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COPPER-TITANIUM-SILICON ALLOYS

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My invention relates generally to copper alloys in which copper is the major constituent, and particularly to ternary alloys composed of copper, titanium and silicon which have been subjected to temper-hardening treatments that develop increased hardness, strength and electrical conductivity, particularly in respect to these ternary copper alloys in the form of castings.

Heretofore various copper alloys have been temper-hardened by being cooled from high temperatures ranging from 650° to 1000° C. and subsequently annealing same at relatively lower temperatures, say from 250° C. to 500° C., for a period of time inversely proportionate to the annealing temperatures used.

It has been found that such temper-hardening heat treatments of binary as well as ternary copper alloys impart increased hardness, strength and electrical conductivity to the resultant alloy, but also that generally the presence of a third element in addition to copper and titanium materially reduces the electrical conductivity of the heat-treated alloy below the value characteristic of the heat-treated copper-titanium alloy without the third element.

I have discovered, as a result of my experiments and tests, that ternary copper-titanium-silicon alloys, provided the amounts of titanium and silicon are kept within very definite proportions, which alloys are then subjected to the temper-hardening heat treatments that I have described, develop remarkable hardness and strength together with surprisingly good electrical conductivity in the form of castings. While the use of titanium and silicon as components of copper alloys is known with the maximum titanium content up to four per cent and up to five per cent of silicon, such ternary alloys when subjected to heat-hardening treatments have been found too high in electrical resistance for conducting purposes.

On the contrary, I have discovered that copper-titanium-silicon alloys having a titanium content between 0.40 per cent and 1.03 per cent and a silicon content from 0.03 percent to 0.59 per cent, particularly in the form of copper alloy castings, develop when heat-hardened certain mechanical and electrical properties that are entirely different from the binary copper alloys in which titanium and silicon are separately alloyed with the copper, and also from the ternary copper-titanium-silicon alloys having their titanium and silicon contents outside the percentage

ranges I have found to be especially adapted to impart good electrical conductivity.

For example, in the form of castings, I have found a good combination of the desired hardness, strength and electrical conductivity in improved heat-hardened copper-titanium alloys with the addition of silicon not to exceed 0.60 per cent with the silicon content always lower than that of the titanium. Such improved copper-titanium-silicon alloy castings that I have developed and tested after heating two hours at about 1650° F. followed by quenching in water and reheating for 24 hours at about 850° F. possessed the following mechanical properties:

Rockwell hardness	E	79 to 91
Yield point	lbs. per sq. in.	20,000 to 30,000
Tensile strength	do	35,000 to 45,000
Elongation	%	7 to 27

The yield point mentioned herein is the stress producing a deformation of 0.5% under loading which is generally applied in tension for test purposes, but may also be applied in compression.

Such copper alloy castings so treated and tested contained from 0.40% to 1.03% titanium and from 0.03% to 0.59% silicon with the balance substantially copper.

The electrical conductivity of these heat-treated copper-titanium-silicon castings I found to vary appreciably within the ranges of their composition of titanium and silicon according to the following table that represents various tests as to electrical conductivity that I have made on alloys tempered for maximum hardness and strength:—

Titanium content	Silicon content	Electrical conductivity after quenching and tempering
Percent	Percent	Percent
0.4 to 0.43	0.03 to 0.23	26 to 33
0.4 to 0.48	0.4	30.8
0.5 to 0.85	0.03 to 0.19	24 to 36
0.5 to 0.85	0.23 to 0.40	42 to 47
0.5 to 0.85	0.59	20.7
0.96 to 1.03	0.16 to 0.17	18 to 25

From this series of tests, I found that the best electrical conductivity in these copper-titanium-silicon alloys heat-treated for maximum hardness was obtained with 0.50 to 0.85 per cent titanium and 0.23 to 0.40 per cent silicon with the balance substantially copper. My preferred ternary copper alloy casting containing 0.65 per cent titanium and 0.35 per cent silicon

con with the balance copper had electrical conductivity from 40 to 47% as so heat-treated, slight variations in this percentage of conductivity being due to the presence of small amounts of impurities, and differences in foundry practice.

I also found from these tests that copper-titanium-silicon alloys outside the critical range I have given (0.50% to 0.90% Ti and with 0.20% to 0.45% Si) with either more or less titanium and with either more or less silicon were appreciably lower in electrical conductivity. In none of my improved ternary copper-titanium-silicon alloys does the titanium and silicon content exceed one and one-half per cent of either metal alloyed with the copper.

Hence the essence of my discovery resides in those heat-treated copper-titanium silicon alloys, preferably in the form of copper castings, that contain appreciable amounts of silicon not to exceed 0.60 per cent, along with the titanium content not to exceed 1.50 per cent, which titanium content is always greater than that of the silicon, such ternary copper alloys having improved mechanical properties as well as good electrical conductivity due to the combined effects of the titanium and silicon on copper when their respective contents are confined to the definite proportions shown in the foregoing table.

By microscopic examination of samples of copper alloys containing about 0.8% titanium and 0.3% silicon, both as cast and after heat-treatment, it was indicated that an intermetallic compound, probably a titanide or titano-silicide of copper, was caused to dissolve partially in the copper matrix during the high-temperature treatment, and held to some degree in solution on quenching. The alloy with some of the compound in solution was in a comparatively soft condition, having a Rockwell hardness number of about 50 on the E scale, and had comparatively low electrical conductivity, of about 25%.

The subsequent tempering treatment consisting of heating at 850° F. for 24 hours then caused the dissolved intermetallic compound to precipitate more uniformly in fine particles, so that the copper matrix was stiffened against deformation by the presence of the fine particles of hard compound, and its electrical conductivity was markedly improved by the removal of titanium and silicon from solid solution. The hardness after tempering was thus about 82 Rockwell E and the electrical conductivity about 41%.

The useful effect of silicon in these copper-titanium-silicon alloys, in the proportions forming in part the substance of my invention, seems to consist in the lower solubility of the titano-silicide, as compared with the titanide free from silicon, in the temper-hardened copper alloy, so that on account of the presence of the correct proportion of silicon in the alloy, the precipitation of titanium is more complete, giving as indicated in the hereinbefore mentioned table a higher electrical conductivity than when the proper amount of silicon is lacking. However, if too much silicon is present, the excess is not precipitated with the titanium compound, and the conductivity is again less, as is also indicated in this table.

The heat-hardening temperatures which I preferably use to obtain the best results vary considerably with the size of the parts and character of the alloy so treated and in some castings the quenching treatment may be omitted, and only the tempering heat-treatment used, without excessive impairment of the desired properties in the final product. This feature is illustrated in

the table of results presented in the example below marked "A". If the maximum hardness and strength are not required in castings of my new copper-titanium-silicon alloy, they may be tempered at higher temperatures than the best for strength and hardness, with very much improved electrical conductivity. For instance, by tempering the alloy mentioned above, containing about 0.8% titanium and 0.3% silicon, at a temperature 150 to 200° F. above the standard tempering temperature of 850° F., and cooling slowly in the furnace, electrical conductivity of over 62% was attained, but with Rockwell hardness only 67 E, Brinell hardness 65, and yield point 17700 lbs. per sq. in. in tension. It has not been found possible to attain such high conductivity by any heat-treatment in copper alloy castings containing 0.6% or more titanium without the presence of over 0.2% silicon in the alloy.

As a specific example "A", I have made a 275 pound heat of my new copper-titanium-silicon alloy, and then used same for a casting forming part of a water-cooled assembly to hold a large graphite electrode in an electric furnace and to lead the current thereto. The copper for this alloy was melted in a graphite crucible under a glass flux. The crucible was heated by oil. After superheating to about 2536° F., the copper was deoxidized with 2¼ pounds of a silicon-calcium-copper alloy, and 5 pounds 10 ounces of 15% silicon-copper were then added to the melt and stirred in. After 5 minutes further heating the glass flux was removed, and 3 pounds of metallic titanium were added by means of inverted graphite cups (known as "phosphorizers"), which served to keep the titanium submerged in the copper and away from the air until dissolved. The crucible was then withdrawn from the furnace, skimmed, and poured in about five minutes after the titanium addition. The analysis of this heat was 0.87% titanium, 0.35% silicon, and 0.04% iron with the balance copper.

Test bars about 16 inches long and ⅝ inch in diameter were poured with the casting for electrical conductivity and hardness tests after various stages of the heat-treatment. The results obtained are tabulated below. The large casting was given the same heat-treatment, namely, quenching after two hours at 1650° F. followed by tempering 24 hours at 850° to 1000° F.

Condition of test-bar	Electrical conductivity	Rockwell E hardness
	Percent	
As cast, roughly filed and polished.....	27.3	80
Tempered 24 hours at 850° F.....	36.0	91
Heated 2 hrs. at 1650° F. quenched in water.....	26.9	49
Quenched as above, tempered 24 hrs. at 850° F. and air cooled.....	40.1	86
Tempered further at 950° F. for 24 hrs. and slowly cooled.....	46.5	87
Tempered further at 1050° F. for 24 hrs. and slowly cooled.....	71.4	74

Castings previously used for the electrode-holder part such as was poured from this heat were generally of two kinds, namely either pure copper, or aluminum bronze. The former, with about 80% electrical conductivity in the cast state, has a Rockwell hardness of about -30E, and is weak and easily deformed, with a yield point below 10,000 pounds per square inch. The latter, though having Rockwell hardness of 95 to 100 E, has only 18 to 20% conductivity so that

its resistance to the flow of the electric current is too great.

In view of the foregoing tests my temper-hardened copper-titanium-silicon alloy is an improvement over the prior copper-titanium alloys, and particularly since it possesses a better combination of hardness and electrical conductivity when compared with the alloys previously used for castings.

10 I claim as my invention:

1. A heat-hardened copper-titanium-silicon alloy casting containing not to exceed one and one-half per cent of titanium and less silicon than titanium with the balance substantially copper; said alloy
15 having electrical conductivity over 35%, Rockwell hardness above 65 E and a yield point of at least 17,000 pounds per square inch.

2. A heat-hardened copper-titanium-silicon alloy casting containing not to exceed one and one-half per cent of titanium and less silicon than titanium with the balance substantially copper; said alloy having electrical conductivity over 35%,
20 Rockwell hardness above 65 E and a yield point of at least 17,000 pounds per square inch.

3. A heat-hardened copper-titanium-silicon alloy casting containing not to exceed one and one-half per cent of titanium and not to exceed 0.60 per cent of silicon with the balance substantially copper; said alloy having electrical conductivity over
30 35%, Rockwell hardness above 65 E and a yield point of at least 17,000 pounds per square inch.

4. A heat-hardened copper-titanium-silicon alloy casting containing not to exceed one and one-half per cent of titanium and not to exceed 0.60 per cent of silicon with the balance substantially copper; said alloy having electrical conductivity over 35%, Rockwell hardness above 65 E and a
35 yield point of at least 17,000 pounds per square inch.

5. A heat-hardened copper-titanium-silicon alloy casting containing titanium between 0.40 per cent and 1.03 per cent, silicon between 0.03 per cent and 0.59 per cent with the balance substantially copper; said alloy having electrical

conductivity over 35%, Rockwell hardness above 65 E and a yield point at least 17,000 pounds per square inch.

6. A heat-hardened copper-titanium-silicon alloy casting containing titanium from 0.50 to 0.90 per cent, silicon from 0.20 to 0.45 per cent with the balance substantially copper; said alloy having electrical conductivity over 35%, Rockwell hardness above 65 E and a yield point at least
10 17,000 pounds per square inch.

7. A heat-hardened copper-titanium-silicon alloy casting containing titanium about 0.65 per cent, silicon about 0.35 per cent with the balance substantially copper; said alloy having electrical conductivity over 35%, Rockwell hardness above
15 65 E and a yield point at least 17,000 pounds per square inch.

8. A heat-hardened copper-titanium-silicon alloy casting containing approximately 0.87 per cent titanium, 0.35 per cent silicon, 0.04 per cent iron with the balance substantially copper; said alloy having electrical conductivity above 35 per cent and Rockwell hardness above 65 E.

9. A heat-hardened copper casting formed of an alloy containing titanium from 0.50 to 0.90 per cent, silicon from 0.20 to 0.45 per cent with the balance substantially copper, having electrical conductivity of at least 40%, Rockwell hardness over 70 E produced by a heat treatment consisting of heating said casting to about 1650° F. and then tempering same at about 850° F. to 1050° F.

10. A heat-hardened copper casting formed of an alloy containing titanium from 0.50 to 0.90 per cent, silicon from 0.20 to 0.45 per cent with the balance substantially copper, having electrical conductivity of at least 40%, Rockwell hardness over 70 E produced by a heat treatment consisting of heating said casting to about 1650° F. for about 2 hours, then quenching same in water, and then tempering the casting at about 850° F. to 1050° F. for 24 to 48 hours.

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