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ALUMINUM-BASE ALLOYS

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This invention relates generally to the heat treatable strong aluminum-base alloys containing copper, with or without the so-called hardeners or hardening elements manganese, chromium, zirconium, molybdenum, beryllium, boron, and titanium. More particularly the invention relates to aluminum-copper alloys containing silicon. One of the objects of the invention is to provide thermally treated articles of such alloys, possessing greater improvement in one or another physical property than has heretofore been obtainable by thermal treatment. Another object of the invention is to provide articles composed of alloys of the type indicated, with improvement particularly in the direction of yield strength in the artificially aged condition. Another object is to provide high hardness in articles composed of such alloys. A further object is to provide alloy articles which will have improved resistance to corrosion in the artificially aged condition. These and other objects I attain with these alloys by the addition thereto of a small amount of tin, not exceeding 0.1 per cent and preferably more than about 0.05 per cent. In fact, I have found beneficial results to be obtained with as little as 0.005 per cent. The advantages of the invention are, however, obtained only when the alloy is free from magnesium, that is, when the metal is either totally absent or is present only in amount so small as to be a mere impurity, not exceeding, say, about 0.1 per cent.

The alloys to which the invention herein claimed is directed are those containing copper 2.0 to 12.0 per cent and nickel 0.1 to 7.0 per cent, with or without a total of 0.1 to 3.0 per cent of one or more of the so-called hardening elements mentioned above, the rest of the alloy being aluminum.

In amounts of about 0.15 to 15.0 per cent, tin has been known as an alloying element which in aluminum-base alloys containing copper increases the fluidity and improves the machining and polishing characteristics of the alloy. Its use, however, has been generally discontinued, it having been learned, as investigators have pointed out, that tin in the amounts heretofore used adversely affects the hot working characteristics of aluminum and aluminum-base alloys, diminishes the corrosion resistance of such materials, and, generally, serves no useful function not more advantageously obtained with other alloying elements.

Contrary to the accepted opinion and trend of the art, I have discovered that certain small amounts of tin are beneficial and desirable in aluminum-copper alloys with or without one or more of the elements silicon, nickel, and zinc; any of which alloys may also contain one or more of the hardeners manganese, chromium, boron, molybdenum, zirconium, beryllium, and titanium. In accordance with these discoveries and as a result of a series of experiments directed thereto, I have determined that tin is extremely beneficial and desirable when (1) the tin is present in amounts of 0.005 to 0.1 per cent by weight; (2) the alloy contains copper; (3) the alloy contains no magnesium or contains that metal only in so small an amount as to constitute a mere impurity; (4) the alloy is artificially aged, that is to say, when the alloy is subjected to artificial aging (preferably but not necessarily after high temperature heat treatment), say at a temperature between about 100° and 200° C.

The benefits of my invention appear to be due to the response of a peculiar internal alloy structure to the artificial aging treatment. Aging phenomena in aluminum-base alloys are believed to be the result of the precipitation of an alloying element from a solid solution thereof in aluminum which is super-saturated with respect thereto. The precipitation is submicroscopic or on the border line between submicroscopic and microscopic. By careful methods, however, it is possible to prepare metal specimens which, under the action of an etching agent, reveal a structure indicative of the artificially aged condition of the metal.

For example, a section of an artificially aged wrought aluminum alloy article composed of 4.0 per cent of copper without tin, etched with a mixture of hydrofluoric, hydrochloric and nitric acids, shows under a magnification of 500 diameters an aluminum matrix composed of contrasting grains having distinctly marked boundaries. Particles of the constituent $CuAl_2$ are seen scattered through the matrix but substantially none are found in the grain boundaries. The same alloy containing 0.05 per cent of tin shows after the same artificial aging only slight grain contrast, the grain boundaries are distinctly less sharp, and they contain multitudes of small particles of $CuAl_2$. According to the theories of submicroscopic precipitation, the differences in structure noted in the tin-containing alloy indicate a more advanced stage of submicroscopic precipitation of $CuAl_2$, in fact showing that the precipitation has advanced to a large extent beyond the submicroscopic to the microscopic stage. This is evidenced by the particles of $CuAl_2$ in the grain boundaries, resulting from coalescence of particles precipitated in submicroscopic size.

The foregoing enhanced aging phenomenon which occurs in the above described aluminum alloys containing tin is particularly manifested in such alloys by the development, under the action of the artificial aging treatment, of certain unusual and distinctive properties now to be described.

When tin in amounts of 0.005 to 0.1 per cent is present in aluminum alloys containing 2.0 to 12.0 per cent of copper and free from magnesium, a relatively short artificial aging treatment will develop high hardness. Thus an aluminum alloy casting containing 11.78 per cent of copper and 0.05 per cent of tin, heat treated for 16 hours at 515° C. and aged for 15 hours at 150° C., had a Brinell hardness of 122. The same alloy without tin, similarly heat treated and aged, had a Brinell hardness of only 107. Similarly, and under the same treatment, an alloy containing about 4.0 per cent of copper, about 10.0 per cent of silicon, and about 0.04 per cent of tin, developed a Brinell hardness of 124, while a similar alloy not containing tin developed a Brinell hardness of only 106.

A further effect of the tin addition upon aging is particularly evidenced in certain specially valuable and preferred alloys. Under the influence of aging treatments, aluminum alloys containing 2.0 to 6.5 per cent of copper, 0.005 to 0.1 per cent of tin, and substantially free from magnesium, developed yield strengths which are on the order of 30 to 200 per cent greater than the yield strengths of similar alloys not containing tin. While the fundamental reasons for such increase in yield strength are obscure, the effect is very pronounced. For instance, a magnesium-free aluminum-base alloy containing 4.0 per cent of copper and 0.05 per cent of tin was heat treated at 510° C. for 20 minutes, quenched to room temperature, and artificially aged for 18 hours at 150° C. This alloy had a yield strength of 43,000 pounds per square inch. A similar alloy, similarly treated but not containing tin, had a yield strength of only 20,200 pounds per square inch.

In addition to the effects described, my invention possesses another advantage. The artificial aging of aluminum-base alloys containing copper in substantial amount usually results in a decreased resistance of the alloy to corrosion, but I have found that when these alloys, especially those of the preferred copper content (2.0 to 6.5 per cent as stated above), contain tin in the amount prescribed by my invention this detrimental result is considerably lessened by the enhanced aging effect. In particular the artificially aged alloys show a marked decrease in propensity to undergo intercrystalline or intergranular corrosion, a type of corrosion which is more objectionable than the ordinary surface type because it is often not readily apparent and so is apt to escape observation until the corroded part or article fails as a result of the internal weakening.

The aluminum-base alloys which are improved by the enhanced aging induced therein by the addition of small amounts of tin are those containing 2.0 to 12.0 per cent of copper, with or without certain other alloying elements which I have found to be useful in modifying the general properties of the alloy without masking or destroying the beneficial properties above noted. Thus the aluminum-copper alloys may contain 0.1 to 3.0 per cent of a class of "hardening elements" which may be present, separately or together; each, however, not exceeding greatly the following limits: manganese 0.1 to 2.0 per cent, chromium 0.1 to 1.0 per cent, boron 0.1 to 0.5 per cent, molybdenum 0.1 to 1.0 per cent, zirconium 0.1 to 0.5 per cent, beryllium 0.1 to 2.0 per cent, and titanium 0.03 to 0.5 per cent.

I have determined that magnesium is a harmful addition to the alloys above described in that its presence in substantial amounts destroys in large part the effects induced by the addition of small amounts of tin.

The preferred alloys are those in which one or all the above described properties are present to a marked extent, especially the yield strength. These alloys, as above noted, contain 2.0 to 6.5 per cent of copper and 0.005 to 0.1 per cent of tin, 0.05 to 0.1 per cent being preferred, and they are characterized in the artificially aged condition by a yield strength substantially higher than that of the same alloy devoid of tin. In their preferred form, these alloys may also contain 0.1 to 1.0 per cent, in total, of one or more of the hardening elements above mentioned. For making castings of the preferred alloys that are to be used in the unworked condition the alloys may contain a total of 0.1 to 5.0 per cent of an element of the class consisting of zinc, nickel, and silicon. When two or all three of the elements zinc, nickel, and silicon are present, the total should not exceed 5.0 per cent, the lower limits being nickel 0.05 per cent, zinc 0.05 per cent, and silicon 0.05 per cent. For making wrought articles, the same foregoing lower limits should be observed, but where two or all three of the named elements are present, the upper limits should be, nickel 1.0 per cent, silicon 3.0 per cent, and zinc 5.0 per cent. For rolling or forging, the total amount of these elements should not exceed 3.0 or 4.0 per cent, but if the alloy is to be extruded a total of about 9.0 per cent is permissible. In general, for making cast unworked articles the lower limits for each element, when used alone, should be, silicon 0.1 per cent, nickel 0.1 per cent, and zinc 0.1 per cent, and the upper limits should be, silicon 14.0 per cent, nickel 7.0 per cent, and zinc 14.0 per cent. Furthermore, if two or more of the elements are present in cast unworked articles, the lower limits should be, silicon 0.05 per cent, nickel 0.05 per cent, and zinc 0.05 per cent, the total amount of any two or more of the elements being 14.0 per cent, the total nickel content, however, not exceeding 7.0 per cent.

As specifically illustrating these alloys, an example of a wrought aluminum-base alloy without magnesium, containing about 4.4 per cent of copper, about 0.85 per cent of manganese, about 0.75 per cent of silicon, about 0.4 per cent of iron may be cited. Two alloys of this composition, with and without the addition of 0.05 per cent of tin, were heat treated at 520° C. for 15 minutes, quenched in water, and subjected for 18 hours to an aging treatment at 143° C. The tin-free alloy had a tensile strength of 58,700 pounds per square inch, a yield strength of 33,250 pounds per square inch, and an elongation of 16.8 per cent in two inches. The other alloy containing 0.05 per cent of tin had a tensile strength of 63,190 pounds per square inch, a yield strength of 46,250 pounds per square inch, and an elongation of 11.0 per cent in two inches. The effect of tin upon the yield strength and hardness of heat treated and artificially aged cast alloys is illustrated by the following examples. Aluminum-base alloys containing copper 4.0 per cent, nickel 2.0 per cent; and copper 4.0 per cent, nickel 5.0 per cent; with and without the addition of 0.05 per cent tin, were cast, heat treated at 504° C. for 20 hours, quenched in water, and aged at 154° C. for 16 hours. The yield strength and hardness values of these alloys that were obtained are as follows:

Alloy composition			Yield strength lbs. per sq. inch	Brinell hardness
Copper	Nickel	Tin		
Percent	*Percent*	*Percent*		
4.0	2.0	----------	9,610	51.9
4.0	2.0	0.05	28,830	102.0
4.0	5.0	----------	8,710	49.3
4.0	5.0	0.05	14,780	60.5

The aging treatments and heat treatments to which the above mentioned alloys are subjected in order to develop their advantageous properties are the thermal treatments well known to the art. The heat treatment usually comprises heating the aluminum-copper alloys to above about 400° C. but below the temperature at which the lowest melting constituent of the alloy becomes molten, generally known as the point of incipient fusion. The alloy thus treated is, in the preferred practice, cooled rapidly, as by quenching in water or air, to room temperature. The artificial aging usually comprises heating the aluminum-copper alloy to temperatures of about 100 to 200° C. until the desired increase in properties is obtained. The artificial aging in the preferred practice of the invention is preceded by heat treatment, but the enhanced aging effect herein described and its general results may be developed to an advantageous extent by the artificial aging alone.

The aluminum-base alloys herein described and claimed are those containing at least 70.0 per cent of aluminum, which metal may contain impurities, such as amounts of iron up to about 1.5 per cent and, likewise, small amounts of silicon such as are known to occur in virgin aluminum.

The enhanced aging herein described as resulting from the addition of tin in the stated amount to magnesium-free aluminum alloys containing from 2.0 to 12.0 per cent of copper is obtained in both cast and wrought articles. In the case of castings of such alloys containing tin, I have found that heat treatment at elevated temperatures without artificial aging produces a higher ductility than is obtainable by heat treatment of a casting of the same alloy without the tin. This species of the invention I do not claim specifically herein but do so in my copending application Serial No. 606,755, filed April 21, 1932, and issued as United States Letters Patent 2,022,686, under date of December 3, 1935.

In the appended claims the term tensile property, or the like, is intended to include hardness as a property which can be favorably affected by the enhanced artificial aging produced by my invention. Also within the spirit of the appended claims the article may be an ingot or other body designed for further casting or for working, or it may be a cast or wrought article which is suitable for immediate use or sale or which may require some further operation to fit it for use or sale.

Articles and methods involving aluminum-copper alloys containing silicon; zinc; silicon and nickel; silicon and zinc; nickel and zinc; and silicon, nickel and zinc; and aluminum-copper alloys containing none of the elements silicon, nickel and zinc; are not claimed herein but are claimed in my copending applications Serial Nos. 95,177, 95,179, 95,180, 95,181, 95,182 95,183, and 606,756, respectively. This application is a continuation-in-part of my copending application Serial No. 606,756, filed April 21, 1932.

I claim:

1. In a method of making an article of aluminum alloy, forming an article of a magnesium-free alloy containing copper 2.0 to 12.0 per cent, nickel 0.1 to 7.0 per cent, and tin 0.005 to 0.1 per cent, the remainder being essentially aluminum; and artificially aging the article whereby a tensile property of the alloy is improved over that of a like alloy free from tin.

2. In a method of making an article of aluminum alloy, forming an article of a magnesium-free alloy containing copper 2.0 to 6.5 per cent, nickel 0.1 to 5.0 per cent, and tin 0.005 to 0.1 per cent, the remainder being essentially aluminum; and artificially aging the article whereby a tensile property of the alloy is improved over that of a like alloy free from tin.

3. In a method of making an article of aluminum alloy, forming an article of a magnesium-free alloy containing copper 2.0 to 12.0 per cent; nickel 0.1 to 7.0 per cent; tin 0.005 to 0.1 per cent; and at least one hardening element of the class consisting of manganese 0.1 to 2.0 per cent, chromium 0.1 to 1.0 per cent, boron 0.1 to 0.5 per cent, molybdenum 0.1 to 1.0 per cent, zirconium 0.1 to 0.5 per cent, beryllium 0.1 to 2.0 per cent, and titanium 0.03 to 0.5 per cent, the total hardening content being 0.1 to 3.0 per cent, and the remainder being essentially aluminum; and artificially aging the article whereby a tensile property of the alloy is improved over that of a like alloy free from tin.

4. In a method of making an article of aluminum alloy, forming an article of a magnesium-free alloy containing copper 2.0 to 12.0 per cent, nickel 0.1 to 7.0 per cent, and tin 0.005 to 0.1 per cent, the remainder being essentially aluminum; and artificially aging the article between about 100° C. and 200° C. inclusive, whereby a tensile property of the alloy is improved over that of a like alloy free from tin.

5. In a method of making an article of aluminum alloy, forming an article of a magnesium-free alloy containing copper 2.0 to 6.5 per cent, nickel 0.1 to 5.0 per cent, and tin 0.005 to 0.1 per cent, the remainder being essentially aluminum; and artificially aging the article between about 100° C. and 200° C. inclusive, whereby a tensile property of the alloy is improved over that of a like alloy free from tin.

6. In a method of making an article of aluminum alloy, forming an article of a magnesium-free alloy containing copper 2.0 to 12.0 per cent; nickel 0.1 to 7.0 per cent; tin 0.005 to 0.1 per cent; and at least one hardening element of the class consisting of manganese 0.1 to 2.0 per cent, chromium 0.1 to 1.0 per cent, boron 0.1 to 0.5 per cent, molybdenum 0.1 to 1.0 per cent, zirconium 0.1 to 0.5 per cent, beryllium 0.1 to 2.0 per cent, and titanium 0.03 to 0.5 per cent, the total hardening content being 0.1 to 3.0 per cent, and the remainder being essentially aluminum; and artificially aging the article between about 100° C. and 200° C. inclusive, whereby a tensile property of the alloy is improved over that of a like alloy free from tin.

7. In a method of making an article of aluminum alloy, forming an article of a magnesium-free

alloy containing copper 2.0 to 12.0 per cent, nickel 0.1 to 7.0 per cent, and tin 0.005 to 0.1 per cent, the remainder being essentially aluminum; heat treating the article between about 400° C. and the temperature of incipient fusion; and artificially aging the article between about 100° C. and 200° C. inclusive, whereby a tensile property of the alloy is improved over that of a like alloy free from tin.

8. In a method of making an article of aluminum alloy, forming an article of a magnesium-free alloy containing copper 2.0 to 12.0 per cent, nickel 0.1 to 7.0 per cent, and tin 0.05 to 0.1 per cent, the remainder being essentially aluminum; heat treating the article between about 400° C. and the temperature of incipient fusion; and artificially aging the article between about 100° C. and 200° C. inclusive, whereby a tensile property of the alloy is improved over that of a like alloy free from tin.

9. In a method of making an article of aluminum alloy, forming an article of a magnesium-free alloy containing copper 2.0 to 6.5 per cent, nickel 0.1 to 5.0 per cent, and tin 0.005 to 0.1 per cent, the remainder being essentially aluminum; heat treating the article between about 400° C. and the temperature of incipient fusion; and artificially aging the article between about 100° C. and 200° C. inclusive, whereby a tensile property of the alloy is improved over that of a like alloy free from tin.

10. In a method of making an article of aluminum alloy, forming an article of a magnesium-free alloy containing copper 2.0 to 6.5 per cent, nickel 0.1 to 5.0 per cent, and tin 0.05 to 0.1 per cent, the remainder being essentially aluminum; heat treating the article between about 400° C. and the temperature of incipient fusion; and artificially aging the article between about 100° C. and 200° C. inclusive, whereby a tensile property of the alloy is improved over that of a like alloy free from tin.

11. In a method of making an article of aluminum alloy, forming an article of a magnesium-free alloy containing copper 2.0 to 12.0 per cent; nickel 0.1 to 7.0 per cent; tin 0.005 to 0.1 per cent; and at least one hardening element of the class consisting of manganese 0.1 to 2.0 per cent, chromium 0.1 to 1.0 per cent, boron 0.1 to 0.5 per cent, molybdenum 0.1 to 1.0 per cent, zirconium 0.1 to 0.5 per cent, beryllium 0.1 to 2.0 per cent, and titanium 0.03 to 0.5 per cent, the total hardening content being 0.1 to 3.0 per cent, and the remainder being essentially aluminum; heat treating the article between about 400° C. and the temperature of incipient fusion; and artificially aging the article between about 100° C. and 200° C. inclusive, whereby a tensile property of the alloy is improved over that of a like alloy free from tin.

12. In a method of making an article of aluminum alloy, forming an article of a magnesium-free alloy containing copper 2.0 to 6.5 per cent; nickel 0.1 to 5.0 per cent; tin 0.005 to 0.1 per cent; and at least one hardening element of the class consisting of manganese, chromium, boron, molybdenum, zirconium, beryllium, and titanium, the total hardening content being 0.1 to 3.0 per cent, and the remainder being essentially aluminum; heat treating the article between about 400° C. and the temperature of incipient fusion; and artificially aging the article between about 100° C. and 200° C. inclusive, whereby a tensile property of the alloy is improved over that of a like alloy free from tin.

13. An article of artificially aged aluminum alloy free from magnesium and containing copper 2.0 to 12.0 per cent, nickel 0.1 to 7.0 per cent, and tin 0.005 to 0.1 per cent, the remainder being essentially aluminum.

14. An article of artificially aged aluminum alloy free from magnesium and containing copper 2.0 to 12.0 per cent, nickel 0.1 to 7.0 per cent, and tin 0.005 to 0.1 per cent; and at least one element of the class of hardeners composed of manganese, chromium, boron, molybdenum, zirconium, beryllium, and titanium, the total hardening content being 0.1 to 3.0 per cent, the remainder of the alloy being essentially aluminum.

15. An article of artificially aged aluminum alloy free from magnesium and containing copper 2.0 to 6.5 per cent, nickel 0.1 to 5.0 per cent, and tin 0.005 to 0.1 per cent, the remainder of the alloy being essentially aluminum.

16. An article of artificially aged aluminum alloy free from magnesium and containing copper 2.0 to 6.5 per cent, nickel 0.1 to 5.0 per cent, tin 0.005 to 0.1 per cent; and at least one element of the class of hardeners composed of manganese, chromium, boron, molybdenum, zirconium, beryllium, and titanium, the total hardening content being 0.1 to 3.0 per cent, the remainder of the alloy being essentially aluminum.

17. An article of thermally treated aluminum alloy free from magnesium and containing copper 2.0 to 12.0 per cent, nickel 0.1 to 7.0 per cent, and tin 0.005 to 0.1 per cent, the remainder being essentially aluminum; the alloy being characterized by a structure produced by heating the alloy to over 400° C., but below incipient fusion, cooling the alloy, and thereafter artificially aging the alloy.

18. An article of thermally treated aluminum alloy free from magnesium and containing copper 2.0 to 12.0 per cent, nickel 0.1 to 7.0 per cent, and tin 0.005 to 0.1 per cent; and at least one element of the class of hardeners composed of manganese, chromium, boron, molybdenum, zirconium, beryllium, and titanium, the total hardening content being 0.1 to 3.0 per cent, the remainder being essentially aluminum; the alloy being characterized by a structure produced by heating the alloy to over 400° C. but below incipient fusion, cooling the alloy, and thereafter artificially aging the alloy.

19. An article of thermally treated aluminum alloy free from magnesium and containing copper 2.0 to 6.5 per cent, nickel 0.1 to 5.0 per cent, and tin 0.005 to 0.1 per cent, the remainder being essentially aluminum; the alloy being characterized by a structure produced by heating the alloy to over 400° C. but below incipient fusion, cooling the alloy, and thereafter artificially aging the alloy.

20. An article of thermally treated aluminum alloy free from magnesium and containing copper 2.0 to 6.5 per cent, nickel 0.1 to 5.0 per cent, and tin 0.005 to 0.1 per cent; and at least one element of the class of hardeners composed of manganese, chromium, boron, molybdenum, zirconium, beryllium, and titanium, the total hardening content being 0.1 to 3.0 per cent, the remainder being essentially aluminum; the alloy being characterized by a structure produced by heating the alloy to over 400° C. but below incipient fusion, cooling the alloy, and thereafter artificially aging the alloy.

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