United States Patent Office 2,908,566 Patented Oct. 13, 1959

2,908,566

ALUMINUM BASE ALLOY

Roger G. Cron, Hawthorne, and Romeo A. Zuech, Redondo Beach, Calif., assignors to North American Aviation, Inc.

No Drawing. Application June 1, 1956
Serial No. 588,633

10 Claims. (Cl. 75—147)

This invention relates to aluminum base casting alloys and in particular it relates to aluminum-silicon casting alloys characterized by high strength, good ductility, and excellent casting qualities.

A considerable gap has heretofore existed between the tensile strength of known, commercially available, ductile aluminum base alloys of the cast type and those of the wrought type. In many applications, such as in the aircraft industry, the weight penalty resulting from the use of large relatively low strength aluminum castings, which would be required in order to reduce the unit stress to a safe value, cannot be tolerated. This difference in the range of tensile strengths creates a further design problem by requiring the use of wrought type alloys for all applications that require tensile strengths and ductilities above the ranges attainable by using cast aluminum alloys. This in turn necessitates extensive machining operations on the aluminum forgings in order to produce a finished part, with consequent high production costs. Some high strength, special purpose aluminum casting alloys are known in the art; but they are either too brittle to be of practical commercial use for structural members subjected to high impact or vibration loading or else they are unreliable or require better foundry control than is ordinarily available in a production foundry.

The alloy of the present invention comprises an aluminum-silicon hypoeutectic system alloyed with small quantities of magnesium, beryllium and, in some instances, elements of the titanium or boron group to produce a readily castable alloy having an exceptionally high tensile strength in view of its good ductility as compared to the aluminum base casting alloys previously available. This alloy finds particularly advantageous use in the aircraft industry but is not limited thereto and is equally suited to applications in other industries where there is a need for ductile high strength aluminum alloy castings. With this alloy it is possible to achieve significant weight reductions in cast parts as well as now being able to cast many parts that formerly had to be machined from wrought aluminum forgings at a machining cost of up to hundreds of dollars per unit.

In general the tensile strength of casting alloys is known to increase with an increase of the particular hardening constituent used, but at the expense of ductility. The strengthening properties of silicon as an alloying constituent for aluminum are well known in the art. For the alloy of the present invention it has been determined that the silicon should be limited to the range of from about 6% to 10% by weight of the alloy. Decreasing the silicon content below 6% will unduly reduce the machining qualities of the alloy while a silicon content greater than about 10% will result in an alloy that is too brittle to be of practical utility as a structural material in devices that must withstand impact and vibration loading. A preferred silicon content, for achieving the optimum balance of high strength and good ductility, is that ranging from about 7.6% to 8.6% by weight of the alloy. In this respect good ductility is here considered to be evidenced by any value of elongation corresponding to or above a minimum value of 3% elongation.

The addition of magnesium to the aluminum-silicon system to form an aluminum-magnesium-silicide further increases the strength of the alloy. As is known, the magnesium acts as an accelerator in increasing the hardness of the alloy when it is subjected to heat treatment and aids in producing a hard, machinable alloy. Magnesium is added to our new alloy in the range of from about 0.2% to 0.6% by weight of the alloy. Care must be taken, however, to prevent the magnesium from being oxidized; for such oxides are of no value in strengthening the alloy and only cause depletion of the amount of magnesium that is available for alloy hardening purposes.

To counteract the iron impurities in the alloy and to prevent oxidation of the magnesium, beryllium is added in amounts ranging from 0.05% to 0.5% by weight of the alloy. The beryllium thus has an important two-fold function. The principal function of the beryllium is basic to the manner in which the new alloy achieves its high strength without sacrificing ductility in that it changes the long needle-like crystalline structure of the iron impurities to a comparatively harmless rounded nodular or spheroidal form. This typical, needle-type microstructure of any iron impurity found in aluminum is inherently mechanically weak and results in a comparatively weak and brittle alloy. Consequently, alteration of the needle structure of the iron to a nodular form eliminates these weak spots in the alloy, increases the ductility of the alloy and, by allowing a more complete and more effective utilization of the high strength that the alloy has when uncontaminated by any iron impuritiy, the tensile strength of the alloy is increased. The second function of the beryllium is achieved by oxidation of part of the beryllium to form a protective skin around the whole melt to prevent oxidation of the magnesium during the melting process. The magnesium is then capable of forming the aluminum-magnesium-silicide without appreciable oxidation loss and thus effectively aids in strengthening the alloy. Thus the addition of beryllium is the principal instrumentality for increasing the ductility and tensile properties of our new alloy, since the beryllium component allows the addition of higher percentages of a strengthening constituent, such as silicon, without producing the embrittlement that is normally characteristic of such high strength aluminum casting alloys.

To illustrate the importance of the beryllium constituent for increasing the strength and ductility of the alloy, the results of tests conducted on tensile test bars poured from a melt having substantially the same aluminum-silicon-magnesium-titanium composition as the alloy of this invention, but containing no beryllium, and a similar number of test bars poured from the same melt after the addition of 0.25% beryllium are herein set forth. The average mechanical properties of the metal containing no beryllium included a yield strength of 34,000 p.s.i. (pounds per square inch), an ultimate tensile strength of 43,600 p.s.i. and an elongation of only 3.5%. By contrast the metal containing 0.25% beryllium had a yield strength of 34,500 p.s.i., an ultimate tensile strength of 46,300 p.s.i. and an elongation of 7.5%.

Manganese has been utilized in the past to modify the needle structure of the iron impurity to a certain extent, but metallographic examination reveals that the iron is not extensively modified by the manganese but still retains a rather elongated brittle structure of the type known in the art as "Chinese script." Furthermore, in some

instances, the addition of manganese adversely affects the heat treatment of the alloy and causes a decrease in yield strength. The spheroidal iron microstructure formed by the addition of beryllium, however, results in a stronger alloy with much higher yield and ultimate strengths and excellent properties for heat treatment.

Titanium can be added as a grain refining element in the range of from about 0.05% to 0.3% by weight of the alloy. Boron, columbium, zirconium, tantalum or molybdenum are other suitable elements that could be used as refiners in place of titanium. Addition of any of the above grain-refining elements is however not necessarily essential to achieving the combination of high strength and good ductility in a hypoeutectic aluminum-silicon casting alloy since grain size has but little apparent effect on the casting properties of such an alloy below the eutectic composition. However even in such a hypoeutectic alloy the grain-refining elements improve surface finish to a considerable extent and eliminate the mottling which is characteristic of coarse grained material, thereby improving radiographic examination qualities.

Small amounts of other ingredients or impurities may also be present in the alloy. Iron may be present in amounts up to a maximum of approximately 0.6%. The smaller the amount of iron in the alloy, the less the amount of beryllium required since the primary function of the beryllium is to change the weak, needle-like microstructure of the iron into the less harmful nodular form. Additionally, manganese, copper, zinc and chromium may each be present as impurities in amounts up to a 0.2% allowable maximum without harmful interference with the desirable properties of our new alloy. Other impurities should not exceed 0.05% each with a total allowable maximum of 0.15% for all such other impurities.

In some instances, dependent upon the mechanical properties required, it may be desirable to add additional elements such as copper or zinc in amounts up to approximately 3% to improve the hardness and tensile strength of the metal. Addition of either one of these alloying elements, however, will lessen the ductility, lower the corrosion resistance, increase the specific gravity, and decrease the castability of the alloy.

The preferred composition limits for our new alloy are as follows: 7.6 to 8.6% silicon; 0.4 to 0.55% magnesium; 0.1 to 0.3% beryllium; 0.1 to 0.3% titanium; 0.002 to 0.006% sodium; 0.2% maximum of copper; 0.4% maximum of iron; 0.2% maximum of manganese; 0.2% maximum of zinc; 0.2% maximum of chromium; 0.5% maximum of each other impurity up to 0.15% total maximum; remainder aluminum.

As illustrations of our improved alloy, the following table is given of the mechanical properties of three representative melts of varying chemical content prepared within the broader composition ranges of the alloy. Each melt was sand cast into tensile test bar molds at 1290° F., solution heat-treated for 16 hours at 1020° F., quenched in warm water and artificially aged for 4 hours at 320° F.

Table I

Chemical Analysis, Percent					Mechanical Properties		
Si	Mg	Be	Ti	Fe	Yield Strength, p.s.i.	Ultimate Tensile Strength, p.s.i.	Elongation, Percent in 2 inches
8.0	0.51	0.20	0.10	0.33	36,000	46,100	5.5
7.53	0.44	0.15	0.13	0.28	35,400	45,800	5.0
9.65	0.57	0.18	0.15	0.36	41,800	47,700	2.8

The well-known result of increasing the percentage amount of silicon, i.e., an increase in tensile strength with an accompanying decrease in ductility, is clearly shown by the above listed alloys; but even in the alloy having the highest silicon content of 9.65% the elongation has decreased to a value only slightly below the 3% minimum required in aircraft structural castings and would be usable in other applications not subject to such high impact or vibration load conditions.

Table II sets forth the percentage composition, heat treatment and mechanical test results for four test bars taken from each of three melts of varying chemical content within the preferred composition limits.

Table II

Chemical Analysis, Percent					Heat Treatment	Type of Test Bar	Mechanical Properties			Hardness [1]	X-Ray Results
Si	Mg	Be	Ti	Fe			Yield Strength, p.s.i.	Ultimate Tensile Strength, p.s.i.	Elongation, Percent		
8.1	0.45	0.20	0.12	0.21	16 H. at 1,020 F.	Separately cast	36,100	45,500	4.5	R_E96	Moderate amount of Shrinkage porosity.
					4 H. at 320 F.	Machined from casting	38,300	45,000	3.0	R_E97	
7.6	0.44	0.23	0.11	0.23	16 H. at 1,020 F.	Separately cast	44,500	50,500	2.5	R_E99	Do.
					5 H. at 350 F.	Machined from casting	44,400	49,500	2.0	R_E99	
8.6	0.48	0.21	0.11	0.27	16 H. at 1,020 F.	Separately cast	47,000	51,500	2.0	R_E102	Do.
					6 H. at 350 F.	Machined from casting	47,500	54,000	3.0	R_E102	

[1] Rockwell E Hardness.

The marked effect of the age hardening process at elevated temperatures is shown by a comparison of the yield and ultimate tensile strengths of the alloy containing 7.6% silicon with those of the alloy having 8.1% silicon. Aging for 5 hours at 350° F. strengthened the lower silicon content alloy to a considerably higher tensile value than a 4 hour aging period at 320° F. produced in the higher silicon content alloy.

At present one of the aluminum base casting alloys most widely used throughout the aircraft industry for structural castings is the alloy designated as 356–T6, in accordance with the Aluminum Company of America method of alloy designation. The T6 suffix refers to a well understood and commonly practiced type of heat treatment. The 356–T6 alloy is a sand cast alloy containing 6.5% to 7.5% silicon, 0.2% to 0.4% magnesium, and the remainder aluminum. This alloy is presently considered to be a high strength aluminum alloy for a sand casting and contains more silicon than is usual in sand cast alloys. It has an average ultimate tensile strength of 33,000 pounds per square inch, a yield strength of 24,000 pounds per square inch and 3.5% elongation.

The alloy of the present invention, referred to in Table III as 42B–T6, when compared with this widely used standard aircraft sand casting alloy, 356–T6, has up to 40% higher tensile strength with a similar ductility, and additionally has better casting properties. The average properties of a representative series of 30 separately cast tensile test bars having a chemical composition within the preferred composition range are compared, in Group A of Table III, with like mechanical properties of an equal number of separately cast tensile test bars of 356 alloy which were within the normal composition

range of that alloy and were heat treated to a T6-temper condition. The 356 alloy test specimens were taken from 30 consecutive production heats of 356–T6 alloy made in an aircraft production foundry operating under strict metallurgical control and achieving mechanical properties for the 356 alloy that are higher than those normally attained in production work. Mechanical properties of the strongest test bar taken from the 30 test specimens of each of these two alloys are compared in Group B of Table III; while similar properties are compared in Group C of Table III for the weakest test bar taken from each group of test specimens. The term "Spec." as used in this table indicates typical design specifications for the individual metals as set up for a production foundry in the aircraft industry.

The heat treatment for all of the 42B alloy test specimens of Table III was similar to the standard T6 heat treatment and consisted of the preferred heat treatment for our new alloy. This preferred heat treatment includes solution heat treating at from 1000° F. to 1010° F. for a period of from 12 to 18 hours, a quench in warm water initially at a temperature of from 150° F. to 180° F., followed by precipitation hardening or aging at temperatures within the range from 310° F. to 340° F. for a period of from 3 to 6 hours.

Table III

Group No.	Alloy	Yield Strength, p.s.i.	Ultimate Tensile Strength, p.s.i.	Elongation, Percent	Hardness, Rockwell E
A	42B–T6	37,000	46,000	4.0	96
A	356–T6	26,700	38,000	5.7	84
B	42B–T6	43,800	50,000	5.5	101
B	356–T6	30,900	41,000	7.5	89
C	42B–T6	33,900	43,600	3.0	94
C	356–T6	23,000	35,500	4.0	78
Spec.	42B–T6	28,000	42,000	3.0	
Spec.	356–T6	20,000	30,000	3.0	

Group No. A—Average of 30 tensile test bars.
Group No. B—Individual maximum strength test bar of all 30 test bars.
Group No. C—Individual minimum strength test bar of all 30 test bars.
Spec.—Typical aircraft industry design specifications as set up for the individual metals.

The superiority of the 42B–T6 aluminum alloy over the standard 356–T6 alloy is obvious from a comparison of the properties listed in Table III, even though the 356 alloy is produced by a controlled procedure aimed at maximum results; while the composition and procedures relative to the 42B alloy and process were deliberately varied within specific limits to determine the properties to be expected from the average production foundry. The average yield strength of the 30 test specimens of 42B–T6 alloy is 38.6% greater than that of the 30 test specimens of 356–T6 alloy, while the ultimate tensile strength of the former is 21% higher than that of the latter. Similarly for the individual test bar of each alloy having the strongest mechanical properties of all the test specimens, the 42B–T6 bar had a yield strength 41% greater and an ultimate tensile strength 22% greater than that of the 356–T6 bar; while the weakest bar tested of the 42B–T6 alloy had a 47.4% greater yield strength and a 23% greater ultimate strength. The design specifications as listed and currently being used by one aircraft production foundry call for 40% higher yield and ultimate tensile strengths of the 42B–T6 alloy as compared to those of the 356–T6 alloy.

Casting quality of the new alloy as determined by radiographic inspection is at least as good as that of the 356 alloy. Machinability is also as good or better than that of the 356 alloy in spite of the higher silicon content. This may be explained by the higher hardness combined with modification of the silicon and iron. Corrosion resistance is probably better than that of the 356 alloy due to the addition of the beryllium. Fluidity in the mold is definitely improved with this new alloy and allows complex shapes to be readily cast at a lower temperature. Furthermore, since the silicon, magnesium and beryllium are all of lower specific gravity than aluminum, the resultant new alloy is of lower specific gravity than most other high strength aluminum alloys including the 356 alloy. This is even more pronounced with respect to alloys using copper or zinc as a hardening constituent. Also it should be noted that while this alloy has been tested and used as a sand cast alloy, it can also be used for die casting or with permanent molds with an even greater increase in strength.

The procedure for producing this alloy may consist either of alloying pure aluminum ingots with pure magnesium and aluminum-silicon, aluminum-beryllium and aluminum-titanium master alloys; or it may be produced by alloying commercial aluminum-silicon-magnesium-titanium alloys such as 356 with pure magnesium, aluminum-silicon, and aluminum-beryllium master alloys. The temperature during the alloying operation should range from a minimum of 1380° F. to a maximum of 1450° F.

Sodium modification of the aluminum-silicon eutectic is required to change the coarse silicon crystals to small spheroidal crystals with a resultant increase in ductility and tensile strength. A satisfactory treatment for such purpose is the addition of from 0.02% to 0.06% metallic sodium to each heat at a melt temperature of from 1380° F. to 1400° F. Potassium or lithium could also be used for such modification. Sodium addition normally results in a pronounced loss of metal fluidity, however, the higher silicon content of the alloy results in such outstanding fluidity characteristics of the alloy that it can be satisfactorily poured at a temperature in the range of from 1250° F. to 1300° F.

The new alloy of this invention is not a mere laboratory alloy but is one that has been evolved with the production skills of an ordinary foundry in mind. For example, it is well known that both the strength and ductility of a cast metal increase with the speed of solidification. Thus even better results could have been obtained through the use of massive chills in the mold at strategic places to promote directional solidification; but the correct placement of such chills is often beyond the ability of the average foundryman so such chills were not used.

By way of summarizing the basic principles underlying the present invention it may be repeated that the tensile strengths of casting alloys increase with an increase of the particular hardening constituents used, but with corresponding losses of ductility. Similarly the higher precipitation hardening temperatures, within limits, increase strength at the expense of ductility. These principles are well known in the art. In addition, two embrittling factors which also detract from the strength of an aluminum-silicon alloy are the coarse silicon crystals in the aluminum-silicon eutectic and the iron impurities present in the aluminum and having a weak needle-shaped crystalline microstructure. In the alloy of the present invention these embrittling factors are decreased or eliminated with a resultant regain of some of the ductility previously lost by the addition of the silicon and magnesium hardening constituents. The coarse silicon crystals are modified to small round crystals by the addition of small amounts of sodium with a definite increase in ductility and tensile strength. The iron needle structure in turn is changed to a harmless spheroidal structure by the addition of a small amount of beryllium which increases the ductility and strength of the alloy and also performs a secondary function of protecting the magnesium against the formation of interfering oxides.

The term "aluminum base alloy" as used herein and in the appended claims comprehends the alloy as cast in sand or in chill molds or in any combination of these casting methods.

While certain percentages and limits of the alloying elements have been stated, within which limits our best

results were obtained, and although certain heat treatments have been described, it will be understood that these factors may be varied without departing from the spirit or scope of this invention.

We claim:

1. An aluminum base alloy consisting of silicon in amounts ranging from 6% to 10%, 0.2% to 0.6% magnesium, 0.05% to 0.5% of beryllium, and the remainder essentially of aluminum.

2. An aluminum base alloy consisting of silicon in amounts ranging from 6% to 10%, 0.2% to 0.6% magnesium, 0.05% to 0.5% of beryllium, an element selected from a group consisting of titanium, boron, columbium, zirconium, tantalum, and molybdenum in an amount from 0.05% to 0.3%, and the remainder essentially of aluminum.

3. An aluminum base alloy having a high ultimate strength, high yield point, and good ductility consisting of 6% to 10% silicon, 0.2% to 0.6% magnesium, 0.05% to 0.5% beryllium, 0.05% to 0.3% of an element taken from a group consisting of titanium, boron, columbium, zirconium, tantalum, and molybdenum, and the remainder of aluminum containing the usual impurities including up to 0.6% of iron and up to 0.2% each of copper, zinc, manganese and chromium.

4. An aluminum base alloy consisting of silicon in amounts ranging from 7.6% to 8.6%, 0.4% to 0.55% magnesium, 0.1% to 0.3% beryllium, and the remainder essentially of aluminum.

5. An aluminum base alloy consisting of silicon in amounts ranging from 7.6% to 8.6%, 0.4% to 0.55% magnesium, 0.1% to 0.3% beryllium, an element selected from a group consisting of titanium, boron, columbium, zirconium, tantalum and molybdenum in an amount from 0.1% to 0.3%, and the remainder essentially of aluminum.

6. An aluminum base alloy having high tensile strength and good ductility consisting essentially of 7.6% to 8.6% silicon, 0.4% to 0.55% magnesium, 0.1% to 0.3% of beryllium, 0.1% to 0.3% of an element selected from a group consisting of titanium, boron, columbium, zirconium, tantalum, and molybdenum, and the remainder aluminum and impurities including no more than 0.6% iron and 0.2% each of copper, zinc, manganese and chromium.

7. An aluminum base alloy having high tensile strength and good ductility consisting of 6.0% to 10.0% silicon, 0.2% to 0.6% magnesium, 0.05% to 0.5% beryllium and the remainder aluminum and minor impurities including no more than 0.6% iron.

8. An aluminum base alloy having high tensile strength and good ductility consisting of 7.6% to 8.6% silicon, 0.4% to 0.55% magnesium, 0.1% to 0.3% beryllium, and the remainder aluminum and impurities including no more than 0.6% iron and no more than 0.2% each of copper, zinc, manganese and chromium.

9. An aluminum base alloy having high tensile strength consisting of 6.0% to 10.0% silicon, 0.2% to 0.6% magnesium, 0.05% to 0.5% beryllium, 0.1% to 0.3% of an element selected from a group consisting of titanium, boron, columbium, zirconium, tantalum, and molybdenum, no more than about 3% copper, and the remainder essentially of aluminum.

10. An aluminum base alloy having high tensile strength consisting of 6.0% to 10.0% silicon, 0.2% to 0.6% magnesium, 0.05% to 0.5% beryllium, 0.1% to 0.3% of an element selected from a group consisting of titanium, boron, columbium, zirconium, tantalum, and molybdenum, no more than about 3% zinc, and the remainder essentially of aluminum.

References Cited in the file of this patent

UNITED STATES PATENTS

1,879,748	Horsfield et al.	Sept. 27, 1932
1,899,631	Norton	Feb. 28, 1933
1,908,023	Kempf	May 9, 1933
1,952,048	Archer et al.	Mar. 27, 1934
2,525,130	Hall et al.	Oct. 10, 1950
2,565,768	Gittings	Aug. 28, 1951
2,602,413	Miller	July 8, 1952
2,823,995	Blackmun	Feb. 18, 1958

FOREIGN PATENTS

596,067	Great Britain	Dec. 29, 1947
652,636	Great Britain	Apr. 25, 1951