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[54] **HIGH STRENGTH ALUMINUM BASE ALLOY**

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[58] **Field of Search** 75/142, 141; 148/32, 148/32.5, 2, 3, 12.7, 159

[56] **References Cited**

UNITED STATES PATENTS

2,525,130 10/1950 Hall et al. 75/142

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[57] **ABSTRACT**

A high strength aluminum base alloy having good wear resistance consisting essentially of silicon from 7 to 20 percent, magnesium from 0.1 to 0.6 percent, silver from 0.1 to 1.0 percent, copper from 3.5 to 6 percent, balance essentially aluminum, and processing same.

11 Claims, No Drawings

HIGH STRENGTH ALUMINUM BASE ALLOY

BACKGROUND OF THE INVENTION

Aluminum alloy castings having good physical properties especially high strength and wear resistance, have long been needed for a variety of reasons. Generally, aluminum casting alloys currently available have provided strength levels well below those obtainable with machined plates and billets, machine forging and wrought assemblies.

U.S. Pat. No. 3,475,166 teaches a high strength aluminum casting alloy having good physical properties. This patent teaches an alloy having good elevated temperature properties which would be desirable for designing pistons or stressed engine parts with reduced weight. However, this material does not have adequate resistance to galling, scuffing, or wear.

Accordingly, it is a principal object of the present invention to provide a new and improved aluminum base casting alloy having high strength and wear resistance.

It is a further object of the present invention to provide an aluminum alloy as aforesaid which has good elevated temperature properties and also good resistance to galling, scuffing or wear.

It is a particular object of the present invention to provide an aluminum casting alloy as aforesaid which is useful in the design of pistons or other highly stressed engine parts which operate at elevated temperatures.

Further objects and advantages of the present invention will appear hereinafter.

SUMMARY OF THE INVENTION

In accordance with the present invention it has been found that the foregoing objects and advantages may be readily obtained. The aluminum base alloy of the present invention consists essentially of silicon from 7 to 20 percent, preferably from 7 to 12 percent, magnesium from 0.1 to 0.6 percent, silver from 0.1 to 1.0 percent, copper from 3.5 to 6 percent, balance essentially aluminum. Naturally, numerous optional additives and conventional impurities may be readily utilized as will be seen from the ensuing specification.

In accordance with the present invention, it has been found that the present alloys have good elevated temperature properties combined with good resistance to galling, scuffing or wear. The addition of silicon in the large amounts utilized herein has been found to provide wear resistance, surprisingly without detracting from the strength of the matrix.

Furthermore, it has been surprisingly found that the basic heat treatability of the alloy matrix is not affected by silicon additions in the range of from 7 to 20 percent, and in fact some tensile strength increase can be obtained. In addition to the foregoing, other significant advantages may be obtained in accordance with the alloy of the present invention. For example, Brinell hardness is surprisingly high, indicating excellent wear resistance.

In addition, the present invention teaches a method of processing the aluminum base alloy set forth above. The method comprises casting the alloy in the temperature range of 1,250° to 1,500° F and aging the alloy in the temperature range of 300° to 500° F for from one to 24 hours. Preferably a solution heat treatment is provided after casting and before aging at a temperature of 850° to 975° F for from one to 40 hours, followed by quenching.

DETAILED DESCRIPTION

As indicated hereinabove, the aluminum base alloy of the present invention contains large amounts of silicon from 7 to 20 percent. Preferably, the silicon range is from 7 to 12 percent since over 12 percent silicon you are in the primary silicon range and provide coarse silicon particles. Fine, uniform silicon particles, which are in the 7 to 12 percent range, provide a better product which is easier to cast. Also, the higher silicon contents would tend to detract slightly from elevated temperature strength. This is a significant additive. As indicated, the silicon is mainly present in the alloy of the present invention as dispersed elemental silicon particles. These impart hardness, wear resistance and also tend to lower the coefficient of thermal expansion. In accordance with the present invention it has been surprisingly found that the hard particles of silicon can be added to the alloy while retaining the good elevated temperature properties thereof. Furthermore, the basic heat treatability of the alloy of the present invention has been found to be unaffected by the silicon additions in this range. In the 7 to 12 percent range, the silicon is preferably present in the eutectic form as a uniformly distributed dispersion having a fine particle size. The particle size can be controlled by controlling the solidification rate to produce the desired fine particle size, generally by rapid cooling from casting.

The alloy of the present invention contains magnesium in an amount from 0.1 to 0.6 percent, and preferably from 0.3 to 0.5 percent. It has been found that the magnesium addition is necessary in combination with the copper in order to obtain appreciable response to heat treatment.

The silver addition is in the amount of from 0.1 to 1.0 percent and preferably from 0.3 to 0.7 percent. Silver provides a significant extra strengthening and hardening effect.

The copper addition is in the amount of 3.5 to 6 percent and preferably 4.5 to 5.5 percent. The copper addition has been found to provide a strengthening effect. Copper is the principal precipitation hardening agent, forming the supersaturated solid solution during solution heat treatment, from which submicroscopic particles form during artificial aging treatment. The manner and effectiveness of the precipitation process is favorably affected by the magnesium and silver additions.

Naturally, numerous additives and impurities may be present in the resultant alloy. Thus, manganese and chromium may be present in amounts up to 0.7 percent and 0.5 percent respectively, generally in an amount of 0.1 to 0.7 percent manganese and 0.1 to 0.5 percent chromium. Either of these additives are particularly desirable if iron is present since they change the form of the iron from coarse, needle shaped particles to rounded or equiaxed particles and lessen brittleness. Iron may be present in an amount up to 1.5 percent. If at least 0.5 percent iron is present, manganese and/or chromium should be present also as above. Titanium may also be included in an amount from 0.01 to 0.35 percent for cast grain refining, and zinc may be included in an amount up to 0.5 percent. Nickel may also be added in amounts up to 2.5 percent to add to elevated temperature stability. Naturally, if desired, any of the foregoing may be present in an amount as low as 0.001 percent. In addition to the foregoing, others may be present in an amount up to 0.05 percent each, total 0.25 percent.

The alloys of the present invention are particularly useful in the manufacture of pistons for internal combustion engines. The manufacturers of piston actuated internal combustion engines are constantly striving to obtain improved performance by reducing the weight of the piston. In so doing, the piston must have sufficient mechanical strength at operating temperatures and resistance to shape change. The alloys of the present invention are characterized by highly desirable elevated temperature properties together with surprising resistance to galling, scuffing and wear which would make them especially suitable for this use.

In addition, however, the alloys of the present invention are particularly useful for other highly stressed engine parts which operate at elevated temperatures, for example, in the new Wankel engines which are demanding with respect to dimensional stability and resistance to wear.

The findings of the present invention are particularly surprising since when large amounts of an additive are incorporated in an alloy system one would normally anticipate a drastic alteration in the characteristics of the basic system. However, in accordance with the present invention, it is surprising that one does not destroy the desirable characteristics of the matrix alloy, such as heat treatability, elevated temperature properties and high strength.

The alloys of the present invention are cast in the temperature range of 1,250° to 1,500° F. They are mainly intended to be cast into approximate shape and machined or ground to final dimensions. However, other forming operations, such as forging, can be employed. Following casting or forging, the alloy is preferably solution heat treated at 850° to 975° F for one to 40 hours, preferably from 900° to 950° F for 12 to 20 hours, followed by quenching into cold or boiling water. This should be followed by an artificial aging treatment which will develop the strength and stability that the particular service temperatures require. The artificial aging is for one to 24 hours at 300° to 500° F. The solution heat treatment is particularly preferred as it develops higher properties.

The alloys of the present invention and improvements thereof will be more readily apparent from a consideration of the following illustrative examples.

EXAMPLE I

Several castings were made of the permanent mold (Durville) type from 2,000 gram melts using the following procedure. Melting was done in an alumina coated clay graphite crucible, using an induction coil for heating. Silicon, copper, magnesium and silver were added in elemental form, others were added as master alloys. After melting, the melt was fluxed with Cl_2 gas for ten minutes before pouring. The mold had a cavity four inches high by four inches wide by one and three quarters inches thick, with a riser on top. The resultant alloys had the compositions set forth in Table I below, with the balance being essentially aluminum in each case.

TABLE I.—ALLOY COMPOSITION

Chemical Composition in Weight Percent

Alloy No.	Si	Cu	Mn	Mg	Ag	Fe	Ti
1	6.9	4.9				0.14	0.1
2	7.0	5.1		0.5		0.08	0.09
3	6.8	5.0		0.5	0.6	0.09	0.09
4	6.9	5.0	0.6	0.5		0.08	0.09
5	11.2	5.0		0.5		0.1	0.1

EXAMPLE II

The alloys prepared in Example I were all heat treated at 920° F for 16 hours, the temperature was then raised to 940° F for 6 hours and the materials were water quenched in cold water. The resultant properties are shown in the following tables. Table II shows the Brinell hardness of the resultant samples tested immediately after quenching, aged at room temperature for one week and in the T6 temper. The T6 temper consisted of solution heat treated and quenched material aged at room temperature for 24 hours and then at 310° F for 20 hours. Table III shows the tensile properties of duplicate machined round standard tensile specimens in the T6 temper.

TABLE II

Brinell Hardness — Kg/mm^2

Alloy No.	Immediately after quench	Aged room temperature one week	T6 Temper
1	79.6	78.5	121
2	98.8	111	143
3	95.1	110	150
4	95.1	112	140
5	98.8	111	143

TABLE III

Tensile Properties

Alloy No.	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Elongation — % 2"
1	39.4, 39.0	52.7, 52.5	2.2, 2.0
2	59.1, 59.0	64.3, 63.8	0.9, 1.0
3	63.0, 62.6	67.0, 66.6	1.0, 1.0
4	60.6, 60.6	63.8, 63.7	1.0, 1.0
5	60.8, 60.5	65.4, 64.2	1.1, 1.0

EXAMPLE III

For comparison, the tensile properties were determined on the following alloy: An aluminum base alloy containing 0.04 percent silicon, 4.80 percent copper, 0.27 percent manganese, 0.46 percent magnesium, 0.61 percent silver, 0.03 percent iron, 0.30 percent titanium, balance aluminum, said alloy being identified as Alloy 6. The alloy was poured from 1350°F into permanent molds of three-fourths inch square section and 7 inch length with a riser along the edge. The material was solution heat treated at 985° F for 16 hours, followed by quenching in cold water followed by holding for 24 hours at room temperature followed by treatment for 20 hours at 310°F. The tensile properties of duplicate specimens are shown in Table IV below.

TABLE IV

Tensile Properties

Alloy No.	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Elongation—% 2"

6	60.0, 59.9	67.8, 68.2	7.0 and 9.9

TABLE V

Brinell Hardness — Kg/mm²

Alloy No.	T6 Temper
6	119, 119

Alloy **3**, which is the alloy of the present invention, is seen to have hardness and tensile strength properties better than the alloys without silver. In addition, Alloy **3** of the present invention has higher strength at room temperature than Alloy 6 which is the standard commercial alloy even though a lower solution heat treatment was used. This shows that the matrix strength has been retained or enhanced and, therefore, the alloy of the present invention will have correspondingly high strength in elevated temperature service. The tensile elongation naturally is reduced from that of Alloy 6 because of the hard brittle silicon particles; however, ductility is not a necessary property for this type of alloy whereas the improved wear resistance is significant.

Alloy 2, compared with Alloy 1, shows that magnesium is a necessary addition in order to obtain response to heat treatment and the high base level of strength properties desired. Alloy 4, compared with Alloy 2, shows that manganese which is known to interact with iron, silicon and aluminum to form a hard intermetallic phase, will not compromise the basic matrix properties. Alloy 5, compared with Alloy 2, shows one can add the necessary amount of silicon to impart wear resistance for a given application.

The Brinell hardness data shown in Tables II and V show that hard particles such as silicon add to the hardness of the alloy, even though the matrix tensile strength is not increased appreciably. Thus, Alloy **1** with low tensile strength has comparable Brinell hardness to Alloy 6 with high tensile strength. A hardness increase of the type in Alloy 1 is significant in terms of wear resistance and galling. Thus, the superior Brinell hardness of Alloy 3, the alloy of the present invention, is a measure of its enhanced wear resistance when compared with standard Alloy 6, as well as when compared with the silver free Alloys 2, 4 and 5.

This invention may be embodied in other forms or carried out in other ways without departing from the spirit or essential characteristics thereof. The present embodiment is therefore to be considered as in all respects illustrative and not restrictive, the scope of the invention being indicated by the appended claims, and all changes which come within the meaning and range of equivalency are intended to be embraced therein.

What is claimed is:

1. An aluminum base alloy consisting essentially of silicon from 7 to 20 percent, magnesium from 0.1 to 0.6 percent, silver from 0.1 to 1.0 percent, copper from 3.5 to 6 percent, balance aluminum.

2. An aluminum base casting alloy having good wear resistance and elevated temperature properties consisting essentially of silicon from 7 to 12 percent, magnesium from 0.1 to 0.6 percent, silver from 0.1 to 1.0 percent, copper from 3.5 to 6 percent, balance aluminum.

3. An aluminum alloy according to claim **2** containing iron in an amount up to 1.5 percent.

4. An aluminum alloy according to claim **3** containing a material selected from the group consisting of from 0.1 to 0.7 percent manganese and from 0.1 to 0.5 percent chromium.

5. An aluminum alloy according to claim **2** containing from 0.01 to 0.35 percent titanium.

6. An aluminum alloy according to claim **2** containing up to 2.5 percent nickel, up to 0.5 percent zinc, up to 0.7 percent manganese, up to 0.5 percent chromium, up to 0.35 percent titanium, up to 1.5 percent iron, others, each up to 0.05 percent, total up to 0.25 percent.

7. An aluminum alloy according to claim **2** in the heat treated condition.

8. An aluminum base casting alloy having good wear resistance and elevated temperature properties for use in pistons and highly stressed engine parts consisting essentially of silicon from 7 to 12 percent, magnesium from 0.3 to 0.5 percent, silver from 0.3 to 0.7 percent, copper from 4.5 to 5.5 percent; balance essentially aluminum.

9. A process for providing an aluminum base casting alloy having good wear resistance and elevated temperature properties which comprises:

A. casting an aluminum base alloy consisting essentially of silicon from 7 to 20 percent, magnesium from 0.1 to 0.6 percent, silver from 0.1 to 1.0 percent, copper from 3.5 to 6.0 percent, balance essentially aluminum in the temperature range of 1,250° to 1,500° F; and

B. aging said alloy at a temperature of 300° to 500° F for one to 24 hours.

10. A process according to claim **9** including the step of solution heat treating after casting but before aging, said solution heat treating being at a temperature of 850° to 975° F for from one to 40 hours.

11. A process according to claim **10** including the step of quenching following solution heat treating.

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