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UNITED STATES PATENT OFFICE.

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ALUMINUM-COPPER ALLOY.

No Drawing. Original application filed January 4, 1921, Serial No. 435,024. Divided and this application filed April 29, 1924. Serial No. 709,748.

To all whom it may concern:

Be it known that we, ZAY JEFFRIES, of Shaker Heights, and ROBERT S. ARCHER, of Lakewood, both in the county of Cuyahoga and State of Ohio, have invented certain new and useful Improvements in Aluminum-Copper Alloys, of which the following is a full, clear, and exact description.

The invention which forms the subject of our present application (a division of our copending application Serial No. 435,024, filed January 4, 1921 now Patent No. 1,508,556, issued September 16, 1924) relates to the production of aluminum alloy castings, particularly castings made of alloys containing silicon or copper or both, with or without other metals, and its chief object is to provide a simple and effective method which will produce light-weight castings with a hitherto unobtainable combination of physical properties, especially as regards elastic limit, tensile strength and ductility. To this and other ends the invention consists in the novel method and product hereinafter described.

As will be seen from the subjoined description, the invention is based upon the combination of certain steps, some of them novel with us, and in part the invention resides in the discovery that certain alloys are especially susceptible to improvement by heat treatment after casting, and that certain methods of casting such alloys further and peculiarly adapt them to such treatment; and in the additional discovery of temperature and duration of heat treatment in combinations appropriate to the particular alloys and methods of casting involved. With the aid of these discoveries we have been able to produce castings having improved physical properties with respect to elastic limit, tensile strength and ductility to an extent hitherto unattainable, with the result that it is now possible to use aluminum alloy castings for purposes for which their use has previously been impracticable.

The tensile strength of commercially pure cast aluminum is about 12,000 pounds per square inch and its elongation about 25 per cent. By adding varying proportions of hardening metals, particularly copper and zinc, it is possible to increase the tensile strength so that the sand cast alloy will have an ultimate strength of nearly 30,000 pounds per square inch, but the elongation is thereby reduced to less than 5 per cent. By adding a very large amount of zinc the tensile strength may be raised to approximately 40,000 pounds per square inch, but the elongation is reduced to almost nothing, and the alloy is very brittle. By casting any of these alloys in a chill mold, the tensile strength may be increased in general by approximately 5,000 pounds per square inch and the elongation may also be increased. But it has heretofore been impossible to simultaneously produce tensile strengths of over 30,000 pounds per square inch and an elongation of 8 per cent or over.

By our method, however, we have been able to extend very greatly the range of the tensile strength and elongation, and of the combination of the two, so that we have obtained castings having very much higher tensile strengths than those hitherto known in the art, and yet elongations better than those at present obtained with casting alloys having only moderate tensile strengths.

In general, elongation decreases as tensile strength increases, but our new method enables us to produce very much better simultaneous results in both of these respects than have hitherto been possible.

It is also to be noted that the high tensile strength alloys previously known have required the presence of substantial amounts of zinc, even in many cases up to 33 per cent, and have therefore been considerably heavier than pure aluminum, while we obtain our results with an addition, in general, of not more than 5 to 10 per cent of total heavier alloying metal or metals and yet produce a casting which is not only stronger and more ductile but likewise lighter than would otherwise be obtained.

Various prior investigators have proposed to obtain castings possessing the desirable combination of high tensile strength and ductility by heat treatment of a properly made casting, but their contributions to the art have so far not led to commercially useful results. For example, the best results published prior to our work are those

of Wilm, who reports having obtained chill castings with a tensile strength of about 32,000 pounds per square inch and an elongation of 5 to 7 per cent. More recently Merica and Karr have by heat treatment of an alloy containing copper and a large amount of zinc, obtained a tensile strength of 41,200 pounds per square inch but with an elongation of only 4 per cent. This alloy contained about 19 per cent of heavy alloying metals and hence had a specific gravity greater than 3. With lighter alloys, for example one containing small amounts of copper, magnesium and manganese, they obtained a tensile strength of 35,500 pounds per square inch and an elongation of 2.3 per cent. In none of the three cases mentioned above were the properties enough better than those possessed by untreated castings to justify the cost of the treatment.

Our invention involves the discovery of important reasons for previous lack of practical success along this line, and embraces a combination of old and new steps so that we are now able by means of our improved method to produce articles, cast in either sand or chill molds, having physical properties far superior to those of any such castings hitherto produced. By means of our novel method we have produced sand castings of an aluminum alloy containing 4 per cent copper and 0.2 per cent magnesium, having a tensile strength of about 50,000 pounds per square inch and an elongation of 8.5 per cent, with relatively high elastic limit; also chilled castings having a tensile strength of 54,000 pounds per square inch and an elongation of 18 per cent, with relatively high elastic limit.

This combination of high tensile strength and elongation enables these castings to be used for purposes for which aluminum castings have not hitherto been suitable and for which it has been necessary to use the much heavier ferrous materials such as steel or malleable iron.

One example of our process comprises as its first step the preparation of an aluminum alloy containing about 3 to 5.5 per cent copper, preferably 4 per cent, with no magnesium or with magnesium up to about 0.3 per cent, the iron content in particular being as low as possible, preferably not to exceed 0.25 per cent. Iron and silicon are always present as impurities in aluminum as now obtainable, and a part of our invention consists in so choosing the raw materials as to limit the iron content of the finished alloy to an amount as low as possible, preferably not over 0.25 per cent. The use of silicon in substantial amounts will be considered hereinafter.

The ingredients are mixed in the molten state, care being taken to avoid excessive temperatures at all stages of the melting operation, and the mixture is poured into either a sand mold or a chill mold, and caused to solidify. After solidification a microscopic examination reveals masses of an aluminum-rich constituent surrounded by a network of a hard, brittle constituent, which has been reported to be chiefly $CuAl_2$. In the form of a sand-cast test bar about one half inch in diameter the alloy has a tensile strength of 18,000 to 25,000 pounds per square inch with an elongation of 2.5 to 4 per cent in two inches. A chill cast test bar of the same size has a tensile strength of about 24,000 to 28,000 pounds per square inch and an elongation up to 6 per cent in two inches. The iron in the alloy is found both in the form of needles, reported to be $FeAl_3$, and in a different form, apparently as a silicide of iron. The presence of the iron ($FeAl_3$) needles up to a certain amount is beneficial to the strength and ductility of the alloy in the cast condition, probably due to the fact that the ordinary path of fracture in the cast alloys is through the brittle network of $CuAl_2$ which is strengthened by the iron needles. It is found that these iron needles are very detrimental to the physical properties of the casting after the heat treatment discussed below.

The next step in the example of our process now being described consists in heating the castings to, and maintaining them at, a temperature of 500° to 540° C. for a period of time depending upon the results desired and the manner in which the casting was made. The principal object of heating the castings at the temperature mentioned is to cause the $CuAl_2$ in the network to go into solution in the solid aluminum-rich constituent. It is found that at the temperatures referred to, this $CuAl_2$ dissolves slowly, in fact surprisingly slowly. In sand castings the time necessary for maximum solution of this $CuAl_2$ may be as much as 48 hours, at the temperatures mentioned; while in chill castings, because of the finer network structure, the time for maximum solution is less—for example, 7 hours has been found to be sufficient in some cases.

If the copper content exceeds the amount which is soluble in the solid state just below the freezing point of the eutectic, some of the $CuAl_2$ will remain in the network after heat treatment, and the physical properties of the casting will not be as good as can be obtained with a lower copper content. In most if not all cases the best combination of physical properties results only when substantially all of the $CuAl_2$ in the network has been dissolved in the aluminum-rich constituent.

A temperature of heat-treatment high enough to fuse the eutectic, that is, the temperature of incipient fusion of the alloy,

is in most cases unfavorable to the best ultimate results, and it has been found that in some instances 540° C. is too high unless the rate of heating up to that point is very slow or the time of heating below that point is comparatively long.

A further result of heating the castings at the temperature mentioned is to re-dissolve any $CuAl_2$ which may have precipitated in small particles within the aluminum-rich constituent rather than in the network during the previous cooling of the castings.

After the heating period the castings are preferably cooled rapidly, as by quenching in water. By the above described procedure, sand castings of an alloy containing 4 per cent copper, 0.2 per cent magnesium and less than .25 per cent iron have been produced with a tensile strength, after aging, of about 50,000 pounds per square inch and an elongation of 8.5 per cent. Chill castings have been made by the same process, of the same alloy, having a tensile strength of 54,000 pounds per square inch after aging and an elongation of 18 per cent.

As stated above, quenching is preferable to slow cooling, but good results can in some cases be obtained by cooling in a current of air. A marked difference has been observed between the results obtained by cooling in a current of air and those obtained by cooling in still air. Even slow cooling, however, produces improvement as compared to the cast condition, not only in the physical properties but also in resistance to corrosion.

The physical properties of castings subjected to the treatments above referred to can be further changed by artificial aging, that is, by heating them, immediately after cooling, to a temperature of 100° to 150° C. for a time, one hour being in many cases sufficient. As a result of such heating the tensile strength is increased and the elongation decreased, and the elastic limit is increased very markedly.

The method of casting is an important factor. Thus a method producing fine grain and improved physical properties, yields castings which are generally more amenable to the heat-treatment than does a casting method which produces coarse grain. For example a bar having a cylindrical test section two inches long and a half-inch in diameter, composed of alloy containing about 4 per cent copper and cast in a sand mold, has a tensile strength of about 18,000 pounds per square inch and an elongation of about 4 per cent. If the bar is heat-treated by our method, say at a temperature around 520° C. for 24 hours, the tensile strength may be more than doubled (increasing to about 37,000 pounds per square inch) and the elongation is increased to about 12 per cent, or three times its original value. On the other hand, if the bar is cast in such a manner as to cause rapid solidification, say by chill casting in an iron mold, it will have, after heat-treatment by our method, a tensile strength of about 40,000 pounds per square inch, and an elongation of about 20 per cent.

The addition, to the aluminum-copper alloys, of a small amount of magnesium, say 0.2 or 0.3 per cent, increases the tensile strength and elastic limit, but is less favorable to ductility or elongation.

For the best results, our experience indicates that the iron content of the aluminum copper alloy should be low, but if care is taken to make the castings by the chill method, a higher percentage of iron can be used, good results being obtained with chill castings containing even more than 0.4 per cent of iron. On the other hand, in the case of heat-treated sand castings, more than that amount of iron gives less advantageous physical properties. The presence of the iron is evidenced by crystalline needles, probably of the composition $FeAl_3$, which usually form in the net work containing $CuAl_2$. These needles are not soluble to any considerable extent in the solid aluminum alloy, and remain intact and in place while the $CuAl_2$ is absorbed into the body of the solid-solution crystals of aluminum during heat-treatment. The iron needles tend to have a beneficial effect on the physical properties of the alloy as cast, that is before heat-treatment, but after the $CuAl_2$ in the network has been dissolved into the aluminum-rich constituent by heat-treating, the iron needles are a source of weakness, diminishing both tensile strength and elongation.

The complete elimination of the iron needles is therefore highly desirable, but the complete avoidance of iron or even its reduction below about 0.25 per cent is not always practicable commercially. However, when silicon is present in excess of the iron, the quantity of $FeAl_3$ formed is lessened, and some of the iron combines with the silicon to form what appears to be an iron silicide. We have discovered that the latter compound freezes in a form less harmful than the needles of $FeAl_3$. In the case of chill castings, it is found that the $FeAl_3$ needles are much smaller than in the sand castings, and hence they are not so objectionable in the heat-treated casting. Since there is considerable difficulty in commercially producing aluminum free from or containing less than 0.25 per cent of iron, the desired silicon-iron relationship is most advantageously obtained by adding silicon when necessary. For example, if the iron content of the aluminum ingot is 0.35 per cent and the silicon 0.3 per cent, we find it advantageous to add about 0.35 per cent silicon. We have also found that the addi-

tion of a small quantity of zinc, say 0.25 per cent, improves both the tensile strength and elongation of the heat-treated castings.

Chromium up to 0.5 per cent or a little more increases the tensile strength in the heat-treated casting, but reduces the elongation.

With regard to the limits of copper content, we have observed that up to about 2 per cent copper, nearly all the $CuAl_2$ remains in solution upon solidification, and that beyond 5.5 per cent copper some of the $CuAl_2$ usually remains out of solution even after heat-treatment. In some cases the metal can be heated above the melting point of the eutectic of $CuAl_2$ and aluminum without impairing its physical properties provided the metal is cooled to a temperature slightly below that of complete solidification and held there for some time before quenching. When substantial percentages of iron, silicon, magnesium and zinc are present, or any of them, the higher permissible temperature is lowered.

It is found that the coarser the grain produced in casting, the longer must the heat-treatment be continued to produce the most beneficial results. Accordingly sand castings with large cross-sectional areas require longer heating than chill castings. Usually holding at temperature for about 7 hours is sufficient for chill castings, whereas 24 hours may be necessary with sand castings.

In addition to the production of a superior grade of sand castings, permanent mold or chill castings (including die castings), the application of our invention is also most important in connection with the forging and pressing of aluminum alloys. If it is desired to produce a forging of a given shape, a casting of suitable composition, say 4 per cent copper and 0.2 per cent magnesium, is made, preferably in a chill mold, and is subjected to heat-treatment by our method to produce a starting material for forging.

In this case, instead of quenching from the heat-treatment temperature and then reheating the article to forging temperature, we find it preferable to simply cool slowly from the heat-treatment temperature to the forging temperature. The piece is then finished to size under the press or hammer, after which it is given a short heating, say at 520° C., followed by quenching.

The duration of the heat-treatment step of our method depends, in large measure, other conditions being the same, upon the degree of improvement desired in the physical properties of the casting.

The essential thing to be kept in mind is the relatively long time required for cast alloys in general, as compared to those rolled aluminum-copper alloys known to the prior heat-treating art. This is caused, in the case of the cast copper alloys, by the greater difficulty in getting the unbroken $CuAl_2$ network into solution in the aluminum.

In the copper alloys containing about 4 per cent copper, for example, it is found that heating for very long periods, say 48 hours or more, at temperatures only slightly below 500° C. will not, in general, produce as good results as a five hour treatment at 520° C. In chill castings of the copper alloys it has been found that even two hours heating at 520° C. produced substantially as good results as about 22 hours at 500° C. In order to reduce the time to a minimum, we prefer, if suitable temperature control is available, to use as high a temperature as can be safely employed without spoiling the castings by overheating.

It is to be understood that the invention is not limited to the specific details herein described but can be practised in other ways without departure from its spirit.

We claim—

1. In the art of making aluminum-alloy castings, the method comprising preparing an aluminum alloy containing between about 3 and 5.5 per cent of copper, casting the alloy, heating the casting to a temperature of about 500° to 540° C. for at least about 7 hours, and cooling the casting.

2. In the art of making aluminum-alloy castings, the method comprising preparing an aluminum alloy containing between about 3 and 5.5 per cent of copper, casting the alloy, heating the casting to a temperature of about 500° to 540° C. for at least about 7 hours, and cooling the casting rapidly.

3. In the art of making aluminum-alloy castings, the method comprising preparing an aluminum alloy low in iron and containing between about 3 and 5.5 per cent of copper, casting the alloy, heating the casting to a temperature of about 500° to 540° C. for at least about 7 hours, and cooling the casting.

4. In the art of making aluminum-alloy castings, the method comprising preparing an aluminum alloy low in iron and containing between about 3 and 5.5 per cent of copper, casting the alloy, heating the casting to a temperature of about 500° to 540° C. for at least about 7 hours, and cooling the casting rapidly.

5. In the art of making aluminum-alloy castings, the method comprising preparing an aluminum alloy containing between about 3 and 5.5 per cent of copper and not more than about 0.3 per cent of magnesium, casting the alloy, heating the casting to a temperature of about 500° to 540° C. for at least about 7 hours, and cooling the casting.

6. In the art of making aluminum-alloy castings, the method comprising preparing an aluminum alloy containing between about 3 and 5.5 per cent of copper and not more than about 0.3 per cent of magnesium,

casting the alloy, heating the casting to a temperature of about 500° to 540° C. for at least about 7 hours, and cooling the casting rapidly.

7. In the art of making aluminum-alloy castings, the method comprising preparing an aluminum alloy low in iron and containing between about 3 and 5.5 per cent of copper and not more than about 0.3 per cent of magnesium, casting the alloy, heating the casting to a temperature of about 500° to 540° C. for at least about 7 hours, and cooling the casting.

8. In the art of making aluminum-alloy castings, the method comprising preparing an aluminum alloy low in iron and containing between about 3 and 5.5 per cent of copper and not more than about 0.3 per cent of magnesium, casting the alloy, heating the casting to a temperature of about 500° to 540° C. for at least about 7 hours, and cooling the casting rapidly.

9. In the art of making aluminum-alloy castings, the method comprising preparing an aluminum alloy containing between about 3 and 5.5 per cent of copper and a small amount of zinc, casting the alloy, heating the casting to a temperature of about 500° to 540° C. for at least about 7 hours, and cooling the casting.

10. In the art of making aluminum-alloy castings, the method comprising preparing an aluminum alloy containing between about 3 and 5.5 per cent of copper, casting the alloy, heating the casting to a temperature of about 500° to 540° C. for at least about 7 hours, cooling the casting, and reheating the alloy at a relatively low temperature for a time sufficient to increase the tensile strength of the alloy.

11. In the art of making aluminum-alloy castings, the method comprising preparing an aluminum alloy containing between about 3 and 5.5 per cent of copper, casting the alloy, heating the casting to a temperature of about 500° to 540° C. for at least about 7 hours, cooling the casting rapidly, and reheating the alloy at a relatively low temperature for a time sufficient to increase the tensile strength of the alloy.

12. In the art of making aluminum-alloy castings, the method comprising preparing an aluminum alloy containing between about 3 and 5.5 per cent of copper and not more than about 0.3 per cent of magnesium, casting the alloy, heating the casting to a temperature of about 500° to 540° C. for at least about 7 hours, cooling the casting, and re-heating the alloy at a relatively low temperature for a time sufficient to increase the tensile strength of the alloy.

13. In the art of making aluminum-alloy castings, the method comprising preparing an aluminum alloy low in iron and containing between about 3 and 5.5 per cent of copper and not more than about 0.3 per cent of magnesium, casting the alloy, heating the casting to a temperature of about 500° to 540° C. for at least about 7 hours, cooling the casting, and reheating the alloy at a relatively low temperature for a time sufficient to increase the tensile strength of the alloy.

14. As a new article of manufacture, a heat-treated casting of an aluminum alloy containing between about 3 and 5.5 per cent of copper, characterized by the substantial absence of undissolved inter-granular copper-rich constituent, and having high tensile strength and elongation.

15. As a new article of manufacture, a heat-treated casting of an aluminum alloy containing between about 3 and 5.5 per cent of copper and a relatively small amount of magnesium, characterized by the substantial absence of undissolved inter-granular copper-rich constituent, and having high tensile strength and elongation.

16. As a new article of manufacture, a heat-treated casting of an aluminum alloy containing between about 3 and 5.5 per cent of copper, and magnesium not exceeding about 0.3 per cent, characterized by the substantial absence of undissolved inter-granular copper-rich constituent, and having high tensile strength and elongation.

17. As a new article of manufacture, a heat-treated casting of an aluminum alloy containing between about 3 and 5.5 per cent of copper and having a low iron content, characterized by the substantial absence of undissolved inter-granular copper-rich constituent, and having high tensile strength and elongation.

18. As a new article of manufacture, a heat-treated casting of an aluminum alloy containing between about 3 and 5.5 per cent of copper and a relatively small amount of magnesium, and having a low iron content, characterized by the substantial absence of undissolved inter-granular copper-rich constituent, and having high tensile strength and elongation.

19. As a new article of manufacture, a heat-treated casting of an aluminum alloy containing between about 3 and 5.5 per cent of copper, and magnesium not exceeding about 0.3 per cent, and having a low iron content, characterized by the substantial absence of undissolved inter-granular copper-rich constituent, and having high tensile strength and elongation.

20. As a new article of manufacture, a heat-treated, artificially aged casting of an aluminum alloy containing between about 3 and 5.5 per cent of copper, characterized by high tensile strength and substantial absence of undissolved inter-granular copper-rich constituent.

21. As a new article of manufacture, a heat-treated, artificially aged casting of an

aluminum alloy containing between about 3 and 5.5 per cent of copper and a relatively small amount of magnesium, characterized by high tensile strength and substantial absence of undissolved inter-granular copper-rich constituent.

22. As a new article of manufacture, a heat-treated, artificially aged casting of an aluminum alloy containing between about 3 and 5.5 per cent of copper, and magnesium not exceeding about 0.3 per cent, characterized by high tensile strength and substantial absence of undissolved inter-granular copper-rich constituent.

23. In the art of making aluminum-alloy castings, the method comprising preparing an aluminum alloy containing between about 3 to 5.5 per cent of copper, casting the alloy and causing rapid solidification thereof, heating the casting to a temperature of about 500° to 540° C. for at least about 7 hours, and cooling the casting.

24. In the art of making aluminum-alloy castings, the method comprising preparing an aluminum alloy containing between about 3 and 5.5 per cent of copper, casting the alloy and causing rapid solidification thereof, heating the casting to a temperature of about 500° to 540° C. for at least about 7 hours, and cooling the casting rapidly.

25. In the art of making aluminum-alloy castings, the method comprising preparing an aluminum alloy containing between about 3 and 5.5 per cent of copper and not more than about 0.3 per cent of magnesium, casting the alloy and causing rapid solidification thereof, heating the casting to a temperature of about 500° to 540° C. for at least about 7 hours, and cooling the casting.

26. In the art of making aluminum-alloy castings, the method comprising preparing an aluminum alloy containing between about 3 and 5.5 per cent of copper and not more than about 0.3 per cent of magnesium, casting the alloy and causing rapid solidification thereof, heating the casting to a temperature of about 500° to 540° C. for at least about 7 hours, and cooling the casting rapidly.

27. In the art of making aluminum-alloy castings, the method comprising preparing an aluminum alloy containing between about 3 and 5.5 per cent of copper, casting the alloy and causing rapid solidification thereof, heating the casting to a temperature of about 500° to 540° C. for at least about 7 hours, cooling the casting, and reheating the alloy at a relatively low temperature for a time sufficient to increase the tensile strength of the alloy.

28. In the art of making aluminum-alloy castings, the method comprising preparing an aluminum alloy containing between about 3 and 5.5 per cent of copper, casting the alloy and causing rapid solidification thereof, heating the casting to a temperature of about 500° to 540° C. for at least about 7 hours, cooling the casting rapidly, and reheating the alloy at a relatively low temperature for a time sufficient to increase the tensile strength of the alloy.

29. In the art of making aluminum-alloy castings, the method comprising preparing an aluminum alloy containing between about 3 and 5.5 per cent of copper and not more than about 0.3 per cent of magnesium, casting the alloy and causing rapid solidification thereof, heating the casting to a temperature of about 500° to 540° C. for at least about 7 hours, cooling the casting, and reheating the alloy at a relatively low temperature for a time sufficient to increase the tensile strength of the alloy.

30. In the art of making aluminum-alloy castings, the method comprising preparing an aluminum alloy low in iron and containing between about 3 and 5.5 per cent of copper and not more than about 0.3 per cent of magnesium, casting the alloy and causing rapid solidification thereof, heating the casting to a temperature of about 500° to 540° C. for at least about 7 hours, cooling the casting, and reheating the alloy at a relatively low temperature for a time sufficient to increase the tensile strength of the alloy.

31. As a new article of manufacture, a chill-cast, heat-treated casting of an aluminum alloy containing between about 3 and 5.5 per cent of copper, characterized by the substantial absence of undissolved inter-granular copper-rich constituent, and having high tensile strength and elongation.

32. As a new article of manufacture, a chill-cast, heat treated casting of an aluminum alloy containing between about 3 and 5.5 per cent of copper and a relatively small amount of magnesium, characterized by the substantial absence of undissolved inter-granular copper-rich constituent, and having high tensile strength and elongation.

33. As a new article of manufacture, a chill-cast, heat-treated and artificially aged casting of an aluminum alloy containing between about 3 and 5.5 per cent of copper, characterized by high tensile strength and substantial absence of undissolved inter-granular copper-rich constituent.

34. As a new article of manufacture, a chill-cast, heat-treated and artificially aged casting of an aluminum alloy containing between about 3 and 5.5 per cent of copper and a relatively small amount of magnesium, characterized by high tensile strength and substantial absence of undissolved inter-granular copper-rich constituent.

In testimony whereof we hereto affix our signatures.

ZAY JEFFRIES.
ROBERT S. ARCHER.