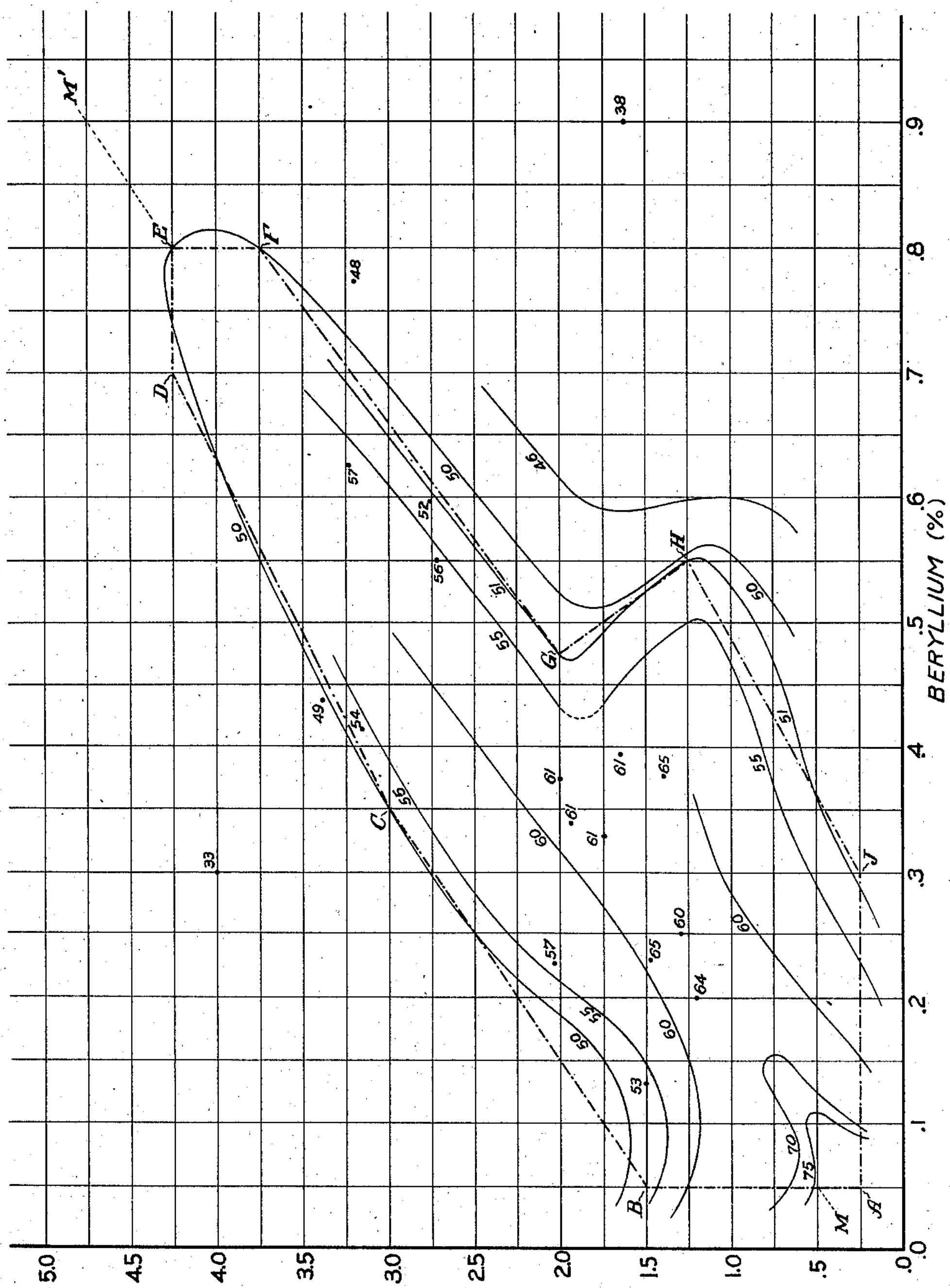
July 14, 1942. C. B. SAWYER ET AL 2,289,593

ALLOY

Filed Aug. 3, 1940



INVENTORS:

CHARLES B. SAWYER

BENGT R. F. KJELLGREN

GERALD G. CHRISTENSEN

BY G G Christensen

ATTORNEY

Patented July 14, 1942 **2,289,593**

UNITED STATES PATENT OFFICE

2,289,593

ALLOY

Charles B. Sawyer, Cleveland Heights, Bengt R. F. Kjellgren, University Heights, and Gerald G. Christensen, Cleveland, Ohio

Application August 3, 1940, Serial No. 350,780

10 Claims. (Cl. 148—32)

This invention relates to beryllium copper alloys containing nickel, and it relates more especially to such alloys in which the copper is more than about 90%, and the nickel and beryllium together amount to less than about 5%.

Beryllium copper alloys containing nickel form the subject of several patents which have been granted in the past. United States Patent No. 1,893,984, issued to Corson, is the earliest United States patent which relates to alloys of the type here under consideration. It discloses ternary copper-beryllium-nickel alloys which may contain up to about 2% beryllium and up to as much as 40% nickel. Other patents issued subsequently have dealt with other ranges of beryllium and nickel in ternary alloys, while still others have been concerned with quaternary alloys in which the nickel and beryllium ranges have been diversified, and in which various fourth-metal alloying additions have been included. While a wide range of mechanical properties can be obtained in these prior alloys, depending on the relative proportions of the various alloying elements of each, few of the alloys have possessed maximum electrical conductivities of much over fifty per cent of that of copper. The few that have conductivities in excess of this latter value contain relatively large amounts of alloying ingredients which are considerably more expensive than nickel, and in addition possess certain metallurgical characteristics which militate against their use under some conditions.

It is a primary object of this invention to provide an improved beryllium copper alloy in which nickel is the basic third-metal addition but in which fourth-metal additions may also be included either to enhance the effects of the nickel or to improve the alloy in some of its metallurgical aspects without diminishing appreciably the advantages to be gained from the primary nickel addition.

It is another primary object to provide an alloy of the class described which possesses improved electrical conductivity.

It is another primary object to provide an age-hardened alloy of the class described which possesses high electrical conductivity together with desirable mechanical properties such as strength, hardness, proportional limit, fatigue limit, abrasion resistance, etc.

It is another object to provide an improved alloy of the class described which is suitable for use as an electrical conductor in both the as-cast unheat-treated condition, and in its numerous heat-treated conditions.

It is a further object to provide a pressure welding electrode composed of an improved age-hardened alloy of the class described.

It is another object to provide an improved alloy of the class described which may be cast readily into intricate shapes.

It is another object to provide an improved alloy of the class described which may be fabricated readily from the cast condition by means of any of the usual processes of forging, rolling, hammering, drawing, extruding, etc.

Numerous industrial devices and apparatus require parts which are made of material having good electrical conductivity and possessing moderate hardness with resistance to wear or abrasion. Welding electrodes of various types exemplify such uses. Copper alloys have, in general, been most successful in meeting the needs of such applications. Few copper base alloys, however, have adequate hardness together with adequate electrical conductivity. It has been known for a number of years that copper may be heat-hardened when it is alloyed with small amounts of beryllium. The values of hardness obtainable in such binary beryllium copper alloys are more than adequate to meet the requirements of the applications mentioned above. However, such binary alloys do not have suitable electrical conductivities. Furthermore, such binary alloys are unduly expensive since beryllium contents of around 1.0% or more are necessary to provide the hardening effect. It has also been known for a number of years that the amount of beryllium required to harden copper can be materially reduced if various third metals are introduced into the binary alloys. Corson pointed out in the patent referred to above that nickel is a third-metal addition to beryllium copper which has this effect. Other workers have shown that several other elements also have the same kind of effect. When the properites of these various ternary beryllium copper alloys became known, it seemed likely that they would be able to meet the requirements of hardness and electrical conductivity which are involved in the previously mentioned applications. It has been found, however, that few of the ternary alloys or even of the more complex alloys of copper and beryllium have values of electrical conductivity and hardness which are desired. In the beryllium-copper-nickel alloys in particular, Corson has indicated that conductivities of around 33% may be expected in such alloys after they have been worked and precipitation-hardened to a condition which gives the alloy suitable mechanical properties. The hardness of the alloy has been indicated to be around 110 Brinell. It has commonly been considered that while greater hardness values might be obtained in the Corson alloys, conductivities in excess of the value stated could not be expected, this being on the general theory that as the hardness is increased, the conductivity is decreased. However, in investigating the low beryllium alloys of the Corson field, we have found that exceptionally good electrical conductivities can be obtained along with desirable values of hardness by suitably proportioning the beryllium and nickel contents of the alloys.

This invention is based on the discovery that an improved alloy results if the nickel and beryllium contents are proportioned to fall within a restricted range of values. The improved alloy which results is characterized by high electrical conductivity, particularly after a precipitation heat-treatment, and by a desirable range of mechanical and metallurgical properties which adapt it for use in numerous fields of application. Preferred compositions lying within the limits of the invention are particularly adapted for use as pressure-exerting welding electrodes. Other preferred compositions are adapted for use in unheat-treated castings which should, in use, possess strength, hardness and good electrical or thermal conductivity. Still other preferred compositions are adapted for use in applications which require exceptionally high electrical or thermal conductivity with only moderate strength or hardness. All compositions falling within the limits of the invention are characterized by their susceptibility to precipitation hardening heat-treatments, and by their capacity for being fabricated by the usual metal working methods and apparatus. When the alloys are so fabricated and suitably heat-treated, they possess even higher values of electrical conductivity than can be obtained in the as-cast heat-treated metal.

The invention will be understood more fully through reference to the accompanying drawing which illustrates graphically the approximate limits of the invention together with typical values of electrical conductivity which may be obtained in as-cast age-hardened alloys having suitable proportions between the beryllium and nickel contents thereof. The limits of the invention are marked by the closed traverse ABCDEFGHJA, and the electrical conductivities of alloys falling within the approximate field of invention are shown by means of contours which mark the approximate outer limits of regions in which may be obtained at least the electrical conductivity which is indicated by the index number of each contour. It will be understood that the index number represents the conductivity measured in per cent of the conductivity of standard copper. Thus, an index number of 50 indicates that in the field bounded by the "50" contour, electrical conductivities of 50% or more are obtainable. The conductivities indicated in the drawing were measured at about 23° C., and represent values which may be obtained in an as-cast, unworked alloy having the indicated beryllium and nickel contents. Prior to measurement, each composition was subjected to an age-hardening heat-treatment consisting of: quenching the alloy in water after it had been heated for two hours at a temperature of about 900° C.; then reheating the quenched alloy for a period of two hours at a temperature of about 500° C. It will be recognized that this is substantially the heat-treatment disclosed by Corson as suitable for precipitation-hardening of his ternary beryllium-copper-nickel alloys.

It will be observed from the drawing that for the particular heat-treatment employed, a conductivity of not less than about 50% can be obtained in alloys containing as much as .8% beryllium, by increasing the nickel proportionately as the beryllium content is increased. This is merely a general statement, however, for it will be observed that it does not apply strictly to the whole field of the invention. It will be noted particularly, however, that the increase in nickel content is nearly a linear function of the increase in beryllium content in the particular region which is adjacent to the diagonal line M—M'. An investigation of this region has shown that an optimum ratio prevails between the nickel and beryllium contents. It has been found that the ratio may be expressed by the following formula:

$$\frac{\%\text{ nickel minus } 0.25}{\%\text{ beryllium}}=5$$

When the proportions of nickel and beryllium comply approximately with this formula, better values of electrical conductivity can be secured than in alloys which do not comply therewith.

It has been pointed out above that the contours of the drawing mark approximate outer limits of areas of composition which contain alloys capable of possessing electrical conductivities of indicated values. It should be appreciated, however, that while the contours are based on and derived from conductivity measurements of numerous alloys which fall within the scope of the invention, yet the contours are only careful estimates of fields of alloy compositions, expressed graphically rather than verbally. They should be regarded more in the nature of guides to the field of composition which represents the invention, rather than being regarded as exact graphical delineations of precise critical boundaries between fields of composition. In other words, it should be recognized that the contours may be subject to some degree of correction as the number of conductivity measurements of distinct alloy compositions is extended throughout the field of the invention.

Through reference to the drawing it will be observed that when lines are drawn to connect the points A, B, C, D, E, F, G, H, J, and A in succession, a closed traverse is formed which encloses the field of discovery which represents the invention. Furthermore, it will be observed that the area of compositions so enclosed includes alloys which, for the most part, have electrical conductivities of 50% or more after they have been subjected to the particular heat-treatment on which the drawing is based. Included within the closed traverse ABCDEFGHJA are other areas which include alloys capable of being heat-treated so as to possess electrical conductivities of, for example, 55%, 60%, 65%, or 70% or more. Specific examples selected from these various areas are described below, where it will be seen that the alloys possess other desirable mechanical properties in addition to these exceptionally high conductivities.

One area containing compositions which are of particular merit is the area bounded by the traverse ABCDEFGA. Another area which constitutes a preferred portion of the invention is the area which includes alloys containing from about .75% nickel to about 2.0% nickel with beryllium contents falling within the limits of the invention as marked by the traverse ABCDEFGHJA. Still another preferred range lies within the closed traverse ABCDEFGHJA, but includes alloys which contain from about .75% nickel to about 2.0% nickel, and from about 0.20% beryllium to about .45% beryllium. Another field of alloys having merit for particular uses is the field of the invention which lies between about .05% beryllium and about .20% beryllium, with nickel between about .25% and about 1.75%. Still another compositional field containing alloys having outstanding properties is the field marked by traverse BCDEFGB with nickel contents above about 2%. A preferred range within this latter field is bounded by the traverse and by nickel contents of more than about 2% and less than about 3.75%. The following specific examples selected from each of these indicated fields will provide a more complete understanding of the merits of the alloys of the invention.

TABLE I.—*As-cast alloys*

Be	Ni	Treatment	Tensile (p. s. i.)*	Yield (p. s. i.)*	Elongation	Elec. cond.	Brinell hardness
					Percent	*Percent*	
.69	3.30	Quenched from 900° C.; aged 2 hours @ 500° C	98,000	45,000	15	50.9	215
		Quenched from 900° C.; aged 2 hours @ 400° C	100,000	57,000	13	48.5	215
		As-cast; not heat-treated	----	----	----	45.0	----
.59	2.78	As-cast; not heat-treated	----	----	----	46.5	----
		Quenched from 900° C.; aged 2 hours @ 450° C	----	----	----	51.4	209
.23	1.47	As-cast; not heat-treated	----	----	----	48.5	----
		Quenched from 900° C.; aged 2 hours @ 550° C	73,000	47,000	----	57.7	181
.23	1.48	As-cast; not heat-treated	----	----	----	42	----
		Quenched from 900° C.; aged 1 hour @ 450° C	86,500	52,500	5	53	----
.22	1.49	As-cast; not heat-treated	39,000	11,000	----	39	----
		Quenched from 1,000° C.; aged 2 hours @ 500° C	80,000	60,000	----	61.5	200
.28	1.39	Quenched from 900° C.; aged 2 hours @ 500° C	86,000	60,000	----	53.0	200
.13	.74	As-cast; not heat-treated	----	----	----	49.0	----
		Quenched from 1,000° C.; aged 2 hours @ 500° C	----	----	----	73.0	----
		Quenched from 900° C.; aged 4 hours @ 475° C	51,400	37,250	----	71.2	124

*Pounds per square inch.

The following examples illustrate the improvements in properties and conductivity which can be obtained by subjecting the as-cast alloys of the invention to mechanical working treatments of various kinds.

An alloy containing .32% beryllium and 1.47% nickel was quenched from about 900° C. and was then forged cold to about 80% of its original cross-sectional area. The forged material was subsequently aged by heating it at 450° C. for two hours. Its electrical conductivity in this age-hardened condition was 69%. This may be compared with a conductivity of about 55% in the as-cast condition after having been age-hardened by quenching from about 900° C. and reheating for two hours at 500° C.

A cast ingot analyzing .25% beryllium and 1.33% nickel was quenched after having been heated for three hours at 900° C. The quenched ingot was then hot-rolled at about 900° C. to a diameter of 5/16 inch. The rolled material was again heated to 900° C. and quenched, and then cold drawn from 5/16" to .178" diameter. The proportional limit of the latter material was determined, 18" samples being used. The following table indicates the results obtained under various conditions of heat-treatment.

TABLE II

	Tensile (p. s. i.)	Prop. limit (p. s. i.)
As quenched from 900° C	43,000	4,700
As quenched from 900° C.; aged 2 hours @ 400° C	91,000	46,600
As quenched from 900° C.; aged 2 hours @ 425° C	102,500	55,800

Another lot of 5/16" hot-rolled material was reheated to 900° C. for three hours and quenched, and was then drawn cold from 5/16" diameter to .128" diameter. Half of the latter material was heated at 900° C. for one hour and quenched, and reduced in area about 40% by cold-drawing. The material was then tested in the as-drawn condition and in several as-drawn and heat-treated conditions with the following results:

Table III

	Tensile (p. s. i.)	Yield (p. s. i.)	Elec. cond.
			Per cent
As drawn	72,000	67,000	39.0
As drawn and aged 2 hours @ 400° C	122,000	103,000	57.5
As drawn and aged 2 hours @ 425° C	128,000	104,000	60.0
As drawn and aged 2 hours @ 500° C	115,000	80,000	64.0

The other half of the above lot of the .128" diameter cold-drawn material was heated at 750° C. for one hour, quenched, and reduced in area about 40% by cold-drawing. The following results indicate the nature of the material.

Table IV

	Tensile (p. s. i.)	Yield (.5%)	Elec. cond.
			Per cent
As drawn	72,000	----	59.8
As drawn and aged 2 hours @ 450° C	80,000	64,000	70.8

It will be noted that the worked alloys have very desirable properties in both the as-worked and in the worked and heat-treated conditions. It will also be noted that the electrical conductivity of alloys of the invention may be improved considerably by working them, and especially by age-hardening the "quenched and worked" material.

It will be understood from the above examples that the alloys of the invention possess diverse properties which make certain compositional groups more suitable for some uses than for others. In general, alloys of the invention which contain less than about 2% nickel and more than about .2% beryllium are particularly adapted for use in electrical conductors of all kinds which require high electrical conductivity together with hardness and resistance to fatigue. By reason of their high proportional limits, these alloys make good current-conducting springs. By reason of their hardness, strength, and electrical conductivity, they are especially good for use in pressure-exerting welding electrodes of all kinds, and for many uses where abrasion- and wear-resistance are desired. Motor and generator slip-rings exemplify the latter uses.

Alloys of the invention which contain more than about 2% nickel are especially useful in making articles which are used in their as-cast condition and which need good electrical or thermal conductivities. The alloys are extreme fluid in the molten state and can be readily cast into intricate shapes. Furthermore, the alloys have nearly as good values of conductivity in the as-cast condition as in the usual heat-treated conditions. It will be understood, of course, that the conductivity of an alloy in the as-cast condition is determined to a large extent by the casting conditions. If the molten metal is solidified in a chill mold, its conductivity will be somewhat low and its properties are more apt to approach the properties of as-quenched material. If the metal is solidified in a sand mold where it is cooled more slowly, the conductivity will be higher and the properties will approach the properties of material which has been age-hardened slightly.

It has been indicated above that alloys containing between about .05% and .20% beryllium, and nickel between about .25% and 1.75% constitute another preferred field of the invention. It will be observed from Table I that alloys in this field have moderate values of strength and hardness in age-hardened as-cast or worked conditions. In addition, they possess unusually high electrical and thermal conductivities. By reason of these properties the alloys of the field are especially suitable for making hammered or forged articles which require exceptionally high conductivities without unusually high strength or hardness. Many parts of electrical and thermal instruments, machines, and apparatus involve such requirements.

Those skilled in the art will appreciate that the merits of copper-beryllium-nickel alloys of the invention may be retained even though the alloys contain appreciable amounts of other metals or elements. Such other constituents may be added to enhance the effects of the nickel-beryllium proportions of the invention and/or to improve diverse metallurgical characteristics of the alloys without impairing one or more of the electrical, thermal or mechanical properties appreciably.

Reference has been made in the preceding specification to the thermal conductivities of alloy compositions of the invention. Inasmuch as it has long been an established fact that thermal and electrical conductivities of most metals parallel each other closely under most conditions, the electrical conductivities indicated throughout the specification may be regarded as being close approximations also of relative thermal conductivity.

Having now disclosed the invention, what we claim is:

1. A copper base alloy containing beryllium and nickel in amounts which fall substantially within the graphical area of composition bounded by the closed traverse formed by joining the following points in sequence: from .05% beryllium at .25% nickel, thence to .05% beryllium at 1.5% nickel, thence to .35% beryllium at 3.0% nickel, thence to .70% beryllium at 4.25% nickel, thence to .80% beryllium at 4.25% nickel, thence to .80% beryllium at 3.75% nickel, thence to .475% beryllium at 2.0% nickel, thence to .55% beryllium at 1.25% nickel, thence to .30% beryllium at .25% nickel, thence to the starting point of .05% beryllium at .25% nickel, the balance being substantially all copper.

2. An alloy as claimed in claim 1 wherein the nickel and beryllium are present in approximately the following ratio:

$$\frac{\%\ \text{nickel minus } 0.25}{\%\ \text{beryllium}}=5$$

3. An alloy as claimed in claim 1 wherein the beryllium content is between about .2% and .4%, and the nickel content is less than 2.0%.

4. An alloy as claimed in claim 1 wherein the nickel content is more than 2.0%.

5. An age-hardened copper base alloy containing beryllium and nickel in amounts which fall substantially within the graphical area of composition bounded by the closed traverse formed by joining the following points in sequence: from .05% beryllium at .25% nickel, thence to .05% beryllium at 1.5% nickel, thence to .35% beryllium at 3.0% nickel, thence to .70% beryllium at 4.25% nickel, thence to .8% beryllium at 4.25% nickel, thence to .8% beryllium at 3.75% nickel, thence to .475% beryllium at 2.0% nickel, thence to .55% beryllium at 1.25% nickel, thence to .30% beryllium at .25% nickel, thence to the starting point of .05% beryllium at .25% nickel, the balance being substantially all copper.

6. An age-hardened alloy as claimed in claim 5 wherein the nickel and beryllium are present in approximately the following ratio:

$$\frac{\%\ \text{nickel minus } 0.25}{\%\ \text{beryllium}}=5$$

7. An age-hardened alloy as claimed in claim 5 wherein the beryllium content is between about .2% and .4% and the nickel content is less than 2.0%.

8. An age-hardened alloy as claimed in claim 5, said alloy being characterized by an electrical conductivity of more than about 50% of the conductivity of standard copper after the said alloy has been age-hardened by subjecting it to a solution heat-treatment at about 900° C., quenching, and reheating for approximately two hours at 500° C.

9. A casting made of the alloy as claimed in claim 1 wherein the nickel content is between about 2% and 4.25%.

10. A pressure-exerting welding electrode composed of an age-hardened alloy as claimed in claim 5, said electrode being characterized by an electrical conductivity of more than about 50% of the conductivity of standard copper after the said electrode has been age-hardened by subjecting it to a solution heat-treatment at about 900° C., quenching, and reheating for approximately two hours at 500° C.

CHARLES B. SAWYER.
BENGT R. F. KJELLGREN.
GERALD G. CHRISTENSEN.