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The effect of aluminum on bronze

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THE EFFECT OF ALUMINIUM ON BRONZE

by

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A

T H E S I S

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LIST OF ILLUSTRATIONS

N.B. The numbers above correspond to those listed in the tables on page 7.

OBJECT

The object of this thesis is to determine the effect of aluminium on bronze and find the best composition for commercial use.

METHOD OF PROCEDURE

A number of alloys, containing tin and copper in the ratio of 8 to 92, and varying percentages of aluminium, were made up and examined microscopically.

This work gave the following results:

(a) With 1% aluminium the alloy contained two constituents, the compound, Cu_4Sn, which was identified by its hardness, color, and crystalline form, and another constituent which corresponded to the Alpha solution in a bronze containing 10% tin. This constituent differed, however, in the fact that it was much harder and apparently tougher than the Alpha solution in ordinary bronze. In this paper we will also call this constituent the

Alpha solution.

(b) With 2% aluminium the same constituents were observed but the Cu_4Sn was present in larger amount.

(c) With 3%, 4%, 5%, 6%, and 7% aluminium the same constituents were present but in each alloy there was an increase of Cu_4Sn over the preceding one.

As the Cu_4Sn is an undesirable constituent in an alloy which is to be used for any purpose except bearing metal, it is evident that the aluminium does not have a good effect in this respect. However, the increase in the hardness, and possibly toughness, of the Alpha solution, is a very desirable feature.

The proportion of tin in the alloy was therefore reduced in the hope that with less tin, the tendency to form Cu_4Sn would be diminished and at the same time the good effect of the aluminium on the Alpha solution might be preserved.

A series of alloys containing 3% aluminium was then made up with decreasing amounts of tin. This series gave the following results:

(a) With 7.76% tin the alloy contained a considerable quantity of Cu_4Sn.

(b) With 5.82% tin the Cu_4Sn was much reduced and the character of the Alpha solution apparently unchanged.

(c) With 3.88% tin the Cu_4Sn was present only as a few isolated crystals with the Alpha solution as above.

It is therefore evident that with the composition as shown in (c), the metal consists almost entirely of Alpha solution, and should, therefore, make a very desirable alloy.

TECHNIQUE OF EXPERIMENTS

Preparation of Alloys.

Quantities of metal, amounting to 50 grams, were weighed out in the proportions required. The fusion was made in a 10 gram Battersea crucible under a cover of molten borax. The borax was melted in the crucible, the copper, then the tin and finally the aluminium, added.

It was found in the first attempts that the density of the pure aluminium was less than that of the molten borax and that this metal could not, therefore, be alloyed without considerable difficulty. An alloy was then made of equal weights of aluminium and tin and used in the place of pure aluminium. The density of this was 4.085. The molten alloy was then allowed to cool in the crucible.

Preparation for Microscopic Examination.

The button in the crucible was then ground to a flat surface, ¾" in diameter, and polished in the usual way.

It was then heat-tinted at about 300°C., first turning lemon yellow, then to a dark red, then a blue, and finally back to colorless again. At this stage, under the microscope, the Cu_4Sn appears a dark brown and the Alpha solution a very light yellow.

Photo-micrographs were taken with the light from a Nernst lamp.

Tables of Weights and Percentages.

The above mentioned alloys are designated as series "A" and series "B". In the following tables the percentage, composition and the weights used are shown.

Series "A".

	Composition in Percentages.			Weights used in Grams.		
	Cu.	Sn.	Al.	Cu.	Sn.	(Sn.&Al.)
1.	91.08%	7.92%	1.00%	45.54	3.46	1.00
2.	90.16%	7.84%	2.00%	45.08	2.92	2.00
3.	89.24%	7.76%	3.00%	44.62	2.38	3.00
4.	88.32%	7.68%	4.00%	44.16	1.84	4.00
5.	87.40%	7.60%	5.00%	43.70	1.30	5.00
6.	86.48%	7.52%	6.00%	43.24	0.76	6.00
7.	85.56%	7.44%	7.00%	42.78	0.22	7.00

Series "B".

1.	89.24%	7.76%	3.00%	44.62	2.38	3.00
2.	91.18%	5.82%	3.00%	45.59	1.41	3.00
3.	93.12%	3.88%	3.00%	46.56	0.44	3.00

The aluminium-tin alloy was made up of equal weights of the constituent metals and has a specific gravity determined as follows:

Wt. of alloy of Sn. & Al. .... 0.7484 grams.
Wt. of specific gravity bottle & water..21.6716 grams.
Wt. of bottle & water & alloy...........22.2368 grams.

$$\text{Density} = \frac{0.7484}{0.7484-(22.2368-21.6716)} = 4.085$$

Preparation of Alloy for Final Tests.

For the making of physical tests a large quantity of an alloy similar to no. 3 in series "B" was prepared. The composition of this and the weights taken were as follows:

Copper	93.00%	5587 grams.
Tin	4.00%	233 grams.
Aluminium	3.00%	180 grams.

The metal was melted in a no. 6 graphite crucible, the copper being added to the heated crucible first, then the tin and finally the aluminium, the latter on account of its low specific gravity, had to be held under the surface of the other metals until melted to prevent oxidation.

The alloy was cast into pipes of such a size as to require a minimum of machine work in preparation for the tests, for the tensile strength test a 1¼" pipe, 12" long being used, and for the conductivity test a ½" pipe 18" long. These pieces were then machined to the proper size.

Owing to an accident in the machining of one of the pieces it was necessary to remelt and recast another batch. The remaining parts of the first casting were used together with some new metal but the composition of the second alloy is slightly different from the first. This was not enough to make a difference in the tests, however, and will be given later on.

METHOD OF TESTING

Tests were made on the cast, rolled, and drawn alloys. The castings are sound and free from blow-holes; they can be readily forged in the cold if previously quenched from $500^{\circ}C.$, and the quenching frequently repeated.

1. Tests on the Cast Bar.

(a) The cast piece, 1¼" in diameter, was machined to ½" in diameter and 2" long. It was placed in a regular testing machine, from which the tensile strength was determined.

(b) A conductivity test was made on a cast rod of the alloy, 14" in length and machined down to a diameter of ⅜". An ammeter and millivoltmeter were used, from which readings the resistance in ohms was calculated.

(c) The specific gravity was determined in the usual way.

2. Test on the Rolled Material.

(a) A specific gravity determination only was made.

3. Tests on the Drawn Material.

A piece of the rolled material, ½" in diameter, was pulled into wire of .325 m.m. in diameter by means of first forging, under the conditions mentioned above, to a size which would go through the first die and then drawing in the usual way. The wire after starting to draw, did not require further heat treatment. On this the following tests were made:

(a) The tensile strength.

A small piece of the wire, about 6" in length, was made fast at one end and to the other end was attached a bucket, into which sand was poured till the wire snapped. The bucket and sand were then carefully weighed. The break occurred near the bucket.

(b) The conductivity.

About twelve feet of the wire was made into a spool on a glass tube. A current of low amperage was used which gave a fairly high reading on the voltmeter. From this the resistance in ohms was figured.

(c) The specific gravity.

The test was made in the usual way.

(d) The modulus of elasticity.

The wire was stretched taut and its length measured. Then a known weight was attached to it and the length again measured, the difference giving the elongation, from which the modulus of elasticity was calculated.

RESULTS OF TESTS

1. Cast bar.

(a) Tensile strength.

	Before fracture	After fracture
Dimensions	0.5080	0.5010
Area	0.2027	0.1971
Elastic limit in pounds	0	
Max. load producing rupture	2600	
Ultimate strength in lbs./sq. in.	12800	
Elongation in 1¾"	0	

(b) Conductivity.

Amps.	Millivolts	Resistance in milli-ohms
21.5	15.18	.705
23.0	16.30	.710
24.8	17.44	.704
25.0	17.56	.704
26.5	18.60	.702
28.0	19.60	.700
30.5	21.28	.698
33.5	23.60	.704
35.5	24.70	.697
39.0	27.18	.697
39.5	27.40	.693
41.0	28.42	.694
41.5	28.76	.693
42.0	29.20	.696

Average resistance of rod........... 0.0007 ohm.

Diameter of rod..................... 0.9780 cms.

Length of rod.......................41.3000 cms.

$$\text{Conductivity} = \frac{41.30}{75.1 \times .0007} = 7.874 \times 10^{-8}$$

(c) Specific gravity.

Wt. of alloy........................1.2595 grams

Wt. of sp. gr. bottle & water.......39.7654 grams

Wt. of bottle & water & alloy.......40.8690 grams

$$\text{Specific gravity} = \frac{1.2595}{.1559} = 8.079$$

(d) Chemical composition.

Copper................................93.260%
Tin................................... 3.775%
Aluminium............................. 3.070%

2. Forged material.

(a) Specific gravity.

Wt. of alloy........................... 1.9785 grams
Wt. of bottle & water.................39.7335 grams
Wt. of bottle & water & alloy........41.4720 grams

Specific gravity $= \frac{1.9785}{.2400} = 8.24$

3. Wire.

(a) Tensile strength.

Diameter of wire..............0.0128 in.
Area of wire..................0.0001286 sq.in.

Weight	Tensile str./ sq. in.
20 lbs. 4 ozs.	157500 lbs.
20 lbs. 12 ozs.	161300 lbs.
21 lbs. 0 ozs.	163300 lbs.
20 lbs. 12 ozs.	161300 lbs.
21 lbs. 8 ozs.	167300 lbs.

Average tensile strength per sq. in. is 162140 lbs.

(b) Conductivity.

Amps.	Volts	Resistance in ohms
.214	1.159	5.42
.118	0.640	5.43
.159	0.866	5.44
.182	0.999	5.48
.216	1.170	5.42
.374	2.016	5.39
.474	2.562	5.41
.519	2.832	5.46
.520	2.844	5.47
.518	2.824	5.46

Average resistance of wire...... 5.438 ohms

Area of wire.................... 0.00083 sq. cm.

Length of wire..................344.72 cms.

$$\text{Conductivity} = \frac{344.72}{.00083 \times 5.438} = 7.6335 \times 10^{-8}$$

(c) Specific gravity.

Wt. of alloy.......................1.16930 grams

Wt. of bottle & water.............39.75615 grams

Wt. of bottle & water & alloy.....40.78090 grams

$$\text{Specific gravity} = \frac{1.16930}{.14455} = 8.089$$

(d) Modulus of elasticity.

Length of wire....................	38.6	ins.
Area of wire......................	0.0001286	sq.in.
Elongation........................	0.04645	ins.
Weight............................	2.2046	lbs.

$$\text{Modulus} = \frac{2.2046 \times 38.6}{.0001286 \times .04645} = 14.24 \times 10^6$$

(e) Chemical composition.

Copper................................	92.700%
Tin...................................	3.089%
Aluminium.............................	4.112%

CONCLUSIONS

(a) Alloy does not easily tarnish.

(c) It makes good castings.

(d) The tensile strength is only 12800 pounds per sq.in. for the cast metal when it is not subjected to heat treatment.

(d) It can be rolled into plate with proper heat treatment.

(e) It is very easily drawn into wire.

(f) It would make good wire for springs as it is very elastic.

(g) The wire has high tensile strength and very good conductivity, so would make an excellent telegraph and telephone wire.

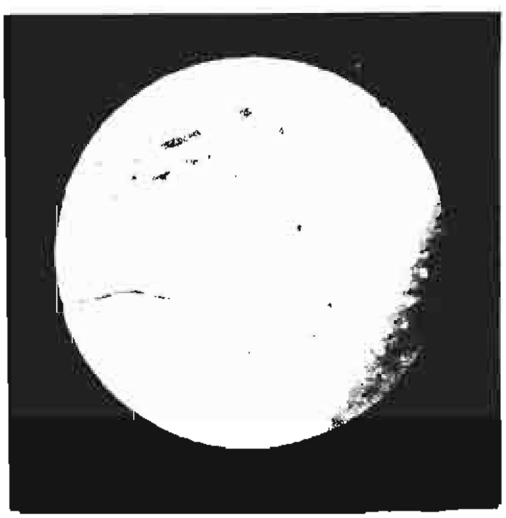
(h) The cost of the alloy is within the commercial limit.

SERIES "A"

All magnified 118 diameters

No. 1.

No. 2.



No. 3.

No. 4.

SERIES "A"

All magnified 118 diameters

No. 5.

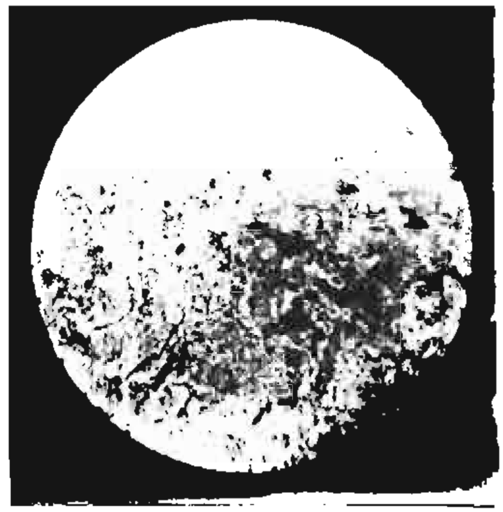
No. 6.

No. 7.

SERIES "B"

All magnified 118 diameters

No. 1.



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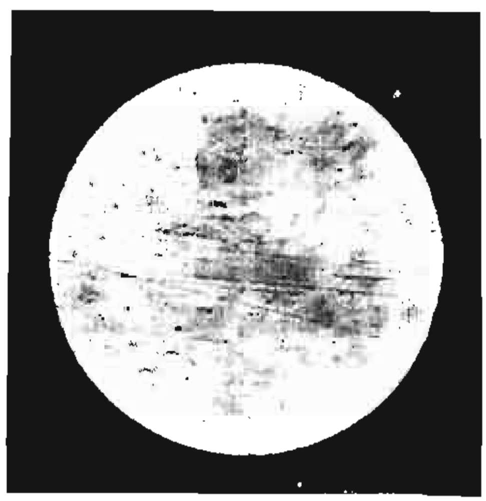

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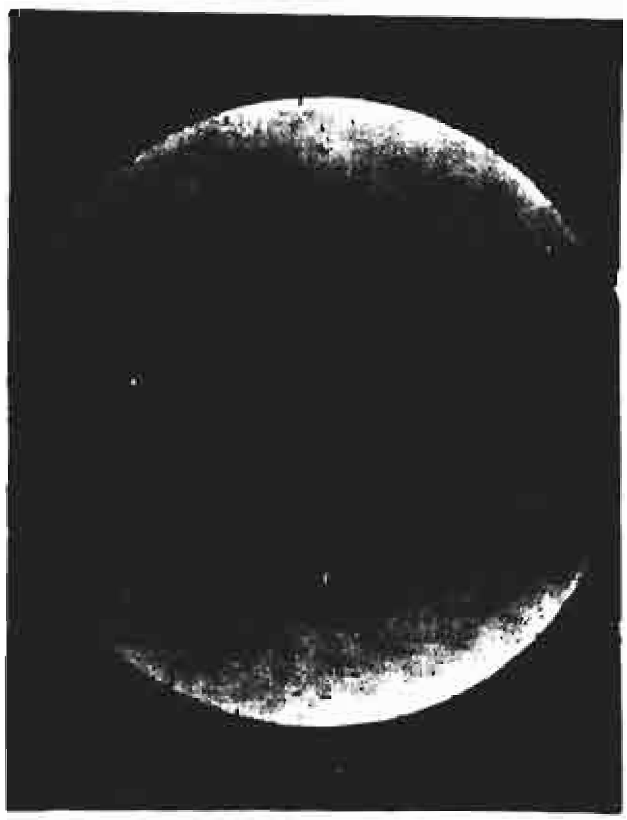
SERIES "B"



Same as "B" no. 3. Magnified 118 diameters
but large focus.

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