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2,851,353

COPPER-BASE ALLOYS

Donald B. Roach, Roland B. Fischer, and John Harry Jackson, Columbus, Ohio, assignors, by mesne assignments, to International Business Machines Corporation, New York, N. Y., a corporation of New York

No Drawing. Application July 15, 1953
Serial No. 368,206

11 Claims. (Cl. 75—159)

This invention relates to copper-base alloys. It has to do, more particularly, with copper-base alloys containing nickel and silicon and a material selected from the group consisting of aluminum and magnesium. The alloys of this invention are particularly useful in the manufacture of current-carrying springs, including spring-contact members, such as those used in electrical computing equipment and in many types of business machines.

For successful manufacture of spring-contact members and current-carrying springs in general, it is necessary to have a material that, in the soft condition, can be readily formed by a punching operation and that can then be hardened by a simple heat treatment to provide the necessary spring properties. Distortions caused by heat treatment should be at a minimum. Since the members are intended to carry electric current, good electrical conductivity also is required. These spring contacts are used to transmit small electric currents in the operation of business machines. These contacts are not "make-and-break" contacts, but are semifixed contacts which are moved manually for different circuit connections for each different setup of the business machine. The spring contacts are usually used in pairs comprising a cantilever spring in contact with a shovel- or platen-type spring. The high strength and spring properties might not be indispensable for such applications if sufficient thickness of spring material could be employed. The design of most spring assemblies, however, is such as to limit the thickness of the spring material to relatively thin sections. Consequently, high strength is required. A high modulus of elasticity is necessary to insure positive contact between the cantilever and the shovel contacts. A high proportional limit is required to insure that the contacts will not take a permanent set (plastic deformation) in service and thereby eliminate positive contact. Excellent ductility in the soft condition is required to insure good forming characteristics. Adequate ductility in the hard condition is required so that the contacts can be properly positioned in the spring assemblies in business machines.

A material that can be adequately formed in the soft condition and that in the hard condition would meet the following specifications would be very satisfactory:

Hardness	51 Rockwell 30N (equivalent BHN 291).
Yield strength	100,000 p. s. i.
Tensile strength	140,000 p. s. i.
Proportional limit	60,000 p. s. i.
Modulus of elasticity	18×10^6 p. s. i.
Elongation	10%.
Electrical conductivity	10% of copper.

In the past, the only material known to be suitable for current-carrying spring applications was a copper-beryl-

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lium alloy containing about 2% beryllium. Such an alloy is expensive, and very accurate control is required in the processing and fabrication of the alloy. For these reasons, and because of the scarcity of beryllium, a material that would avoid these disadvantages has long been sought. The alloys of the present invention are less expensive than copper-beryllium alloys and the alloying ingredients are far more abundant than is beryllium. It is a primary object of the present invention to provide such alloys.

Another object is to provide a spring contact having physical and electrical properties equivalent to those of spring contacts made of beryllium-copper, but which is composed of a material of lower cost and less critical as to supply than beryllium-copper.

It is also an object of this invention to provide age-hardenable alloys having properties in the aged condition such as to make the alloys suitable for current-carrying spring applications.

It has been found, as a part of the present invention, that the alloying with copper of nickel, silicon, and at least one material selected from the group consisting of aluminum and magnesium, in certain preferred ranges of proportions, provides hard alloys having high yield strength, tensile strength, proportional limit, and modulus of elasticity, together with good ductility and electrical conductivity. The properties of these alloys are much better for current-carrying spring applications than are those of other copper alloys that avoid the use of beryllium.

It is, therefore, an object of this invention to provide copper alloys containing the ingredients mentioned above in the preferred ranges of proportions providing the desirable physical characteristics mentioned above.

Other objects and advantages of the present invention will be apparent in view of the following description thereof.

In general, this invention relates to alloys of copper containing nickel, silicon, and at least one material selected from the group consisting of aluminum and magnesium. In particular, the invention relates to such alloys containing from about 5% to about 15% nickel, from about 0.1% to about 2.0% silicon, and either from about 0.1% to about 6.0% aluminum, or from about 0.1% to about 2.0% magnesium, or both. A preferred range has been established, in which nickel is present in an amount ranging from about 8% to about 11%, silicon is present in an amount ranging from about 1.0% to about 1.8%, and aluminum is present in an amount ranging from about 2.0% to about 5.0%. A second preferred range has been established, in which nickel is present in an amount ranging from about 8% to about 11%, silicon is present in an amount ranging from about 1.0% to about 1.8%, and magnesium is present in an amount ranging from about 0.3% to about 0.7%.

An important part of the present invention is the discovery of the critical ranges of proportions of the alloying components as set forth above, which greatly improve the properties of such alloys so as to make them suitable for current-carrying spring applications. Although various copper-base alloys containing nickel and silicon, some of which can be age-hardened, have been known, the above critical ranges have not heretofore been disclosed and the known alloys of copper, nickel, and silicon do not have mechanical properties comparable to those required for current-carrying spring applications. As a part of the present invention, it has been determined that the foregoing ranges of nickel and silicon content are

critical in a spring alloy, and, further, that the addition in such copper-base alloys in the critical ranges set forth herein of at least one material selected from the group consisting of magnesium and aluminum, metals of the third period of the periodic table having the successive atomic numbers 12 and 13, respectively, provides appreciably increased aging effects such as to provide good spring materials. Table I sets forth mechanical properties of several alloys according to the present invention, both in the soft (solution-treated) condition and in the aged condition. By solution-treated condition is meant that soft condition produced by quenching the alloy from a temperature in the range of from 1600° F. to 1850° F. In Table I, the hardness designations of R30T and R30N refer to superficial hardness tests using the Rockwell testing machine with a 30-kilogram load. The symbol "T" designates a ball indenter, while the symbol "N" designates a brale indenter. The equivalent Brinell Hardness Number (BHN) for each hardness measurement is included in Table I.

For comparison purposes, the properties of an excellent copper-beryllium spring-contact alloy, known as Berylco 25, are set forth also in Table I.

Table I.—Tensile properties of various alloys in both solution-treated and aged conditions

Chemical Analysis, percent				In the Soft (Solution-Treated) Condition						In the Hard (Aged) Condition						
Cu	Ni	Si	Al	Hardness, R30T	BHN Equivalent	Tensile Strength, 10 ³ p. s. i.	Elongation, percent	Aging Treatment		Hardness, R30N	BHN Equivalent	Yield Strength, 10 ³ p. s. i.	Tensile Strength, 10 ³ p. s. i.	Elongation, percent	Proportional Limit, 10 ³ p. s. i.	Modulus of Elasticity, 10 ⁶ p. s. i.
								Temp., ° F.	Time, hours							
Bal.	6.0	1.5	2.0	59	100	76	37	900	1	47	260	110	128	13	80	18.9
Bal.	10.0	1.5	0.5	54	91	71	16	1,000	1	46	254	107	127	9	78	20
Bal.	10.0	1.5	1.0	60	102	80	17	900	8	49	275	111	128	8	79	18.5
Bal.	10.0	1.5	2.0	67	104	78	22	900	2	50	283	117	136	11.5	88	18.6
Bal.	10.0	1.5	4.0	61	118	93	35	900	2	51	291	123	141	12	86	18.9
Bal.	14.0	1.5	0.5	60	102	64	20	1,000	1	46	254	103	120	7	71	19.6
Bal.	14.0	1.5	1.0	61	104	73	15	1,000	4	48	267	111	126	6	73	19.8
Bal.	14.0	1.5	2.0	66	116	82	17	900	4	48	267	113	129	7	87	20.0
Bal.	14.0	1.5	4.0	68	121	95	23	900	4	52	300	114	135	9	88	19.4
Bal.	10.0	1.5	0.5Mg	62	107	68	20	900	2	49	275	115	134	8	87	19.2
Bal.	10.0	1.5	0.5Al													
Bal.	10.0	1.5	0.5Mg													
Bal.	10.0	1.5	0.25Cr	64	112	79	17	900	4	52	300	125	141	5	94	19.0
Cu-Be (Berylco 25)																
				52	87	70	45	560	1	52	300	111	149	11.5	59	18.4

The high strengths provided in the copper-nickel-silicon alloys of the present invention are obtained by virtue of the precipitation of nickel silicide phase from the solid solution during an aging heat treatment at an intermediate temperature of from about 700° F. to about 1100° F. Although the phenomenon of age-hardening is well known, the exact mechanism has not been definitely established. It is believed that the substantial increases in strength properties provided by age-hardening are caused not by the precipitate itself, but by strain set up in the zone of the matrix around the precipitate nuclei during the early stages of precipitation. These matrix strains prevent the movement or propagation of dislocations and thereby strengthen the material. Additions of aluminum or magnesium, or both, to the solid solution of copper, nickel, and silicon are believed to provide hardening of the solid solution so as to increase the matrix strain around the precipitate nuclei of a phase consisting principally of nickel silicide and thereby to increase the aging effects. Whatever the reasons, however, the copper-base alloys of this invention containing the alloying ingredients in the specified critical proportions provide excellent properties in the aged condition, as is apparent from Table I. While it may be expected that the presence of aluminum in a copper-base alloy might increase the strength properties, the addition of aluminum is ordinarily associated with a reduction in the ductility of the alloy. It was found, as a part of the present invention, however, that the presence of alumi-

num in the specified critical proportions, with the other alloying ingredients present in their respective critical proportions, serves to increase not only the strength, but also the ductility in both the soft and the hard conditions.

The copper-base alloys of this invention may be prepared in accordance with any suitable present-day technique. A typical procedure for preparing these alloys is set forth below.

First, the alloy is melted using standard foundry procedures. For example, the alloy may be melted in the following manner:

(a) Copper and nickel are melted down in a suitable furnace;

(b) When the charge is molten, phosphorus, as copper-phosphorus master alloy, is added to deoxidize the melt;

(c) Silicon and either aluminum or magnesium, or both, are then added in the required amounts as master alloys of copper in the order mentioned, to produce the desired composition;

(d) The melt is cast as soon as solution of silicon and the other ingredients is complete.

The cast alloy is then hot-worked by either forging

and rolling, or simply by rolling, at a temperature of from 1450° F. to 1650° F. to a suitable cross section, not thinner than 0.060 inch.

In this thickness, the alloy may then be coldworked by rolling, swaging, or drawing to the desired thickness for the fabrication of the desired springs.

The strip, sheet, rod, or wire may then be solution-annealed by heating at a temperature ranging from about 1600° F. to about 1850° F., preferably from about 1700° F. to about 1750° F., for a suitable period of time, and then quenched rapidly as by immersing in cold water or by subjecting the alloy to a stream of cold air.

The alloy may then be fabricated into the desired shapes, or, if desired, it may be cold worked prior to fabrication. The additional cold work will further increase the strength properties that can be obtained by an aging heat treatment.

The parts fabricated from alloy composition may be hardened by an aging heat treatment within a temperature range of from about 700° F. to about 1000° F. for a suitable time, depending upon the combination of properties desired. Table II sets forth typical properties that can be obtained by aging an alloy according to the present invention at various temperatures and for various lengths of time. Also set forth in Table II are the properties of an excellent copper-beryllium spring-contact alloy, Berylco 25, in the solution-treated condition and after a typical effective aging treatment, which properties are included for comparison purposes.

Table II.—Typical properties obtained with an alloy containing 9.29% Ni, 1.65% Si, 4.68% Al, balance Cu after various aging treatments

Aging treatment		In the Soft (Solution-Treated) Condition			In the Hard (Aged) Condition						
Temp., ° F.	Time, hours	Hardness, R30T	BHN Equivalent	Elongation, percent	Hardness, R30N	BHN Equivalent	Yield Strength, 10 ³ p. s. i.	Tensile Strength, 10 ³ p. s. i.	Elongation, percent	Proportional Limit, 10 ³ p. s. i.	Modulus of Elasticity, 10 ⁶ p. s. i.
750.....	¼	57	96	39	37.5	210	113.5	117.5	14	82.2	19.9
750.....	2	57	96	39	44	242	121	133	9	93.8	18.8
800.....	¼	57	96	39	42.5	233	110	127.3	12	94.6	19.5
800.....	1	57	96	39	45	248	123	135	9	99.5	20.9
850.....	¼	57	96	39	44.5	245	122	133	8	102	19.6
850.....	2	57	96	39	47.5	264	130	143	5.5	104	19.4

Cu-Be (Beryleo 25)											
550.....	¾	52	87	45	52	300	131	160	6	95.5	19.2

Both the experimental alloy and the Cu-Be alloy were cold worked, prior to aging, an amount (about 20 percent) equal to the working encountered in typical forming operations.

It is apparent from the disclosure herein that alloys within the critical compositional ranges set forth compare favorably with the copper-beryllium alloy most popular for spring purposes. No other type of copper-base alloy has been shown, or is known at present, to provide comparable properties after an aging heat treatment. Some of the advantages of the alloy compositions of this invention are the absence of beryllium or other critical element, the good formability in the soft condition, and the high proportional limit, modulus of elasticity, yield and tensile strengths, together with the good ductility and electrical conductivity in the hard condition characteristic of these alloys. The properties are unique for copper-base alloys not containing beryllium. Except for the alloys of this invention, the copper-beryllium alloys are the only ones known to provide the combination of properties required for satisfactory current-carrying springs.

Summarizing, the critical compositional ranges are:

- Nickel—5% to 15%, preferably 8% to 11%.
- Silicon—0.1% to 2.0%, preferably 1.0% to 1.8%.
- Aluminum—0.1% to 6.0%, preferably 2.0% to 5.0%.
- Magnesium—0.1% to 2.0%, preferably 0.3% to 0.7% (or both aluminum and magnesium within the respective ranges specified).
- Copper—balance.

Smaller amounts of nickel, silicon, aluminum, or magnesium will not provide the exceptionally good properties required for conducting springs, as set forth in Table I and in Table II. No advantage is obtained by increasing the nickel content, while increases of silicon, aluminum, or magnesium above the critical proportions render the alloy brittle and difficult to work and fabricate. Of course, impurities may be tolerated, provided they are not present in excessive amounts. The minor residual impurities commonly present in copper, such as zinc, iron, manganese, phosphorus, tin, lead, chromium, cadmium, and titanium do not adversely affect the alloys of this invention.

Alloys having the compositions listed below were prepared and further tested thoroughly in factory production gratification tests in connection with the present invention:

Ni	Si	Al	Mg	Cu
5.83	1.92	2.45	----	Balance
9.51	1.80	0.63	----	Balance
9.29	1.65	4.68	----	Balance
9.68	1.81	----	0.36	Balance

Each of the above-listed alloys, when hot-rolled to 0.125-inch thick strip, annealed, cold-rolled to 0.019-inch thick strip, and solution annealed at a temperature of from 1700° F. to 1750° F., was formed adequately by a severe punching operation into the intricate shapes of various springs. After aging treatments at temperatures ranging from 800° F. to 900° F. for suitable times ranging from 15 minutes to four hours, the alloys under test exhibited excellent properties and were entirely suitable for use as current-carrying springs in various types of electrical equipment. The excellent properties of these alloys make them suitable also for use in diaphragms and other pressure-sensitive devices for electrical instruments, control equipment, and for various other purposes.

What is claimed is:

- A copper-base alloy consisting essentially of from about 5% to about 15% nickel, from about 0.1% to about 2.0% silicon, from about 0.1% to about 6.0% aluminum, and the balance essentially all copper.
- A copper-base alloy consisting essentially of from about 8% to about 11% nickel, from about 1.0% to about 1.8% silicon, from about 2.0% to about 5.0% aluminum and the balance essentially all copper.
- An electrical current-carrying spring-contact member made of a copper-base alloy consisting essentially of from about 8% to about 11% nickel, from about 1.0% to about 1.8% silicon, from about 2.0% to about 5.0% aluminum and the balance essentially all copper.
- A copper-base alloy consisting essentially of from about 5% to about 15% nickel, from about 0.1% to about 2.0% silicon, from about 0.1% to 2.0% magnesium, and the balance essentially all copper.
- A copper-base alloy consisting essentially of from about 8% to about 11% nickel, from about 1.0% to about 1.8% silicon, from about 0.3% to about 0.7% magnesium, and the balance essentially all copper.
- A copper-base alloy consisting essentially of from about 8% to 11% nickel, about 1.0% to 1.8% silicon, about 0.3% to 0.7% magnesium, and characterized by good formability in the soft (solution-treated) condition and capable of being age hardened substantially.
- An aged copper-base alloy consisting essentially of from about 8% to 11% nickel, from about 1.0% to 1.8% silicon, from about 0.3% to 0.7% magnesium, and characterized by having a hardness of at least about 49 Rockwell 30 N (equivalent BHN 275), a yield strength of at least about 115,000 p. s. i., a tensile strength of at least about 134,000 p. s. i., an elongation of about at least 5%, a proportional limit of about at least 87,000 p. s. i., and a modulus of elasticity of about at least 19,000,000 p. s. i.
- A copper-base alloy consisting essentially of from about 5% to about 15% nickel, from about 0.1% to

about 2.0% silicon, an amount within the respective specified percentages of at least one material selected from the group consisting of aluminum (from about 0.1% to about 6.0%) and magnesium (from about 0.1% to about 2.0%), and the balance essentially all copper.

9. A copper-base alloy consisting essentially of from about 8% to about 11% nickel, from about 1.0% to about 1.8% silicon, an amount within the respective specified percentages of at least one material selected from the group consisting of aluminum (from about 2.0% to about 5.0%) and magnesium (from about 0.3% to about 0.7%), and the balance essentially all copper.

10. A copper-base alloy consisting essentially of from about 5% to about 15% nickel, from about 0.1% to about 2.0% silicon, an amount within the respective specified percentages of at least one material selected from the group consisting of aluminum (from about 0.1% to about 6.0%) and magnesium (from about 0.1% to about 2.0%), and the balance essentially all copper, having a precipitation phase consisting principally of nickel silicide, said at least one material selected from said group serving to provide increased matrix strain

around the precipitate nuclei of the nickel-silicide-rich phase for increased strengthening and hardening during said aging of the alloy.

11. An electrical current-carrying spring-contact member made of a copper-base alloy consisting essentially of from about 5% to about 15% nickel, from about 0.1% to about 2.0% silicon, an amount within the respective specified percentages of at least one material selected from the group consisting of aluminum (from about 0.1% to about 6.0%) and magnesium (from about 0.1% to about 2.0%), and the balance essentially all copper.

References Cited in the file of this patent

UNITED STATES PATENTS

2,031,315	Jennison	Feb. 18, 1936
2,074,604	Bolton	Mar. 23, 1937
2,157,934	Hensel et al.	May 9, 1939

FOREIGN PATENTS

254,042	Great Britain	July 1, 1926
680,213	Germany	Aug. 3, 1939