	Rockwell B	Stress For Million Cycles Lbs. per Sq. In.	Endurance Limit Lbs. per Square Inch	No. Cycles Millions	Endurance Ratio	Surface Condition	Form of Material
		4.11	.86	.08		Cold Worked	42,500	52½		103	17,000	10,000	100	.24	Comm. finish	Tubing 3/8" O.D. .05 thick
					2.6	Heat treated quenched, rolled annealed, cold stretched, then tempered 1 hr. at 660°F	192,000	3/4		Br. 375		99,500	16	.52		

alloy inserts in steel plates (used for the construction of electrical[4] equipment), to break the magnetic circuit and to secure oil tight joints between the steel plate and the alloy insert. With these welding rods no flux is required in tack welding thin sheets of steel and no difficulties are encountered in applying standard painted and enameled finishes over the welded surfaces. [4]

Welding Procedure

Preparation of Plates and Sheets

Plates for butt welding 1/4 or thicker should be beveled. Plates thinner than this do not require a bevel. If plates or sheets are not beveled the space left for welding should be at least equal to the thickness of the plate or sheet. Using beveled plates a space 1/16 between the plates give the best results.

Cleaning of Plates and Sheets

Plates and sheets of the hot rolled alloy should be sand blasted or pickled in 5 to 10% sulphuric acid at about 140°F to remove the black oxide (CuO), which has been found to give trouble in welding. The pickling can be done at the mill if it is known that the material is to be welded.

When plates are beveled, pickling or sand blasting is not necessary, although it is advisable to remove the black oxide adjacent to the top of the bevel with emery paper, a portable grinding wheel, or a file.

In the case of corner welds, when the sheets have not been previously cleaned, the black oxide can be removed in the same manner.[4]

Welding Rods

In oxy-acetylene or arc welding, the welding rod or electrode should be made of copper-silicon-manganese of percentages identical with material to be welded, drawn to a sufficient degree of hardness to insure uniformity of grain structure, freedom from seams and a bright clean finish.

Fluxes

A flux should be used to obtain the best results in welding these alloys. Ordinary fused borax works satisfactorily, but the best welds[4] have been obtained by using a flux composed of 90% fused borax and 10% sodium fluoride. The flux is applied by first dampening the work with water and then sprinkling on a very thin coating of flux.

Backing Bars

As a greater amount of parent metal is molten at the point of welding in the case of these alloys than in the welding of steel, a backing bar is usually needed to prevent the bottom of the weld from falling out. Copper is generally employed for this purpose, but cast iron or a large section of steel may also be used.[4]

Oxy-Acetylene Welding

If what has been said above is kept in mind, the welding of these alloys by the oxy-acetylene method requires no more skill than welding any non-ferrous metal.

The flame should be slightly oxidizing for the reason that reducing flames are likely to cause absorption of carbon monoxide by the molten metal and produce porous welds.

A flame about five inches long with a very short white tip gives uniformly good results. The length of the flame, however, must be governed to some extent by the thickness of the plates or sheets and the character of the weld.

Arc Welding

In arc welding both the metal and carbon arcs may be employed for joining the alloy to alloy or the alloy to steel.

Metal Arc Electrodes

An electrode of the same composition as the plates or sheets gives the best results, i.e., (copper-silicon-manganese welding rod). Electrodes 1/8 in diemater are usually employed for welding sheets and plates up to 1/4 inch thick; 5/32 rods for 1/4 up to 1/2 thick; 3/16 rods for plates 1/2 or thicker.

Experience has shown that the best results are obtained when the following amperage is used.[4]

90 to 100 amperes for 1/8 electrode

100 to 120 amperes for 5/32 electrode

130 to 160 amperes for 3/16 electrode

Polarity

In metal arc welding the polarity should be reversed, which is the practice followed with most non-ferrous metals.

In welding these alloys a longer arc is maintained than in welding steel. The metal should not be allowed to drop from the electrode but should cross the arc in an almost continuous stream. The welder should not pass his electrode over too long a path, but should concentrate on as small an area as possible.

In starting the weld the electrode will heat up much faster than the work, due to the reversed polarity, so that some metal will be deposited before the parent metal is sufficiently heated to obtain good fusion. If the starting point is preheated to a red heat with a small torch and the welding operation started while the parent metal is still hot, 100% fusion can be obtained.[4]

In welding an alloy, insert into a steel plate, The precaution to preheat the starting point to a red heat should be taken. The weld should be started at the pre-heated point, continued in one direction and finished over the starting point. If that starting point is not pre-heated, a small shrink crack will [4] invariably appear after cooling at that point in the weld.

Should it become necessary to stop the welding operation in order to change electrodes, there will be poor fusion if the weld is resumed at the point where the stop was made. To overcome this condition, it is advisable to resume welding about 1/2 inch back of the crater, so that by the time the crater is again reached the metal at that point will be heated sufficiently to permit the deposited metal to penetrate the parent metal.

When tack welds are necessary the points to be tacked should be pre-heated[4] as mentioned above. If semi-automatic welders are available, better results will be obtained, as the welding operation will not have to be interrupted in order to change electrodes.

Carbon Arc Welding

Satisfactory welds can also be made with the carbon arc. The suggestions given above regarding metal arc welding with respect to preparation of the work, fluxes, etc. also apply to carbon arc welding. With this method, rods of the proper diameter are used to fill the gap in the work to be welded. It is advisable to maintain as short an arc as possible. The welder after a few trials, will be able to determine the proper rate of melting to obtain a good bond between the parent metal and the filler rod. In many[4] cases the filler rod can be laid over the gap between the parts to be welded and held in place by clamps, jigs, or other similar methods. In other cases, due to the character of the work, it is necessary to apply[4] the filler rod in the same manner as employed in oxy-acetylene welding.

The welds, properly made, will show approximately from 80 to 90% of the strength of the parent metal.

Approximate tensile strength of the copper-silicon-manganese welding rods is 65,000 pounds per square inch (annealed rods).[4]

The welds, machined flush, have a tensile strength of about 85% of that of the parent metal.

With the reinforcement bead left on, the welds will equal or slightly exceed the parent metal in strength. Resistance welds on thin sheets cool so rapidly that there is practically no difference in the strength of the seam and of the sheet.[7]

A reinforcement of the order of 1/32 inch, 1/16 inch, and 3/32 inch for the 1/4, 3/8-inch and 1/2-inch sheets in the order named is all that is required to develop the full strength of the base metal. These alloys should be welded as rapidly as possible.

The reason for this is that it is desirable to keep the shrinkage stresses in the red hot metal as low as possible, and, of course the best way to avoid them is to cut the heat flow into the base metal as short as is consistant with good union.

Moreover, the most homogeneous solution the metal can have is that of its liquid state. Hence the quicker the metal is solidified, the more uniform will be the cold metal and the finer its structure. Example:- A 12-inch seam in 1/2-inch plate about 8 minutes.

Annealing of the weld confers no benefit on the connection unless the weld metal first be cold worked. The cold work exerts a marked benefit to the weld reflected in the yield point and the tensile strength. Cold working of the weld metal by severely hammering reducing larger welds by 1/16 inch followed by an anneal of approximately 650 degrees C (1200°F) dull red, improves weld in both tensile strength and ductility.[16]

The weld metal should be placed in beads approximately 1/4 inch thick, wire brished and each bead thoroughly peened with air hammer.

The annealing should be done by an oxy-acetylene torch and where seams run out to an edge, the annealing should always start from an inside point and finish at the edge. If started at the edge a crack may result due to tension at the edge when the torch is moved inwards.[16]

Brazing

This metal may be brazed and soldered in the same manner and with the same equipment used for copper and bronze. Borax or fluxes used for welding serve for brazing.

Zinc chloride and hydrochloric acid make an excellent soldering flux.

Strength and Weight Data -- Welding Rods

Dia.	1/16	3/32	1/8	5/32	3/16	1/4	5/16	3/8	Approx. T.S.Lbs. per sq. inch annealed
Weight Per Foot									65,000
	.01127	.02530	.04511	.07041	.10121	.18006	.28127	.4048	
Feet Per Pound									
	88.73	39.53	22.17	14.20	9.881	5.555	3.555	2.445	

[4]

Welded Tanks (Copper-Silicon-Manganese)

Using the carbon arc, welded joints like those shown in Figures 1, 2 and 3 gave the following results when tested for strength.

Type of Joint	Tensile Strength, Lbs.Per Sq.In.	Thickness of Metal
No. 1	60,200	0.131
No. 1	57,400	0.070
No. 2	49,300	0.067
No. 2	42,300	0.129
No. 3	57,000	0.129

(Copper 96%, Silicon 3%, Manganese 1%) Approx. [4]

FIG 1

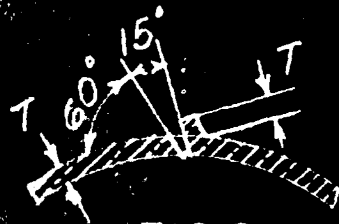
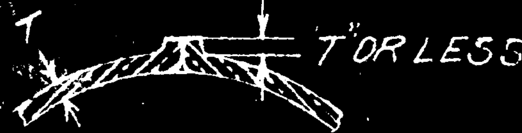


FIG. 2



BEFORE WELDING

FIG. 3

AFTER WELDING

500-Gallon Tank (Copper 96%, Silicon 3%, Manganese 1%) Approx.

The tank is eighty-four inches overall by forty-two inches in diameter. Both shell and heads are of three-eighths metal. The heads were dished and flanged. The heating unit is in the tank.

The shell was formed from a single plate in the same manner as if the material was steel. The longitudinal seam was of a single vee type.

The welding was done with a three-hundred-ampere capacity arc welder, using reversed polarity and five-thirty-seconds inch alloy welding rod of the same composition. The vee groove on the outside of the shell was filled with a single bead, the welder moving his arc in an elliptical path. This is necessary because this material flows more freely than steel and if the arc were played on the top of the molten metal, the metal would flow rapidly in front of the arc. To prevent this, the welder built up a portion of the bead, then dropped the arc into the unwelded groove and brought it back again over the top of the metal just deposited. A water-filled copper tube was used as a backing plate.

When the vee was filled, another bead was run on the inside of the seam. The outside bead was peened with an air hammer. The peening reduced the height of the bead and densified and strengthened the weld metal.

The heads were pushed inside the shell and fastened with lap welds. Beads were run around the girth seams both inside and outside. A port for the heating unit was welded to one head by a single pass.

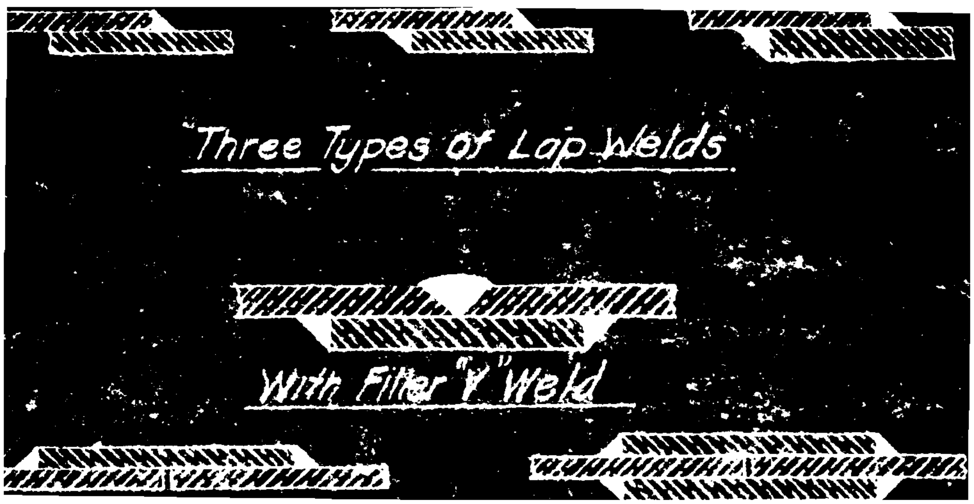
This tank was tested to three hundred pounds hydro-static pressure for a working pressure of one hundred twenty-seven pounds.

The foregoing procedure has been found to produce successful results with tanks of that capacity. Where thicker metal is used, the seams are usually built up in a series of courses, each approximately one-quarter of an inch thick. Each course is peened separately and the final course annealed with an oxy-acetylene torch. The preceeding courses are annealed by the heat of the bead laid over them. For oxy-acetylene and carbon arc welding, the procedure, of course, differs in certain essentials.

Tank Testing Methods

Among the rigid tests to which this metal has been subjected is a "breather" test which consists of a pulsating pressure in the tank from 0 to 150 pounds, thirteen times a minute. Five hundred hours of this test is considered the equivalent of 20 years' normal service.

A more severe test to which this metal has been subjected involved the application of pressure by means of a piston arrangement which variated the pressure


Three Types of Lap Welds
With Filler "V" Weld

from 0 to 300 pounds, fifty-three times per minute. Shell tanks 12 inches in diameter, 48 inches overall and made from .056 gauge metal were held on this test for 700 hours then tested to 700 pounds hydrostatic pressure without showing any signs of failure or change in shape.[17]

7. General Uses and Possible Ordnance Applications. -- The wrought forms of these alloys are sheet, rods, tubes, wire and forgings.

It is being used in the following:

Pipes.

Pipe fittings.

Pump casings and valves.

Ventilating fans.

Ducts and eliminators for storage batteries and plating rooms.

Castings for floor drains for carrying off corrosive liquids.

Acid sludge lines in oil refineries.

Fittings and stills in soap factories.

Fibre plant equipment.

Gates and screen frames for water supply reservoirs and for sewage plants.

Expansion plate for bridge work.

Motor boat shafting.

Bilge pumps.

Marine castings.

Hot water storage tanks.

Vaults.

Branding Irons.

Wood screws, nails and rivets.

Guy wires and cables.

Bolts, nuts and washers for pole line hardware and bus bar clamps.

Lining tanks.

Flashing.

Skylight Frames.

Fuel containers.

Ladder or steps in manholes.

Shovels for handling explosives or corrosive materials.

Gas fired unit flues.

Ordnance Uses

Compressor tanks (as used for 16-inch How. & Barbettes).

Piping for above tanks.

Oil tubes for lubricating.

Piping for connecting "A" and "B" units of speed gears.

Rivets and bolts, "For all types of ordnance materiel".

Springs.

Supports for batteries.

Instruments (Fire control).

Bearings. (where used for slow speeds or unimportant conditions - otherwise bushed).

(These alloys should not be used for gears)

8. Can be Advantageously Substituted for Certain Other Materials. -- These alloys can be substituted for the Ordnance Tin Bronzes as covered by Spec.No. 57-70D for castings and also for naval brass rods, bars, shapes, plates, sheets and strips as called for by Spec. No. 57-161 and Spec. No. 57-162.

9. Foreign Research (British). -- Silicon is well known as a deoxident for conductivity copper, but the aim is generally to add only just sufficient silicon (as cupro-silicon) for the complete removal of the oxygen, leaving no residual silicon in the metal, on account of its effect upon the conductivity. The presence of silicon, however, improves the mechanical properties of copper, but until recently there seems to have been little attempt on any large scale to develop the use of copper, or copper alloys, containing appreciable quantities of silicon.

In the following scheme of research, the properties of the silicon-copper alloys have been examined in the form of wire up to 1. per cent silicon, in the cast condition up to 6.5 per cent silicon, and in the form of sheet up to 5 per cent silicon; silicon-manganese copper alloys have been made containing up to 5. per cent silicon and 5. per cent manganese, and their properties investigated in the cast and rolled conditions. Corrosion and oxidation tests have been carried out on silicon-copper and silicon-manganese-copper sheet.

Mechanical Properties of Cast Silicon-Copper

Material	Silicon Copper						
Composition	Si 3.0 per cent			Si 4.5 to 4.8%			Si 6.5%
Condition	Chill Cast 5/8" bars	Chill Cast 1." bars	Chill Cast and annealed	Chill Cast 5/8" bars	Chill Cast 1." bars	Chill Cast and annealed	Chill Cast 5/8" bars
Limit of Proportionality	-	2.62	2.93	-	1.79	-	-
Yield Point ∅	7.95	6.88	5.55	12.56	11.55	-	13.15
Ultimate tensile strength ∅	16.90	14.87	14.65	19.60	18.14	16.33	14.55
Elongation per cent in 2." ∅	29.00	23.50	36.5	12.25	11.00	15.50	0.00
Reduction of area per cent	52.30	40.90	46.9	24.6	14.70	17.50	1.20
Brinell hardness	-	81.	66.	-	100	95	-

∅ = Tons per sq. inch.

The Properties of Cast Silicon-Copper Alloys

Round bars were cast vertically in chill moulds, and good tensile test results were obtained without difficulty. The silicon content ranged from 3.0 to 6.5 per cent. The castings were machined for tensile strength test, and in every case the machining qualities were excellent. Certain of the test pieces were annealed for 1-1/2 hours at 750 degrees C. to 800 degrees C to destroy the cored structure. The results are as shown in preceding table. The 4.5per cent silicon alloy is very similar in properties to Admiralty gun metal. Three per cent of silicon gives a ductile metal with considerable tensile strength.

With 4.8 per cent of silicon the tensile strength, and especially the yield point, are raised, while the ductility, though much reduced, is still fairly good; 6.5 per cent silicon completely destroys all ductility and diminishes the ultimate strength. This embrittlement is evidently due to the presence of the γ constituent. The true elastic limit is very low. Annealing has but little effect; under its influence slight strength is sacrificed to a small increase of elasticity and ductility. The 5/8" diameter bars yield slightly better figures than the 1 inch; this is probably connected with the greater rapidity of the chill. In the table will also be found figures for the Brinell hardness of the bars, obtained by the use of a 1 mm. ball under a load of 10 kg. They range from 66 to 100 Brinell.

A 5/8 inch bar containing 3 per cent of silicon cast as for tensile tests was bent through an angle of 180 degrees in the cold without showing the least sign of cracking. A small flat ingot 1/4 inch in thickness and containing 3 per cent of silicon was prepared; one end of which was subjected in the cold to repeated sledge-hammer blows until marked cracking occurred. The thickness had been reduced from 0.25 in. to 0.12 in., or 50 per cent on the original; the other end was then heated to full redness, and, in that condition, it received the same treatment.

The malleability was very much greater, the thickness

The malleability was very much greater, the thickness having been reduced to 0.04 in., or by 80 per cent, and the temperature of the metal having fallen below red-heat before cracking commenced.

<u>The Mechanical and Electrical Properties of Silicon Copper Wire containing up to 1 per cent of Silicon.</u>

A series of alloys was prepared covering a range from 0.0 per cent to 1.0 per cent silicon, and were rolled and drawn into wire. Six alloys were prepared, the percentages of silicon added being 0.1, 0.2, 0.3, 0.5, 0.7 and 1.0 per cent, respectively. Duplicate cylinder bars were cast vertically in split chill moulds 14 inches long by 1 inch in diameter, with funnel heads. The pouring temperature was about 1190 degrees C., or 8 to 10 per cent superheat. Before passing to the mills the outer skin was removed in the lathe. All the alloys turned well, but there was a distinct improvement in the machining qualities as the silicon content increased.

The first stage in breaking down the bars consisted in rolling them cold from 1 inch diameter to more or less square rod with rounded corners and about 1/4 inch across. This was performed in nine passes with perfect ease, and without any intermediate annealing, the reduction in area being about 89 per cent on the original. The alloys, even with the highest silicon content, are therefore perfectly malleable. This material already at over 89 per cent cold work, was passed through eight steel dies and finished to .05 inch diameter through a diamond die in the cold without any annealing whatsoever - a total reduction of 99.8 per cent on the original turned castings. Subsequent experiment showed that the wire could be taken to much finer gauges without fear of breakage.

Specimens of the hard rod and wire and also of the bolt after annealing for 1/2 hour at 750 degrees C., were submitted to tensile tests. The results for ultimate strength are plotted with reference to composition and cold work in which the mean of the results for the duplicate castings has been taken. The contours demonstrate in a marked manner that heavy drawing has far more effect with much than little silicon., i.e., on the left of the diagram the contours are crowded together, while on the right they are much separated and attain higher values of tensile strength. Percentage elongations, determined over a gauge length of 2 inches showed comparatively little variation with silicon content; for the hard-rolled rod they were about 9 per cent to 10 per cent, while for the same material after annealing they range from 42 per cent to 48 per cent. All the wires at their final stage of reduction passed the test of wrapping three times on and off their own diameter. In many cases, five wraps were recorded.

The electrical resistance of the wires at their final stage of reduction were determined by the bridge method. The results obtained on specimens one-hundredth of a mile in length were corrected for variations of gauge and temperature. Resistances as high as 121 ohms per mile were recorded, as compared with a standard of 21.73 ohms per mile for high-conductivity copper and 43.2 ohms per mile for telephone bronze of similar gauge. Even .076 per cent silicon (with .040 per cent iron) increases the resistance by 56 per cent.

The iron content of these alloys was rather high, especially in the case of that containing .181 per cent of silicon (.188 per cent of iron). In the hard worked condition, the iron content appears to have little effect upon the mechanical properties, but in the annealed state it increases the ultimate strength at the expense of ductility. Its pernicious influence upon the electrical conductivity is marked. It is possible to apply a rough mathematical correction for iron content on the assumption that its influence is proportional to the amount present. Curves so corrected are distinctly smoother than those of the observed data.

... TENSILE STRENGTH
... SILICON-COPPER WIRE

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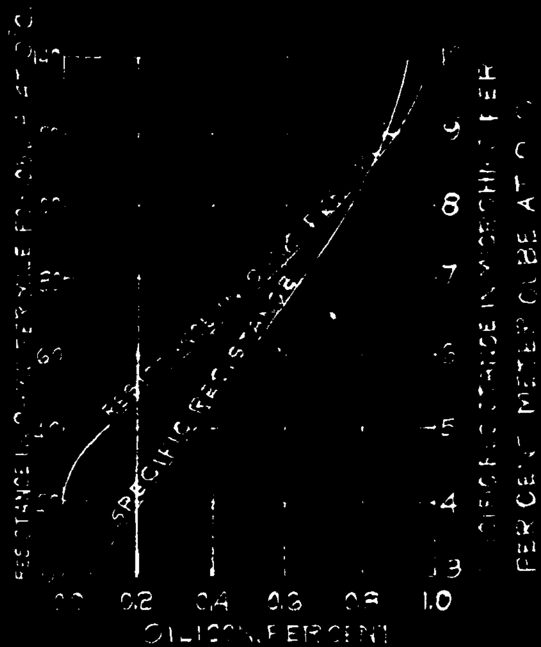

ELECTRICAL ...
... WIRE

Production and Properties of Silicon-Copper Sheet

Strip ingots 12 inches by 3 inches, each weighing 25 lbs., were cast for rolling into sheet. The ingots were of two compositions, nominally 3 per cent and 5 per cent, silicon, duplicates of these making four in all. The casting tehhnique was much the same as that already described for the round bars. One ingot for each composition was rolled hot, the other cold. Both compositions were successfully rolled hot at about 750 degrees C., a full red heat. In the cold, the 5 per cent silicon alloy cracked at the first pass, while the 3 per cent silicon rolled excellently with the following reductions, annealing being carried out between stages:-

1st pass 0.64 inch to 0.250 inch, or 61 per cent
2nd pass 0.25 inch to 0.125 inch, or 50 per cent
3rd pass 0.125 inch to 0.650 inch, or 48 per cent
4th pass 0.65 inch to 0.003 inch, or 49 per cent

A small ingot containing about 6 per cent silicon could not be rolled hot nor cold, but flew to pieces under pressure of the rolls.

At least four and, in some cases, six, specimens 4-1/2 inches by 1-1/2 inches were cut from each piece of sheet, both parallel and perpendicular to the direction of rolling, care being taken to avoid unsound patches. Half the number in each set were packed in powdered charcoal and annealed for 1/2 hour at 750 degrees C. All were then shaped into tensile test pieces. The subsequent tensile tests indicate that copper-silicon sheet possesses very special mechanical properties. The 4.58 per cent silicon alloy is considerably stronger but has less ductile than the corresponding hot-rolled alloy containing 2.51 per cent silicon. The directional properties are retained to a marked degree, even after annealing. Tensile strength up to 50 tons per square inch were recorded for the hard-rolled metal and, in one case, the elongation after annealing exceeded 80 per cent on 4 $\sqrt{area}$, with a tensile strength of 23 tons per square inch. The yield points were very indefinite, and little reliance could be placed upon the figures obtained. The Brinell hardness numbers for the sheet, as determined by a 1 mm. ball under 10 kg. load, ranged from 78 to 178.

A portion of the thinnest sheet containing 3 per cent silicon (annealed) was tested by spinning. The attempt was made to spin 3 in.diameter discs into cylindrical cups 1 inch in diameter. Owing to the unsoundness of the metal this proved a failure. The material was said to be, if anything, more easy to spin than brass, given, of course, sound metal. The cylinder could have been produced with two intermediate anneals at full red-heat, and possibly with one, which compares favorably with the practice for brass.

Though no sign of true season-cracking occurred, even in the ammoniacal atmosphere of the laboratory the spun cups responded to the mercurous-nitrate test for internal stress. By immersion in a solution containing 1 grm. of mercurous nitrate and 1 c.c. of strong nitric acid per 100 cc. of water, cracks appeared in from 3 minutes to 5 minutes. Several cups were given a low-temperature anneal at 270°C to 300°C for 1 hour, which is generally regarded as being sufficient to remove all tendency to season cracking from brass. In cups so treated, the cracks appeared after about the same period of immersion as before, but were more numerous, and the advent of each was heralded by a sharp report. However, a cup annealed for 1/2 hour at 500°C gave no indication of season-cracking. Probably a less drastic treatment than this would suffice to remove internal stress.

Silicon-Manganese-Copper Alloys

With the exception of several pamphlets emanating from American manufacturers, no published work bearing directly upon the silicon-manganese-copper alloys was found. As the result of preliminary tests upon small samples, it appeared that the most useful alloys, combining good strength and hardness with reasonable malleability, probably lie within the somewhat narrow range between 2% and 5% silicon and 0% and 5% manganese.

Alloys outside these limits are either too soft to possess any special advantages or too brittle to be of use for structural or engineering purposes. The compositions selected for study varied from each other by steps of 1.5% in both silicon and manganese content. They were: 1% manganese with 2%, 3.5%, and 5% silicon.
2.5% manganese with 2%, and 3.5% silicon.
4% manganese with 2% silicon.
The precautions taken during casting were the same as those for the plain silicon-copper alloys. All contamination by iron was rigorously avoided; stirrers were of charred wood, and skimmers of gas-retort carbon. The iron moulds, warmed, were dressed with a thin coat of graphite-grease paste, and the best pouring temperature was found to be the lowest possible. Under these conditions, two strip ingots (12 in. by 4 in. by 1/2 in) for sheet and two round bars (14 in. by 1 in. diameter) for tensile tests were successfully poured from one pot of metal for each of the six compositions defined above. Careful analysis of samples from different parts of the castings show no segregation in any one ingot. Relative high percentage of iron was present in all the castings ranging from .04 to .17%, being considerably greater than that which should have been introduced by the cupro-silicon and cupro-manganese used.

Samples taken from well within all the ingots were examined microscopically; for the most part, they appeared to be sound. The typical structure was that of a highly cored dendritic solution, but in a considerable number of samples a second constituent was visible between the dendrit while the γ was present in certain cases. The two secondary phases could be clearly distinguished; etched with ferric chloride, the γ is a bright bluish-white, while the new constituent, for convenience called X, is usually brown. It is probably composite in character.

Mechanical Properties of Silicon-Manganese-Copper Alloys.in the Cast Condition.

Each of the cast cylindrical bars was divided into two halves 7 inches long by 1 inch diameter, and machined into tensile test pieces of the recognized standard dimensions giving 1/4 sq. in. sectional area. Silicon has greater effect upon the ultimate strength than manganese. Alloys ranging between 3% and 4½% silicon possess high strength. With less silicon, the alloys are soft and of poor quality, while with more, they become increasingly brittle, owing to the presence of the γ phase. In moderation, the latter may tend to increase the ultimate strength, but it is much more probable that the high strength in the range mentioned is due to the influence of "X", for when γ is present in any quantity, the ultimate strength is lowered. Within the optimum range of silicon content, namely, 3% to 4½% silicon, increase of manganese raised the ultimate strength to a certain extent, but only at the expense of ductility. The highest ultimate strength recorded was 24.6 tons per sq. in. for the alloy containing 4.74% silicon and 3.19% manganese; its ductility, however, was low. A considerable amount of the constituent "X" was present in this alloy.

The outstanding feature of the results for percentage elongation in 2 in. is a small area of high ductility between 2½ and 4% silicon and 0 and 1½% manganese. ("Everdur": Si, 3.43%; Mn, 1.04%; and Fe, .04%) is included in this area and had the greatest elongation, 25%, of the whole series. With 5% silicon and over, practically all elongation disappears, while the alloys of relatively high manganese content are not especially ductile. The results for reduction of area are of the same general type as those for percentage elongation, except that the area of high ductility is more restricted.

After the tensile test, the grip ends of the test pieces,which were originally located at centers of the castings, were sectioned transversely and the sections used for hardness determinations. Hardness tests were likewise applied to certain of the Izod specimens prepared from the strip ingots, as described later. Brinell hardness figures were obtained by the use of a ball 1 mm. in diameter under a load of 10 Kg. applied for 15 seconds. It was noted that the values for the strip ingots were, in general, about 20 Brinell numbers higher than those for the round bars of the same compositions. The strip ingots were 1/2 inch thick, while the round bars were 1 inch in diameter, which means that the strip ingots were more severely chilled than the bars, and this accounts for their greater hardness. In each case, four distinct ranges were visible, their boundaries being at about the same chemical compositions though the actual hardnesses were different. Silicon has far more influence upon the hardness than manganese, and the four ranges may be described by reference to the silicon content alone, as follows:

Range I - From 0 to 2½ or 3% silicon, all the alloys are relatively soft, the higher limit of hardness being about 70 Brinell in the case of the round bars and 90 for the strip ingots.

Range II - At about 3% silicon there is fairly rapid increase of about 20 Brinell points in each case, marking the first appearance of the constituent "X", to the influence of which the increased hardness is doubtless due.

Range III - Between 3 and 4% silicon, in an area corresponding almost exactly with that of good ultimate strength, the Brinell number remains at an almost uniform and fairly high value, namely, 90 to 100 for the bars and 110 and 120 for the ingots. Here the best Brinell properties occur.

Range IV - With more than 5% silicon the hardness increases rapidly, owing to the presence of excessive amounts of γ.

The Shore scleroscope test was performed, using the universal hammer, upon the Brinell specimens, and the results were found to follow the same general trend as the Brinell numbers. Unlike the Brinell figures, however, there is no marked discrepancy between the values for the round bars and strip ingots.

Samples machined from the strip ingots were subjected to the Izod notched bar test upon a 120 ft. lb. machine, the specimens being of the usual standard dimensions, namely, 1 cm. by 1 cm. section, notched 2 mm. deep at an angle of 45°, with circular bottom of radius .25 mm. The notches were 28 mm. from the ends of specimens to be struck. With the exception of those very rich in silicon, none of the alloys showed brittleness; in fact, specimens of only two compositions suffered breakage in the annealed condition. Three classes of alloys were distinguishable depending upon the content of silicon and to a lesser degree, of manganese. With low percentages of these elements, the alloys are soft and malleable. Their Izod figures, which range from about 45 to 50 ft. lbs. are slightly lowered by annealing. Secondly, around the composition of optimum tensile properties appears a range of tough alloys which remain unbroken under test while absorbing over 50 ft. lbs of energy. Upon annealing, these Izod figures are distinctly raised, while the region is extended to include certain of the more brittle alloys. These latter form the third class - namely, those which broke under test. Both "as cast" and annealed specimens show the embrittling influence of the γ constituent, and the effect of annealing is simply to localize this in its true corner of the field by inducing approximately equilibrium conditions.

It is therefore concluded that, in the chill-cast state, silicon-manganese-copper alloys of about the composition 3½% silicon with 1% manganese had the best all-round mechanical properties of any between the limits of 0 to 5% each of silicon and manganese.

<u>Production and Properties of Silicon-Manganese-Copper Sheet</u>.

This part of the research was designed to investigate the behavior of silicon-manganese copper alloys under both hot and cold rolling, and to ascertain the properties of the resultant sheet. Of the twelve strip ingots cast, as described in the previous section, six were selected for hot rolling and six for cold rolling. With the exception of the alloy containing 5.14% silicon with 1.51% manganese, good sheet was obtained by cold rolling all six ingots.

In the investigation of the plain silicon-copper alloys, one containing 4½% silicon could not be rolled in the cold.

The conditions of hot rolling were much less carefully controlled, the initial temperature being 750° ± 20°C. For the most part, the ingots rolled well as long as a fair degree of temperature was maintained, but upon cooling off, and particularly if the attempt were made to cross-roll a cool specimen, serious cracking took place at the edges. In spite of this fact, hot rolling can be said to give much better results than cold for the alloys relatively high in silicon, provided that the temperature be maintained above redness. As in the case of the plain silicon-copper alloys, however, care must be taken not to exceed a temperature of about 800°C, or the material becomes "crumbly" and hot short. Specimens of hot rolled sheet were afterward pickled and brought to a "soft bright" finish at .062 inch thickness; the last pinch (after the last anneal) being .08 inch, as for the cold rolled sample. From each specimen of sheet in every condition, at least six samples 4 in. by 1 in. were cut, three being taken parallel with (longitudinal) and three at right angles to the direction of rolling (transverse). The samples were machined to tensile test pieces by bolting a number together between two mild-steel plates and shaping the edges. About 250 specimens were thus prepared. Upon measurement, few, if any, of the parallel portions varied by more than .005 in. from the intended width of .25 in.

The selection of the gauge length was governed by the sectional area of the specimens. The standard specification for gauge length is four times the square root of the sectional area. In the majority of cases this worked out at about 1/2 inch, which was accordingly chosen and adopted for all the specimens. The most patent fact revealed by an examination of the results was that the ductility and in many cases the strength also is lower when tested across than along the direction of rolling, and that this condition is by no means destroyed by annealing. The directional properties were rather less marked for the hot rolled specimens, due perhaps solely to the fact that they were cross rolled. Any directional properties which they retain were presumably imparted during the last pass or two, when the metal was becoming cool. The effects of the rolling conditions are summarized below.

Condition	Cold-Worked %	Ultimate Strength	Elongation on 4 $\sqrt{\text{area}}$ %
Hard bright	33	18-45 tons/sq.in.	4-22
Soft bright	11	22-41 tons/sq.in.	7-43
Hot rolled	Indefinite	22-50 tons/sq.in.	8-19
Annealed	0	14-31 tons/sq.in.	20-75

The relative low elongations of the hot rolled specimens were simply due to the cold working effect of the last few passes. Had the rolling been stopped at an earlier stage, i. e. before the metal had cooled down below a red-heat, the results would no doubt have been more comparable with those for the annealed material. However, they show definitely that hot rolling (especially with cross rolling), followed by cold work, imparts good strength without the introduction of objectional directional properties. Such procedure is therefore recommended; it gives greater fuel and mill power economy, as well as a better product than cold rolling with intermediate anneals.

The results of tensile tests carried out on annealed silicon-manganese-copper sheet show that the most ductile alloys contain from 2 to 3½% of silicon with up to 3% of manganese, and correspond fairly well with those of maximum toughness, as shown by the Izod test on the annealed castings.

Corrosion Tests

An extensive series of corrosion, or perhaps rather endurance, tests in various liquids, including mineral and organic acids, was undertaken upon silicon-copper and silicon-manganese-copper, with pure copper as a standard of reference.

Copper and silicon-copper resisted strong sulphuric acid fairly well, but silicon-manganese-copper was moderately attacked. All the metals resisted normal and decinormal sulphuric acid quite well, the rate of attack being from 8 to 13 mg. per square centimeter per month. Normal and decinormal hydrochloric acid attacked all the alloys to a greater extent than sulphuric acid of the same concenntrations, the loss in weight varying from about 30 to 90 mg. per square centimeter per month. As might be expected, normal nitric acid rapidly attacks copper and the silicon alloys. On the other hand, decinormal nitric acid has scarcely more action than sulphuric acid of the same concentration. All the metals showed a fair degree of resistance to normal formic and acetic acids (8 to 15 mg. per square centimeter per month), and mixing the two acids did not increase the rate of attack. In synthetic sea-water, there was little to choose between the alloys.

In general the corrosion of the silicon-copper alloy containing 4.5% of silicon proved very similar to that of the silicon-manganese-copper alloy tests under identical conditions, but was rather less severe. As this material contains no manganese and 1½% more silicon than the ternary alloy, the foregoing result would seem to indicate that it is to the silicon rather than the manganese that the latter owes its resistance to corrosion. For all liquids except normal nitric acid (by which both were rapidly dissolved), the silicon-manganese-copper alloy, containing 3.17 % of silicon and 0.99% of manganese, was slightly inferior to copper tested under identical conditions.

The Oxidation of Silicon-Copper and Silicon-Manganese - Copper Alloys at High Temperatures.

Carefully cleaned, measured and weighed specimens of 3% silicon-copper, 4.5% silicon-copper and a silicon-manganese-copper carrying 4% silicon and 1% manganese, in comparison with arsenical-copper, all in the form of sheet, were heated in air in a muffle to a temperature of 725°C. This temperature was maintained for 1 hour, after which the specimens were allowed to cool in the muffle with free access of air. They were then examined and reweighed. In addition to these experiments, the rates of oxidation of the two silicon-copper sheet samples together with silicon-copper wire (0.92% Si) were determined in pure oxygen at 725°C and 825°C.

The main conclusions drawn from the results of the two series of experiments are as follows: the scale formed on silicon-copper alloys resembled that ordinarily formed on copper, insofar as it consisted of a black cupric-oxide layer superimposed upon a firmly adherent cuprous-oxide film. In the case of alloys containing appreciable quantities of silicon, the cuprous oxide film is buff in color and contrasts strongly with the red oxide produced on copper. The modification of the color is probably due to the admixture of silica. The resistance of silicon-copper alloys to high-temperature oxidation in the neighborhood of 700°C increases with the silicon content. At 725°C, the rate of oxidation of an alloy containing 4.58% silicon was from 1/4 to 1/7 that of copper. The adherence of the outer layer of black oxide was likewise a function of the silicon content. For the 4.58% silicon alloy, it was very firmly adherent. At the temperatures above 800°C, the oxidation rate increases and approximates that of pure copper. The addition of 1% manganese to a 4% silicon alloy did not appreciably alter the rate of oxidation, but rendered the black oxide much less adherent.

Comparison of the Silicon-Copper and Silicon-Manganese-Copper Alloys.

The results of this investigation show that the straight silicon-copper alloys are little if at all inferior in their mechanical properties to the more complicated ternary alloys containing manganese, and that there is no marked difference in their resistance to corrosion. The experiments on the resistance to attack by chemicals indicated the suitability of the alloys, with or without manganese, for certain engineering purposes in chemical industries.[23]

Foreign Research (German)

In a paper on a somewhat similar subject, namely, "A New Silicon-Zinc-Copper Alloy", it was stated that silicon-zinc-copper alloys possessed a homogeneous solid solution structure up to a much higher silicon content, in the copper corner of the ternary thermal-equilibrium diagram, than hitherto been assumed.

Whereas 2% silicon had been thought to be the maximum solid solubility in the 90% copper alloy, it was now shown that about 4% of silicon could be retained in solid solution. These alloys with a high silicon content, especially when it was all retained in solid solutions, possessed valuable properties. They could be worked hot as well as cold. Some of the alloys of this type had outstanding properties as bearing and bell metals. These alloys contained from 71 to 95% of copper, 2 to 6% of silicon and 3.5 to 27% of zinc.

While silicon-zinc-copper alloys decrease in strength and ductility with the addition of tin, owing to the separation of a new hard constituent, their value as bearing alloys was thereby increased. Tests of some of the silicon-zinc-copper alloys, containing a little tin, had shown that they would withstand a specifically higher load, as bearing metals, than could ordinary bronzes.

It was found that while the actual rate of oxidation might be lessened by the addition of silicon, the surface oxidation products contained silica which was insoluble in ordinary pickling reagents, and, in order to remove this silica, it required some type of mechanical cleaning in addition to the usual pickling and washing. It was noted that the silicon-copper sheets made were not all of good quality. It might be that some means of casting, so as to obviate turbulence might be of advantage in obtaining clean ingots. The season-cracking tendencies of the silicon-copper alloys were very marked and it would appear that nothing short of complete annealing would remove them entirely. This provides a serious argument against the use of these alloys.

These alloys also piped very definitely.[24]

Foreign Research (French) Abstract

Copper Alloy Systems with Variable Alpha Phase Range and Their Use in Hardening of Copper.

I When one metal dissolves in another at a high temperature and precipitates on cooling, some hardening effect can take place in the binary alloys, but the amount of it cannot be great because there are but a few solutions forming hard enough precipitates. The limits of solid solubility of these elements in copper narrow with the rise of the temperature as in Cu-Zn, Cu-Sn and Cu-Al systems. Metallic substances which when alloyed with Cu can harden it successfully must easily dissolve at high temperatures and form on precipitation hard by comparatively non-brittle minute particles. When two are used, one must not form any compound with Cu whatever, while the second must have more affinity to it than Cu. Taken separately one of them, but preferably both, must be soluble in solid Cu to some extent.

Eutectic temperatures of Cu with these compounds must not be too low. Many ternary systems are possible but only a few realizable. Cu-Co-Si, Cu-Ni-Si, Cu-C-Si, Cu-Fe-Si and Cu-Mn-Si all harden on drawing.

II A study of Cu-Si series. Alpha solution range increases with the temperature. Limits of solid solubility at low temperature are not definite. The secondary constituents slowly precipitate along cleavage planes. For practical purposes the limit of solid solubility can be placed at 3 of silicon. Long annealing at 200-300° drops it to about 2%. Normalizing, rolling and annealing permits following the changes in physical properties as related to increasing Si content up to 2.3% where the results become irregular. Above 2.3% the excess silicon precipitates causing changes in hardness.

Hardness of alloys quenched and drawn at 400-500° for 3-6 hours increases, reaching a maximum of 280 Brinell with 6.7 silicon. Hardness does not affect tensile strength but strongly changes elongation. For low silicon content the improvement in conductivity is caused by precipitation of more resistant B-phase. With higher silicon content, γ-precipitates. The structure of low silicon alloys is strongly affected by heat treatment, though the physical properties remain almost the same. Grain size increases with silicon.

III <u>A study of hardening copper by heat treating its alloys with silicides</u>. In Cu-Ci-Si systems Si greatly increases the solubility of Cr and its precipitation at lower temperature ranges. The limits of its solubility are not as sharp as inCu-Cr system, and the temperatures required for treatments are lower than those necessary for Cu-Cr alloys. The use of Fe silicides did not prove advantageous, though some hardening could be produced. Alloys with Ni_2Si and Co_2Si give optimum results. The state of solid solution does not cause the maximum resistivity because it can be increased by higher heating. High Ni_2Si alloys harden on mere cooling in the blast of air. Ductility figures are not consistent.

IV In pseudo-binary alloys like Cu with Ni_2Si or Co_2Si, annealing after quenching precipitates constituents in many different shapes. Sorbitic structures gradually (with the increasing Ni_2Si content) change into free eutectoid precipitated at the grain boundaries, reappearing again as a complex structure at 9.6% followed by the former structure with 12%. Alloys produced by keeping silicon at 2.5% and increasing Ni to 50 and 90% could be worked only when a little manganese was added in the casting. Their properties were similar to those obtainable on hardening rich Cu-Ni alloys. Constitutional diagram given shows that up to 30% Ni, the lower limit of solid solubility remains practically constant, being 0.10% silicon at lower temperatures and 1.0% silicon at 9.75°C. Above 30% Ni the proportions of silicon remaining in solution increase With 50% Ni, no hardening or precipitation occurs with less than 0.8% silicon. No free silicides can be found after 975°quench with less than 2.3% silicon. Hardening is produced by formation in Cu alloys of Ni_2Si and Co_2Si. FeSi cannot be used for the purpose. The existence of Ni_2Si is well established. Co_2Si is unstable. Preparation of the alloys does not call for any special precautions. Silicon can be replaced with Be which forms Ni_2Be. Corrosion resistance of the alloys is average. Alpha brass and bronze can be hardened by dissolving in them Ni and Si and heat treating.[27]

10. P. M. G. Metal (88 Copper-10 Hardener-2 Zinc)

P. M.G. metal is a copper-silicon-iron alloy developed as a substitute for phosphor bronze, manganese bronze and gun metal, as the name implies.

It is stated that 88-10-2 P. M. G. alloy is 10% stronger, resists corrosion more, has better casting properties and possesses greater anti-friction properties than most of the bronzes it is intended to substitute.

A hardener for this alloy was developed, 8% of which is claimed to be equivalent of 10% tin.

In tests made at Watertown Arsenal of 88-10-2 grade, the physicals were about the same as those obtained on Instrument Bronze No. 5. As cast, average tensile strength of 54,650 lbs./sq.in. with an elongation of 23.5% in 2 inches were obtained. Machining 88-10-2 P. M. G. metal was equal to Bronze #5. (See Report No. 343.2, June 25, 1931, appended.)

Heat treated. Forged P. M. G., tensile slightly improved; castings showed the most appreciable increase in tensile properties. Greatest hardness obtained by heating casting or forging at 550°C after quenching. Maximum hardness and tensile properties do not occur at same time. The hardness of castings and forgings are close, showing a difference of only 8 Brinell points. The hardness range is approximately 85-121 Brinell with little difference between treated and non-treated specimens.

Annealing. Neither castings or forgings showed any response to normal annealing temperatures.

Hardener-Actual Analysis		P.M.G.(88-10-2) Analysis	
Iron	17.60%	Copper	91.-93.%
Silicon	40.01%	Zinc	2.5-4.5%
Copper	40.53%	Iron	1.3-1.8%
Manganese	.65%	Phosphorus	.10%
Phosphorus	.32%	Manganese	.10%

The hardener is commercially called 40-40-2 alloy; it is of standard composition and all of the ingredients are obtainable from domestic sources. Silicon is the principal hardening agent, hardening copper 2½ times more effectively than tin. 1% of silicon is equivalent to 10% of zinc when alloyed with copper.

See Frankford Arsenal Report No. 12 on P.M.G. metal covering information on casting practice, machining, magnetic properties, physical properties, macrostructure and microstructure, patents, proposed tinless alloys, recommendations, specifications for analysis and physical properties, etc.

Other Tests & Data

A P.M.G. test (British)

Test Piece - 3" round P.M.G. Metal Bar (88% Copper, 10% P.M.G. Hardener, 2% Zinc.

The bar was heated once only in an ordinary smith's hearth which is generally used for the heating of steel billets.

	Yield tons per sq.in.	U.T.S. tons per sq. in.	Elon. in 2"	Brinell Hardness
1st Stage: The temperature was raised to 750°C and then bar was forged down to 1" sq.	18.	33.2	43%	149
2nd Stage: A portion of the bar was extended in length a further 12" by forging without further heating to 5/8" sq.	28.	37.6	22%	187
3rd Stage: A portion of the 5/8" sq. bar was forged without further heating from 5/8 to a point; during the operation being extended a further 10 inches.	28.	37.6	25%	179

Note: Tons are long tons (2240 lbs.)

In the 1" square portion of the bar, the metal was then Bent And Closed Up Cold.

In the 5/8" portion of the bar, the second Bend was made and Closed Up Cold.

Thereafter, the First Bend was Opened up Again Cold and Closed Down Cold.

No Fracture Occurred Anywhere and the metal proved to be sound after these very severe tests.[30]

Report No. 343.2 June 25, 1931

PMG METAL

(Sample obtained from American Brass Co.)

CHEMICAL ANALYSIS

Cu	Si	Mn	Fe	Zn
91.80	3.66	.38	2.24	1.92

PMG METAL (AS CAST)

	Lbs. per Sq. In.			Per Cent		
No.	P. L.	Y. P.*	T. S.	Elon. 1"	Red.of Area	Fracture
1-L	14,000	30,400	48,000	5.0	13.4	90° break, grayish crystalline, copper segregation near edge.
2-L	10,000	26,000	43,000	7.0	9.6	90° break, grayish color, crystalline yellowish segregated spots, checks on stem.
1-T	14,000	26,000	55,000	14.0	11.7	" " "
2-T	10,000	23,000	36,000	9.0	10.7	Irregular 90° break, coarse crystalline, 50% grayish, 50% copper segregation, checks on stem.

*Yield point taken as the load producing an extension under stress of 0.75

TENSILE CHARPY

No.	Ft. Lbs.	Fracture
1-L	9.8	Coarse crystalline, grayish color, dull yellow segregation.
1-T	4.0	Coarse crystalline, pitted 70% copper segregation.

HARDNESS

Brinell 1000Kg Load	Rockwell "B" scale
101	65

28

P. M. G. General. The metal has a very close structure, and offers considerably greater resistance to erosion than either Gunmetal or Phosphor Bronze in hydraulic appliance such as Impellers, Valves, Spindles, etc.

It is a good forging metal with high Brinell hardness in Spindles, etc. and makes a good bearing, when running with steel or similar spindles.

It is inclined to draw in castings, but this can be allowed for.

In Bronze Pump Spindles requiring forged couplings it offers the advantage of greater resistance to wear and abrasion by packing, than forged Manganese Bronze with improved running qualities in combination with White Metal Bushes.

The working and machining of P. M. G. is very similar to Phosphor Bronze except that in forging it requires more thorough soaking in the furnace, while in grinding it is much freer in cutting, Phosphor Bronze choking the wheel much more readily.[31]

It is stated that samples of P. M. G. which have been analyzed carried zinc at 2%, iron at 1.7%, manganese at 0.50% and silicon at 3.67%; that skill would have to be used to keep the amount of iron present in complete solution. Microscopic examination of the samples indicated that the material contained undissolved iron silicide.

In the copper-silicon bronzes, it is believed that high iron is somewhat detrimental and has been avoided. The presence of zinc has also been avoided although investigations indicate small percentages of zinc have no injurious effect and, in fact, may be somewhat of advantage in securing sounder castings. It is believed that P. M. G. metal would be equally as good as No. 5 Bronze.[32]

Forging. For the purpose of forging the P. M. G. Metal, this can be done by heating the metal in coke-fired ovens or ordinary smithy hearths, up to 700-750°C. The metal should be soaked a little longer than Phosphor Bronze, and then when forged it will respond readily and give good results.[31]

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32. Letter - A. B. Co., June 5, 1930