May 19, 1964 P. J. SCHERBNER 3,133,843

METHOD OF LIQUID FORMING A COPPER-BERYLLIUM ALLOY

Filed June 14, 1961

Fig. 1.

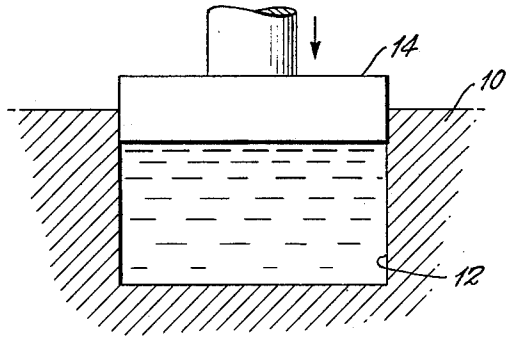
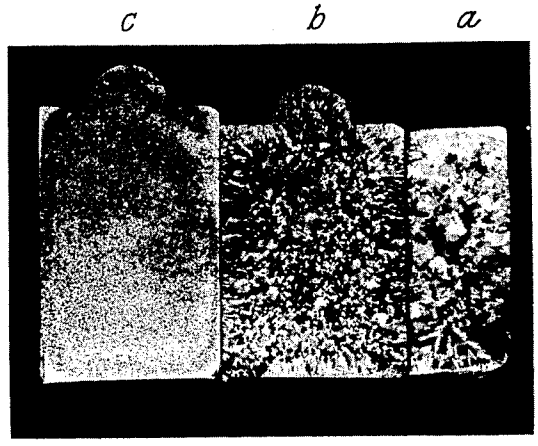



Fig. 2.




Inventor

Paul Joseph Scherbner

By Shoemaker and Mattare

Attorneys

United States Patent Office

3,133,843

Patented May 19, 1964



3,133,843

# METHOD OF LIQUID FORMING A COPPER-BERYLLIUM ALLOY

Paul Joseph Scherbner, Boyertown, Pa., assignor to The Beryllium Corporation, Reading, Pa., a corporation of Delaware

Filed June 14, 1961, Ser. No. 117,159
2 Claims. (Cl. 148—3)

This invention relates to a new beryllium-copper alloy and particularly to a method of forging the same whereby a product having superior qualities is obtained.

An important object of the invention is the production of a new beryllium-copper alloy in which the chemical composition has an effect on the ultimate properties of greater magnitude than that exhibited by the chemical composition of any other known beryllium-copper alloy.

In many industries use is made of metal products which are required to be submerged in water, particularly in sea water where such products become damaged relatively quickly as, for example, underwater repeater housings employed in communication systems.

The beryllium-copper alloy product of the present invention produced in accordance with the hereinafter described process while adaptable to many uses, is particularly well adapted to use in the fabrication of underwater repeater housings or other structures which must be subjected to sea water by reason of the improved chemistry of the composition and the method of forging the metal.

More specifically it is an object of the present invention to produce an alloy product characterized by a microstructure composed of considerably finer and equiaxed crystals or grains than that usually found in other beryllium-copper casting alloys processed by any form of hot work and substantially completely free of Beta phase. As a result the alloy of the present invention processed by either liquid forging or extrusion exhibits improved physical properties such as high tensile strength, yield strength, elongation and hardness.

In the drawings:

FIG. 1 is a diagrammatic illustration of a die and plug for applying pressure to the melted alloy.

FIGS. 2*a*, 2*b* and 2*c* illustrate respectively an etched section of a sand casting of a beryllium-copper alloy showing coarse grain structure; a liquid forging of the alloy under one temperature also showing a relatively coarse grain structure, and another liquid forging of the alloy at a temperature complying with the requirements of the present invention and showing the desirable fine grain texture.

The improved alloy of the present invention consists essentially of beryllium, cobalt and copper as hereinafter more specifically set forth. The beryllium content falls in a relatively narrow range and it is found that by holding the beryllium to this relatively narrow range and by holding the cobalt content to an extremely narrow range, as hereinafter specifically disclosed, optimum properties are realized by subsequent liquid forging or hot extruding cast billets of the alloy.



In addition, such optimum properties may be varied to a number of desirable combinations of elongation, yield point, hardness and elastic limit by a series of heat treatments described in the table hereinafter set forth. Microexamination has shown that the precise chemical composition of the present alloy results in either liquid forged or extruded parts essentially free of the undesirable Beta phase found in other beryllium-copper alloys.

Products produced from the alloy of the present invention and processed by either liquid forging in the manner hereinafter set forth or by hot extrusion, exhibit after heat treatment the superior properties referred to and possess a crystal structure essentially all alpha and exhibit substantially no undesirable beta phase. This single phase alpha structure reduces galvanic action within the parts to an irreducible minimum as it has been established that there can be a difference in potential electromotive force between the alpha and beta phases under some conditions which, when occurring, can result in corrosion and ultimate breakdown of the product.

Although the mechanics of the phenomena responsible for the improved alloy and product herein set forth are not fully understood, it is felt that they are due to a combination of precisely controlled chemical composition of the alloy coupled with the extreme pressure processing methods of liquid forging and hot extrusion. No other existing beryllium copper alloy will exhibit the same, or as good a combination of, physical properties when processed in accordance with the present invention by the same liquid forging or hot extrusion methods.

The alloy of the present invention has the following preferred composition:

| | Percent |
|---|---|
| Beryllium | 1.65 to 1.75 |
| Cobalt (with cobalt+iron+nickel held to 0.25–0.65%) | 0.20 to 0.40 |
| Copper | Balance |

Impurities of Al, Si, Pb and others are held to maximum limits as follows:

| | |
|---|---|
| Aluminum | 0.20 maximum |
| Silicon | 0.30 maximum |
| Lead | 0.005 maximum |
| Others, total | 0.20 maximum |

The following Table I sets forth specific compositions for the alloy within the ranges hereinabove disclosed, together with varying factors associated with each of the indicated compositions in the liquid forging thereof.

*Table I*

| | Be | Co | Co+Ni+Fe | Furnace temp., °F. | Pour temp., °F. | Die temp., °F. | Plug temp., °F. | Pressure, tons* | Time to go under press (sec.) | Total time under press (min.) |
|---|---|---|---|---|---|---|---|---|---|---|
| (a) | 1.69 | .23 | .33 | 1,925 | 1,875 | 700 | 520 | 100 | 15 | 3 |
| (b) | 1.70 | .23 | .33 | 1,900 | 1,875 | 620 | 480 | 120 | 18 | 3 |
| (c) | 1.71 | .28 | .37 | 1,920 | 1,875 | 500 | 500 | 200 | 15 | 3 |
| (d) | 1.72 | .39 | .51 | 1,900 | 1,875 | 645 | 630 | 100 | 13 | 3 |
| (e) | 1.65 | .34 | .52 | 1,960 | 1,875 | 840 | 810 | 100 | 15 | 3 |
| (f) | 1.70 | .35 | .42 | 1,960 | 1,875 | 740 | 600 | 100 | 18 | 3 |
| (g) | 1.70 | .38 | .51 | 1,930 | 1,875 | 635 | 630 | 100 | 14 | 3 |
| (h) | 1.70 | .37 | .44 | 1,930 | 1,875 | 690 | 685 | 100 | 14 | 3 |
| (i) | 1.60 | .30 | .53 | 1,975 | 1,875 | 750 | 695 | 100 | 18 | 3 |
| (j) | 1.70 | .25 | .31 | 1,910 | 1,860 | 600 | 750 | 200 | 15 | 3 |
| (k) | 1.71 | .23 | .29 | 2,050 | 1,875 | 580 | 710 | 200 | 13 | 3 |

Balance Cu.
*Plug area 14 square inches.

The liquid forging in accordance with the hereinafter set forth specific example, and in accordance with Table I, is adapted specifically for direct liquid forging of the desired product itself. It is also contemplated that billets formed by the liquid forging process may then be subsequently extruded as is also herein set forth.

The minimum mechanical properties for liquid forgings of the alloy are after heat treatment as follows:

| | |
|---|---|
| Ultimate tensile strength | 140,000 p.s.i. min. |
| Yield strength at 0.01% offset | 100,000 p.s.i. min. |
| Elongation | 1% min. |
| Rockwell hardness | 33% RC min. |

One important feature of the present invention resides in the liquid forging procedure upon the alloy according to which procedure the liquid metal is subjected to a pressure of not less than 14,000 p.s.i. for a specified period of time. There is no maximum limit to the pressure which may be employed, such being limited only by the strength of the dies and size of the equipment. The minimum pressure is, however, critical and must be applied uniformly over the entire mass in the mold or die.

The accompanying drawing illustrates diagrammatically in FIG. 1 a die body **10** having formed therein the mold or press chamber **12**. A mold body or plug **14** fits snugly in the material receiving chamber **12** and pressure is applied by suitable ram to the plug immediately following the introduction of the molten metal into the mold or die chamber and the pressure of at least the specified minimum is applied to the metal through the plug and maintained for a desired period which is approximately three minutes.

The theory underlying the liquid forging procedure whereby the claimed superior results are obtained with the particular alloy set forth is that, allowing the metal to cool slowly without the application of pressure results in the shrinking away of the metal from the die faces. This then results in the formation of an insulating zone between the metal and the faces of the die which further reduces the rate of cooling. Under these conditions a coarse grain or crystal structure will be produced with considerable beta.

In the present invention the relatively rapid chill of the alloy which occurs in the liquid forging operation, in combination with the specific pressures and temperatures employed, results in the particular alloy being forged having the special characteristics stated.

By holding the pressure applied by the plug at the values shown for the different alloys set forth in Table I, the metal is constantly forced against all surfaces of the die and plug, maintaining an intimate contact between the solidifying metal and mold wall, thus permitting rapid heat transfer so that a relatively rapid chill is effected. Thus by this procedure the resulting product either in the form of the ultimate product to be produced or in the form of a billet, shows a fine equiaxed crystal grain formation which is almost completely free of any beta.



The liquid forging procedures for the present invention are set forth in Table I and in this connection reference will here be had to the designated procedure followed for forging an alloy as set forth in line *c* of the table.

The selected heat of the beryllium-copper alloy consisting, by weight of 1.71% beryllium, 0.37% of combined cobalt, nickel and iron, of which the cobalt content comprises 0.28% and with the remainder copper, was melted and degassed. The furnace temperature was approximately 1920° F., which is approximately 45° F. above required pouring temperature of 1875° as set forth in the second column to the right of line *c* of the table.

The molds or dies for receiving the melt were assembled and coated with a suitable parting agent, such as carbon from smoking acetylene flame, providing the necessary die lubricant, such lubricant being applied just prior to the pouring. The die was at a temperature of 500° F. and the plug at a temperature of 500° F. As soon as the pouring temperature of 1875° F. was attained the metal was skimmed and poured into the waiting mold or die and the plug immediately placed into position on top of the melt and the entire unit placed beneath the press. In the forging of this alloy the time lapse between transferring the melt from the furnace to the mold was 15 seconds.

A total pressure of 200 tons was imposed upon the melt in the die and this pressure was maintained for a minimum of three minutes.

Table I shows procedures followed in the liquid forging of the other alloys set forth in the horizontal lines 2–*b* and *d* to *k*. The alloys set forth in the table cover the range hereinbefore given from the minimum to maximum amounts for the chemicals employed and it will be seen that in all instances not less than 14,000 p.s.i. of pressure was applied to the melt in the die or mold for a minimum time of three minutes.

The following Table II sets forth in the horizontal lines *a* to *n* thereof, the treatments given to the alloy in the different chemical proportions and the results of tests made on the liquid forgings of the same. The latter designations correspond to those of Table I.

*Table II*

| | Sol'n anneal temp., ° F. | Aging temp., ° F. | Ultimate tensile strength (p.s.i.) | Yield strength .01% offset (p.s.i.) | Modulus of elasticity (p.s.i.× $10^6$) | Elong. percent in 2" | Rockwell Hardness "C" scale |
|---|---|---|---|---|---|---|---|
| (a) | 1,500–1,525 | 650–675 | 153,200 | 123,500 | ---------- | 3.0 | 34.0 |
| (b) | 1,500–1,525 | 650–675 | 157,100 | 111,200 | ---------- | 2.5 | 35.0 |
| (c) | 1,500–1,525 | 650–675 | 188,200 | 116,400 | ---------- | 2.0 | 33.0 |
| (d) | 1,500 | 650 | 167,500 | 114,500 | 18.2 | 2.5 | 37.3 |
| (e) | 1,500 | 650 | 157,900 | 109,500 | 18.2 | 3.0 | 33.5 |
| (f) | 1,500 | 650 | 157,800 | 110,500 | 17.9 | 4.0 | 37.0 |
| (g) | 1,525 | 650 | 163,100 | 111,800 | 18.5 | 3.5 | 34.0 |
| (h) | 1,525 | 650 | 159,800 | 111,600 | 18.2 | 3.5 | 36.7 |
| (i) | 1,500 | 650 | 149,900 | 101,600 | 18.0 | 2.5 | 35.3 |
| (j) | 1,500–1,525 | 650–675 | 158,000 | [1] 142,000 | ---------- | 2.0 | 33.0 |
| (k) | 1,500–1,525 | 650–675 | 149,000 | 133,000 | ---------- | 1.0 | 35.0 |
| (l) | 1,475 | 650 | 155,500 | 141,200 | 18.3 | 3.0 | 36.3 |
| (m) | 1,475 | 650 | 154,800 | 140,000 | 17.7 | 3.5 | 34.0 |
| (n) | 1,475 | 650 | 156,000 | 140,800 | 18.2 | 5.0 | 36.5 |

[1] .2% offset.

Referring now to line *c* of Table II, which corresponds to line *c* of Table I, the liquid forging produced by the procedure set forth in line *c* of Table I was solution annealed for three hours at 1525° F. water quenched, and then given a three-hour aging at 675° F. The ultimate tensile strength as shown was 188,200 and yield strength at .01% offset 116,400 with elongation of 2% in 2" and the forging gave a Rockwell hardness on the "C" scale of 33.0.

In the procedure of pouring the molten material into the mold or die the temperature of the metal must be between 1850° and 1875° F., which is just above the point of liquidus, the alloy normally melting at 1775° F.

As set forth in Table I, the time lapse between the time of pouring in the beginning of the application of pressure is very short, ranging from 13 to 18 seconds, the time given for the alloy of line *c* of Table I being 15 seconds. This short time lapse interval is critical as the pressure must be applied before the metal begins to solidify or prior to the point of solidus. Such time interval is normally under 20 seconds but of course may vary slightly depending upon the amount of metal being poured and the size of the mold or die.

A density test run on the forging formed with the alloy set forth in line *c* gave a result of 8.39 gms./cm.$^3$ as compared to ordinary densities of 8.32–8.35 in wrought sand cast alloys of the same composition. In this connection it is to be noted that small differences in densities have great significance.

The mechanical properties of extruded alloy bars obtained from liquid forged 5¼" diameter billets which were extruded to 2¾" diameter rods and then solution annealed at 1450°–1475° for three hours and aged for three hours at 650° to 675° F. The following table sets forth the mechanical properties of such extrusions from liquid forged billets.

The billets from which the extruded bars were formed were selected at random from the compositions set forth in lines *a* to *k* of Table I and liquid forged and treated according to this table and according to Table II.

The minimum mechanical values for extruded beryllium copper alloy are:

| | |
|---|---|
| Ultimate tensile strength | 165,000 p.s.i. min. |
| Yield strength | 110,000 p.s.i. min. |
| Elongation | 3% min. |
| Hardness | 33 RC min. |

The following Table III sets forth the mechanical properties of such extruded bars.

*Table III*

| Solution annealing temp., ° F. | Aging temp., ° F. | Ultimate tensile (p.s.i.) | Yield strength .01% offset (p.s.i.) | Elongation (percent) | Hardness, RC |
|---|---|---|---|---|---|
| 1,450–1,475 | 650–675 | 200,500 | 119,600 | 11.5 | 33.8 |
| 1,450–1,475 | 650–675 | 200,600 | 117,800 | 9.0 | 34.0 |
| 1,450–1,475 | 650–675 | 201,400 | 110,800 | 11.0 | 33.6 |
| 1,450–1,475 | 650–675 | 203,800 | 110,800 | 10.5 | 33.9 |
| 1,450–1,475 | 650–675 | 204,600 | 110,700 | 10.5 | 34.0 |

For comparison with the properties shown in Table III for the extruded liquid forgings, Table IV below shows similar bars extruded from direct cast billets as distinguished from liquid forged billets.

*Table IV*

| Solution annealing temp., ° F. | Aging temp., ° F. | Ultimate tensile (p.s.i.) | Yield strength .01% offset (p.s.i.) | Elongation (percent) | Hardness, RC |
|---|---|---|---|---|---|
| 1,450–1,475 | 650–675 | 179,500 | 133,700 | 5.0 | 36.0 |
| 1,450–1,475 | 650–675 | 180,900 | 131,000 | 3.5 | 36.0 |

Comparison of Tables III and IV shows that the mechanical properties of extrusions from liquid forged billets are much finer than the properties of extrusions from direct cast billets of the alloy.

Microscopic examination of tensile specimens set forth in Table III reveals that the material had an exceedingly small grain size and only slight traces of beta phase. It is probable that the extra fine grain size and almost complete absence of the beta phase is responsible for these excellent mechanical properties.



Referring now to the drawings, the illustrated FIGS. 2*a*, 2*b* and 2*c* show transverse sections of billets of the beryllium-copper alloy to illustrate different grain sizes occurring in sand castings and liquid forgings of the alloy.

These sectioned pieces or billets were etched and examined for grain size and soundness and it will be seen that in the sand cast billet represented by FIG. 2*a* the alloy shows a relatively large grain size or clearly shows a coarse grain.

FIG. 2*b*, illustrating a section of a liquid forging of the alloy, shows also a relatively coarse grained structure, this forging being carried out at a temperature of about 1950° F.

FIG. 2*c* shows the desirable fine grained structure of the liquid forged alloy resulting from following the procedure of the present invention where the forging was effected at a temperature of approximately 1850° F.

Measurements of grain size from macro etched liquid forged parts produced from the alloy were found to possess fine, equiaxed grains. Measurements of these grains indicated an average grain size of 0.090 mm. Microscopic examination revealed a grain structure essentially free of large beta particles. Under higher magnification, some fine beta particules could be observed, but these were well dispersed throughout the material.

As this invention may be embodied in several forms without departing from the spirit or essential characteristics thereof, the present embodiment is therefore illustrative and not restrictive, since the scope of the invention is defined in the appended claims, and all changes that fall within the metes and bounds of the claims, or that form their functional as well as conjointly cooperative equivalents, are therefore intended to be embraced by those claims.

I claim:

1. The method of producing a beryllium-cobalt-copper alloy body consisting of beryllium from about 1.65% to about 1.75%; cobalt from about 0.20% to about 0.40% and remainder copper of not less than 99.295% purity; characterized by a fine equiaxed crystal grain structure of substantially all Alpha phase; an ultimate tensile strength of 204,600 p.s.i.; a yield strength at 0.01% offset of 119,600 p.s.i.; an elongation of 11.5% in 2" and a Rockwell "C" hardness of 33.8; which method consists of pouring the melt, with a time lapse of not more than 18 seconds, at a temperature not exceeding 1875° F., into a die heated to at least 500° F. and with an upper limit of 840° F., closing the die with a plug heated to at least 500° F. and with an upper limit of 810° F., imposing a pressure on the metal in the die of at least 1400 p.s.i. for not less than 3 minutes, then forming the body from the ingot by extrusion, solution annealing the body at about 1475° F. for at least 3 hours, water quenching and then ageing the annealed body at about 650° F. to about 675° F. for approximately 3 hours.

2. The method of forming by liquid forging, a beryllium-cobalt-copper alloy body characterized by a fine equi-axed crystal grain structure of substantially all alpha phase; an ultimate tensile strength of 188,200 p.s.i. minimum; a yield strength of 0.01% offset 116,400 p.s.i. minimum; an elongation of 2% minimum in 2 inches and a Rockwell "C" hardness of 33.8; which method consists in forming the beryllium-cobalt-copper alloy with a beryllium content limited to the range of from 1.65% to 1.75%, a cobalt content limited to the range of 0.20% to 0.40% and the remainder being copper of at least 99.295% purity, then melting the alloy in a furnace temperature of approximately 1920° F., then pouring the melt at a temperature of 1875° F., with a time lapse of not more than 18 seconds, into a die mold having a temperature in the range of from 500° F. to 840° F. and immediately closing the mold with a plug having a temperature in the range of from 500° F. to 810° F., then imposing a pressure of 200 tons upon the melt for a minimum of 3 minutes, then solution annealing the forging produced by

the forging procedure for 3 hours at 1525° F., water quenching, and then ageing for 3 hours at 675° F.

**References Cited** in the file of this patent

UNITED STATES PATENTS

| | | |
|---|---|---|
| 2,172,639 | Hessenbuch | Sept. 12, 1939 |
| 2,142,495 | Hessenbuch | Mar. 5, 1940 |



OTHER REFERENCES

Reiss et al.: "Ultra High Pressure Casting," Transactions of the American Foundrymen's Society, vol. 68, 1960 (date relied on May 9–13, 1960), pages 89–96.

Freedman and Wallace: "Vibration of Solidifying metals," Transactions of American Foundrymen's Society, vol. 65, 1957, pp. 583–588.

# UNITED STATES PATENT OFFICE
# CERTIFICATE OF CORRECTION

Patent No. 3,133,843 May 19, 1964

Paul Joseph Scherbner

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 6, line 50, for "1400" read -- 14,000 --.

Signed and sealed this 27th day of July 1965.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents