Patented Oct. 30, 1923. 1,472,738

# UNITED STATES PATENT OFFICE.

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## ALUMINUM-BASE ALLOY AND METHOD OF TREATING IT.

No Drawing. Application filed December 20, 1921. Serial No. 523,690.

*To all whom it may concern:*

Be it known that we, ROBERT S. ARCHER and ZAY JEFFRIES, citizens of the United States, and residents of Cleveland, in the county of Cuyahoga and State of Ohio, have invented a new and useful Improvement in Aluminum-Base Alloys and Methods of Treating Them, of which the following is a specification.

The object of this invention is to provide an aluminum base alloy, which, after having been worked and quenched is relatively soft and workable and remains so for an indefinite period when maintained at room temperature, and which, when subsequently artificially aged above room temperature, possesses advantageous physical properties.

A further object is to provide a method of treating certain worked aluminum base alloys so that they may be readily shaped or worked at any time and subsequently have improved physical properties.

Aluminum base alloys containing various constituents in different percentages are known, and some of them have been commercially used for some time. Also it is old in the art to quench some of these alloys from certain temperatures and to age them either naturally or artificially, that is to say, either at room temperatures or at elevated temperatures for the purpose of improving their physical properties. For example a typical composition of such a commercial aluminum base alloy is one consisting of 4% copper, 0.5% magnesium and 0.5% manganese, the remainder being commercial aluminum containing small percentages of various elements as impurities. When quenched according to standard practice this alloy has a tensile strength of about 40,000 to 45,000 lbs. per square inch, and an elongation of 20% and upwards in two inches. After being quenched the alloy gradually ages at ordinary room temperatures until at the end of about four days its tensile strength may be 55,000 to 60,000 lbs. per square inch, especially in thin sheets. Its elongation is usually not greatly affected, but may either be increased or decreased. However, its plasticity or workability is decreased by the aging.

Our invention is predicated upon our discovery that a worked aluminum base alloy free from magnesium and containing not less than about 3.5% copper, when quenched will age little if any at normal or room temperature, and that when artificially aged it will have its strength and hardness increased according to the extent of aging. Stated differently, we have discovered that by omitting magnesium as an essential element from aluminum base alloys containing not less than about 3.5% copper, there is produced an alloy, which, when quenched from about 500° C., will not age at room temperature, and which may at any subsequent time be artificially aged to produce different physical properties.

In the practice of the invention copper alone may be the alloying element, or other elements such as manganese, chromium, silicon, and zinc may be added. The choice of a particular composition is governed largely by the use to which the articles made of it are put. If it is desired to obtain an easily workable alloy having reasonably good physical properties, the copper content should be in the neighborhood of from about 3.5 to 4.5%. If high strength and hardness are to be obtained it is desirable to have a high copper content in some cases as high as 5.0%, and also to have manganese or chromium present in small quantities, preferably not exceeding about 1.0%, and silicon present in amount not exceeding about 1.0%. In such an alloy the physical properties are obtained at some sacrifice of working properties, especially the breaking down of the ingots, a matter which will presently be explained. The copper content of the alloy may be more than 5%, although it is quite difficult to roll or forge alloys containing more than this percentage of copper.

The quenching temperature of the alloy may vary according to the amount and character of the alloy constituents present. In all cases, however, the best results are obtained when the alloy has been quenched from the temperature at which as much as possible of the copper and other alloying elements have gone into solution in the aluminum. By way of example, if the copper content is about 4.5% or more, the quenching temperature should not exceed about 540° C. for the best results. The lower the copper content the higher is the

permissible temperature from which the alloy may be quenched without injury, and the lower is the temperature at which maximum or nearly maximum physical properties can ultimately be produced. For example, an alloy containing about 3.5% copper can be safely quenched from a temperature of about 590° C., but such alloy may by artificial aging be given nearly maximum physical properties when quenched from a temperature as low as 500° C. In its quenched state the alloy is relatively soft and readily workable, and its physical properties remain unchanged, or substantially so, for an indefinite period, which is an important advantage when it is desired to press, stamp or otherwise shape or form the alloy at a later time, in contra-distinction to naturally aging alloys, which must be worked, if at all, immediately after quenching.

By varying the time and temperature of aging, various combinations of strength and hardness may be produced which are intermediate between those of the metal as quenched and the highest obtainable by proper aging. However, the alloys are preferably aged at temperatures between about 100 and 175° C. When it is not desired to subject the alloy to cold working after quenching, it may be quenched to the desired artificial aging temperature, rather than to room temperature. When an alloy is aged at higher temperatures, say about 200°, the first effect is hardening, the hardness being somewhat less than that produced by aging at 150° C. Prolonged aging at 200° C. or thereabouts produces decreased tensile strength and hardness, and usually a reduction in the ductility of the alloy. However, useful alloys can be produced when aged at a temperature of 200° C. if the duration of the aging is not too long. The increase in hardness is more rapid the higher the aging temperature, although the maximum hardness or strength obtainable by aging at 200° C. is not as great as the maximum obtainable at 150° C.

The invention thus briefly described may be further explained and fully understood by reference to a few examples of the alloys we have produced and tested. Having reference first to aluminum base alloys containing copper alone, other elements being present only as impurities, a worked alloy containing 3.78% copper, when quenched from a temperature of 530° C. had a tensile strength of 42,250 lbs. per square inch and an elongation of 24% in two inches. When aged for about twenty-four hours at 150° C. it had a tensile strength of 50,300 lbs. per square inch and an elongation of 22% in two inches. Some of this alloy aged for forty hours at 100° C. had a tensile strength of 50,100 lbs. per square inch and an elongation of 25% in two inches. As showing the improved physical properties brought about by increasing the copper content, an alloy containing 4.06% copper, quenched from 530° C. after being heated at such temperature for one hour and then aged for twenty-two hours at a temperature of 150° C., had a tensile strength of 55,300 lbs. per square inch and an elongation of 25% in two inches. Also an alloy containing 4.86% copper quenched from a temperature of 530° at which it was maintained for one-half hour and aged at 150° for sixteen hours had a tensile strength of 59,700 lbs. per square inch and an elongation of 18.5% in two inches. The latter of these alloys when aged for forty hours at 100° C. had a tensile strength of 57,000 lbs. per square inch and an elongation of 25% in two inches.

Alloys containing 4.5% copper and from about 0.5 to 1% manganese may be taken as examples of alloys containing manganese in addition to copper. After forging or otherwise hot working such alloys and then quenching them from a temperature of about 530° C. maintained for one-half hour, they had tensile strengths ranging from 40,000 to 43,700 lbs. per square inch and elongations of from 20 to 25% in two inches. As in the case of alloys containing copper alone, the physical properties of the alloys containing manganese as an added element do not change to any noticeable extent on aging at room temperature even for months. When aged at a temperature between about 100 to 130° C. their strengths increase markedly and their elongations may increase or decrease or remain practically unchanged. A forged alloy having a tensile strength of 55,000 lbs. per square inch and an elongation of 25% in two inches can be easily obtained by aging for twenty-four hours to forty-eight hours at a temperature slightly below 130° C., the hardness being increased at the same time. If the quenched alloy is aged at a temperature between about 130 and 175° C. for a period of about fifteen to twenty-four hours, the tensile strength may be about 60,000 lbs. per square inch, the elongation 18% in two inches, and the Brinnell hardness number about 120.

As an example of the stability of this type of alloy after being quenched, we found that forged test bars of an alloy containing 4.68% copper and 0.68% chromium had a tensile strength of 45,000 lbs. per square inch and an elongation of 24% in two inches immediately after quenching, while other bars from the same ingot of the same alloy tested after aging a year at room temperature had a tensile strength of 47,000 lbs. per square inch, and an elongation of 26% in two inches. Still other bars from the same ingot of the same alloy after artificial aging at 150° C. had a tensile strength vary-

ing between 55,000 and 59,000 lbs. per square inch and an elongation of 20% in two inches.

The physical properties of the alloy we provide may be further improved by the addition of silicon in greater proportion than usually found as an impurity in good grade commercial aluminum ingots. The silicon may be increased to a total of from about 0.5% to 1.0%. An alloy containing such an added percentage of silicon has increased tensile strength both after quenching and after artificial aging, and is relatively ductile especially when aged at from about 100° to 175° C. In the form of rolled sheets it has been found to have a tensile strength of more than 65,000 lbs. per square inch, and an elongation of more than 20% in two inches after having been quenched from a temperature above 500° C, and aged at about 125° C. for forty eight hours.

As a specific example of alloys containing copper, manganese and silicon, an alloy containing 3.5% copper, 0.93% manganese and 0.6% silicon, after having been quenched from a temperature of 530° C. had a tensile strength of 43,100 lbs. per square inch and an elongation of 21% in two inches. When artificially aged at 150° C. for twenty-two hours the alloy had a tensile strength of 58,000 lbs. per square inch and an elongation of 20% in two inches. The preferred alloy, that is to say, the alloy capable of being given the best physical properties is one containing about 4.5% copper, 0.75% manganese and 0.75% silicon, quenched from a temperature of from about 500 to 540° C. and aged at a temperature of from about 100 to 175° C.

We have found that an alloy containing 3.95% copper, 1.22% iron and 0.31% silicon, the silicon being present in this proportion as a natural consequence of the manufacture of the aluminum as distinguished from being intentionally added, develops a maximum tensile strength of 31,600 lbs. per square inch and an elongation of 20.5% in two inches, after it has been quenched and artificially aged. It thus appears that the relatively large percentage of iron present in the alloy decreases the maximum strength obtainable. The same has been found to be true of calcium in the absence of magnesium. For example, an alloy containing 3.98% copper, 0.64% calcium, and 0.29% silicon, developed a maximum tensile strength of 32,100 lbs. per square inch with an elongation of 20% in two inches. However, we have found that the bad effects of iron may be largely, if not entirely, overcome by the addition of silicon. The silicon, should be at least equal to, and preferably in excess of, the iron content, and may be present in quantities up to about 5% without seriously impairing the good physical properties of the alloy. However, the cold-working properties of an alloy having such a high silicon content are not as good as those having between about 0.5% and 1% silicon.

The addition of chromium to the alloy containing more than about 3.5% copper and free from magnesium is beneficial. For example, an alloy in the form of rolled sheet ⅛" thick containing 4.72% copper and 0.68% chromium had a tensile strength of 64,100 lbs. per square inch and an elongation of 20% in two inches after having been quenched from a temperature of 530° C. and aged for twenty-two hours at 150° C.

Small amounts of zinc, say up to 5% may be present in the alloy without substantially altering its character, although, because of certain disadvantages incident to the purposeful introduction of zinc, we prefer not to add it, but desire to point out that zinc may be present and that the invention is not limited to alloys free from it.

The alloys we provide have important advantages, some of which have been mentioned. The present commercial high strength aluminum alloys containing magnesium are dfficult to work. In the first place, there is more trouble in breaking down the ingots, than in the alloys we provide. In the second place, after the worked commercial alloys have been quenched from a relatively high temperature, there is no known way of keeping them from aging spontaneously except by cooling them to a very low temperature, for example, that of liquid air. As a consequence thereof their hardening and loss in plasticity are not under control, and there is substantially only one set of physical properties obtainable, namely, those arrived at after the alloys have completely aged, although these properties may be somewhat improved by artificial aging. As distinguished from this, the alloys which we provide remain soft and plastic at room temperature when quenched, and their strength and hardness may be increased by controlling the time and temperature of aging so that any degree of strength and hardness between that obtained immediately after quenching and the maximum obtainable by the most effective aging can be imparted to articles made from the alloys. It is frequently necessary in the fabrication of certain articles of worked aluminum base alloys to put them into finished shape by deforming them at room temperature, as by pressing, stamping, etc. In the present commercial alloys it is generally necessary to effect this working within a few hours and sometimes within an hour after they are quenched because their aging at room temperature may reduce the plasticity to such an extent that cold-forming processes may otherwise not be possible. With the alloys which we provide the deforming operations can be performed at any time after the alloys

are quenched, and at any subsequent time the articles can be aged to increase the hardness and strength.

Throughout this specification and in the appended claims our improved alloy is described and defined as being free from magnesium. By this we mean that the alloy contains no purposely added magnesium. It may contain traces of magnesium such as will not effect any, or substantially any, natural aging of the alloy. For example, if magnesium-containing scrap be inadvertently used in the preparation of the alloy, traces of magnesium will be present in the final product. However, the use of such material should be avoided if natural aging is to be entirely, or substantially entirely prevented.

We claim as our invention:

1. A worked and quenched workable aluminum base alloy having substantially fixed physical properties while maintained at room temperature, free from magnesium and containing not less than about 3.5% copper, the physical properties of the alloy being capable of variable improvement by aging the alloy at a temperature above about 100° C.

2. A workable aluminum base alloy free from magnesium and containing not less than about 3.5% copper, the alloy having been worked and subsequently quenched from a temperature above about 500° C., and having substantially fixed physical properties while maintained at room temperature, the physical properties of the alloy being capable of variable improvements by aging the alloy at a temperature above about 100° C.

3. An aluminum base alloy free from magnesium and containing not less than about 3.5% copper, the alloy having been worked and subsequently quenched from a temperature above about 500° C., and subsequently aged at a temperature above about 100° C.

4. An aluminum base alloy free from magnesium and containing not less than about 3.5% copper, the alloy having been worked and subsequently quenched from a temperature of from about 500° to 540° C., and subsequently aged at a temperature of from about 120° to 160° C.

5. A worked and quenched workable aluminum base alloy having substantially fixed physical properties while maintained at room temperature, free from magnesium and containing manganese and not less than about 3.5% copper, the physical properties of the alloy being capable of variable improvements by aging the alloy at a temperature above about 100° C.

6. A workable aluminum base alloy free from magnesium and containing manganese and not less than about 3.5% copper, the alloy having been worked and subsequently quenched from a temperature above about 500° C., and having substantially fixed physical properties while maintained at room temperature, the physical properties of the alloy being capable of variable improvements by aging the alloy at a temperature above about 100° C.

7. An aluminum alloy free from magnesium and containing manganese up to about 1% and not less than about 3.5% copper, the alloy having been worked and subsequently quenched from a temperature above about 500° C., and subsequently artificially aged at a temperature above about 100° C.

8. A worked and quenched workable aluminum base alloy having substantially fixed physical properties while maintained at room temperature, free from magnesium and containing copper, manganese and silicon, the physical properties of the alloy being capable of variable improvements by aging the alloy at a temperature above about 100° C.

9. A workable aluminum base alloy free from magnesium and containing manganese up to about 1%, silicon up to about 1%, and copper not less than about 3.5%, the alloy having been worked and subsequently quenched from a temperature above about 500° C., and having substantially fixed physical properties while maintained at room temperature, the physical properties of the alloy being capable of variable improvements by aging the alloy at a temperature above about 100° C.

10. An aluminum base alloy free from magnesium and containing manganese up to about 1%, silicon up to about 1%, and copper not less than about 3.5%, the alloy having been worked and subsequently quenched from a temperature above about 500° C., and subsequently artificially aged at a temperature above about 100° C.

11. A worked and quenched workable aluminum base alloy having substantially fixed physical properties while maintained at room temperature, free from magnesium and containing about 4.5% copper and 0.75% manganese, the physical properties of the alloy being capable of variable improvements by aging the alloy at a temperature above about 100° C.

12. An aluminum base alloy free from magnesium and containing about 4.5% copper and 0.75% manganese, the alloy having been worked and subsequently quenched from a temperature above about 500° C., and artificially aged at a temperature above about 100° C.

13. A worked and quenched workable aluminum base alloy having substantially fixed physical properties while maintained at room temperature, free from magnesium and containing about 4.5% copper, 0.75%

manganese and 0.75% silicon, the physical properties of the alloy being capable of variable improvement by aging the alloy at a temperature above about 100° C.

14. An aluminum base alloy free from magnesium except as an impurity and containing about 4.5% copper, 0.75% manganese, and 0.75% silicon, the alloy having been worked and subsequently quenched from a temperature above about 500° C., and artificially aged at a temperature above about 100° C.

15. The method of treating a worked aluminum base alloy free from magnesium and containing not less than about 3.5% copper, which consists in quenching the alloy from a temperature above about 500° C., thereby rendering the alloy capable of having its physical properties improved at any time by artificial aging.

16. The method of treating a worked aluminum base alloy free from magnesium and containing manganese and not less than about 3.5% copper, which consists in quenching the alloy from a temperature above about 500° C., thereby rendering the alloy capable of having its physical properties improved at any time by artificial aging.

17. The method of treating a worked aluminum base alloy free from magnesium and containing manganese, silicon and not less than about 3.5% copper, which consists in quenching the alloy from a temperature above about 500° C., thereby rendering the alloy capable of having its physical properties improved at any time by artificial aging.

18. The method of treating a worked aluminum base alloy free from magnesium and containing manganese up to about 1%, silicon up to about 1% and copper not less than about 3.5%, which consists in quenching the alloy from a temperature above about 500° C., thereby rendering the alloy capable of having its physical properties improved at any time by artificial aging.

19. The method of treating a worked aluminum base alloy free from magnesium and containing about 4.5% copper and about .75% manganese, which consists in quenching the alloy from a temperature above about 500° C., thereby rendering the alloy capable of having its physical properties improved at any time by artificial aging.

20. The method of treating a worked aluminum base alloy free from magnesium and containing not less than 3.5% copper, which consists in quenching the alloy from a temperature above about 500° C., and subsequently aging the alloy at a temperature above about 100° C.

21. The method of treating a worked aluminum base alloy free from magnesium and containing not less than 3.5% copper, which consists in quenching the alloy from a temperature above about 500° C., and subsequently aging the alloy at a temperature of from about 120° C. to 160° C.

22. The method of treating a worked aluminum base alloy free from magnesium and containing manganese and not less than about 3.5% copper, which consists in quenching the alloy from a temperature above about 500° C., and subsequently aging the alloy at a temperature above about 100° C.

23. The method of treating a worked aluminum base alloy free from magnesium and containing manganese and silicon and not less than about 3.5% copper, which consists in quenching the alloy from a temperature above about 500° C., and subsequently aging the alloy at a temperature above about 100° C.

24. The method of treating a worked aluminum base alloy free from magnesium and containing about 4.5% copper and about .75% manganese, which consists in quenching the alloy from a temperature above about 500° C., and subsequently aging the alloy at a temperature of from about 120° C. to about 160° C.

In testimony whereof, we hereunto sign our names.

ROBERT S. ARCHER.
ZAY JEFFRIES.

Witnesses:
MERLE B. PRICE,
THOMAS J. DORAN.