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ALUMINUM-BASE ALLOY FOR USE AT ELEVATED TEMPERATURES

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ABSTRACT OF THE DISCLOSURE

Aluminum base alloy containing silicon, nickel, iron, magnesium and optionally copper has improved combination of characteristics which particularly include high strength at 600° F. along with adequate ductility at room temperature.

The present invention relates to aluminum-base alloys and, more particularly, to aluminum-base alloys containing nickel and silicon

It is well known that some presently available aluminum-base alloys have many desirable characteristics, including light weight and good wear resistance, which enable aluminum-base alloys in the form of castings and other products, frequently in a heat-treated condition, to be used very satisfactorily at room temperatures and temperatures a little above room temperature. It is also well known that commercially available aluminum-base alloys undergo very substantial losses in strength when heated to elevated temperatures and that the strength thereof at 600° F. is unsatisfactorily low. Accordingly, the usefulness of aluminum-base alloys for articles which are exposed in service to elevated temperatures of up to about 600° F. has been, at best, very limited. Heretofore, the art has endeavored to provide aluminum-base alloys which could be produced on a commercial basis and were satisfactory for use at temperatures from room temperature up to elevated temperatures as high as 600° F. For such use, an alloy needs adequate ductility and a high level of tensile strength, including ultimate tensile strength and yield strength, at temperatures from about room temperature up to 600° F. also, for prolonged service at elevated temperatures an alloy should be metallurgically stable at the required service temperatures and thus should not undergo detrimental microstructural changes or suffer substantial loss of tensile strength or ductility or other desirable characteristics when exposed for prolonged periods, e.g., periods totaling 1000 hours, at elevated temperatures up to 600° F. Although experiments in the prior art have shown that the room temperature and/or elevated temperature hardness and/or strength of aluminum is increased by alloying it with other elements, e.g., copper, magnesium and/or nickel, the problem of providing an aluminum-base alloy which is wholly satisfactory for making articles which must endure extended service at elevated temperatures of 600° F. has not been successfully overcome in the prior art. For instance, although some known aluminum-base alloys containing copper and magnesium in amounts such as 0.5% to 4% copper and 0.5% to 1.5% magnesium and up to 13% silicon have at least moderately good strength when first exposed to elevated temperatures, such alloys are not metallurgically stable at 600° F. and the strength thereof decreases to an unsatisfactorily low level when the alloys have been at 600° F. for prolonged periods. In other instances, aluminum-base alloys containing copper, magnesium, silicon, nickel and/or iron have been found to possess high hardness at elevated temperatures but have not been satisfactory for many purposes because the room temperature ductility thereof is inadequate. Good castability and machinability are also frequently required of

aluminum-base alloys inasmuch as it has often proved advantageous in industry to cast and machine articles of manufacture, including pistons, cylinder heads and engine blocks, from aluminum-base alloys. However, although aluminum-base alloy castings have served many useful purposes there still remains a long unsolved problem of providing an aluminum-base alloy having all the important characteristics, including high strength, ductility and metallurgical stability at elevated temperatures, adequate strength and ductility at room temperature, good castability, good wear resistance and good machinability, needed in an aluminum-base casting alloy for use at elevated temperatures of up to about 600° F.

Although many attempts were made to overcome the foregoing difficulties and other difficulties and disadvantages, none, as far as I am aware, was entirely successful when carried into practice commercially on an industrial scale.

It has now been discovered that a highly improved combination of characteristics including high strength, metallurgical stability and adequate ductility at room and elevated temperatures, good castability, good wear resistance, good machinability and other useful characteristics is obtained with a new aluminum-base alloy of a new, specially controlled composition.

It is an object of the present invention to provide a new aluminum-base alloy composition characterized by high strength, metallurgical stability and adequate ductility at room and elevated temperatures and also by good castability, good wear resistance and good machinability.

Another object of the invention is to provide a new cast article of a specially controlled aluminum-base alloy composition.

The invention further contemplates a new process for producing cast, including cast and heat treated, aluminum-base alloy articles characterized by new and improved characteristics.

Other objects and advantages of the invention will become apparent from the following description.

Generally speaking, the present invention contemplates a new aluminum-base alloy containing about 11% to about 13% silicon, 4.5% to about 5.5% nickel, 0.5% to about 0.85% iron, about 0.2% to about 0.65% magnesium, up to about 1% copper and balance essentially aluminum. In addition, the alloy can contain up to about 1% lead, up to about 0.5% titanium, up to about 0.1% sodium and up to about 0.03% boron. The alloy of the invention is characterized by good castability and can be produced as cast articles by casting processes including chill casting processes such as permanent mold casting and die casting.

In carrying the invention into practice it is advantageous to chill cast the alloy and heat treat the castings for about 7 to about 9 hours at about 350° F. to about 450° F., more advantageously, about 7 to about 9 hours at about 350° F. to about 400° F. When in the condition obtained by heat treating in accordance with the invention, the alloy is characterized by stable, high, elevated temperature strength including yield strength of at least 6900 pounds per square inch (p.s.i.) when at 600° F. for periods up to at least 1000 hours and by adequate ductility at room temperature. Yield strength referred to herein is determined by the 0.2% offset method. Adequate ductility (at least 0.2% tensile elongation under load) enables the alloy of the invention to be stressed up to the yield strength thereof without fracturing. Also, when in the chill cast and heat treated condition, the alloy of the invention possesses a room temperature yield strength of at least 25,000 p.s.i. In general, room temperature yield strength is increased as the heat treat temperature is decreased and room temperature ductility is increased as the heat treat temperature is increased. Heat treatment or ex-

posure at temperatures not above 600° F. has no significant effect upon strength and ductility at 600° F.

For obtaining high strength, good castability and adequate ductility and toughness, the alloy of the invention advantageously contains 11.5% to 12% silicon, 4.7% to 5.2% nickel, 0.55% to 0.7% iron, 0.25% to 0.6% magnesium, 0.5% to 1% copper and balance essentially aluminum. When included in the alloy, titanium, advantageously 0.1% to 0.3% titanium, and/or boron, advantageously 0.005% to 0.03% boron, are beneficial for refining the as-cast grain size. Also, it is advantageous to add 0.1% to 0.2% sodium to the alloy for refining the eutectic structure, which refinement is beneficial to obtaining good room temperature ductility.

When the balance of an alloy of the present invention is referred to as being essentially aluminum, it is to be understood that the alloy can also contain other elements in small amounts that are not detrimental to the alloy. Thus, the alloy can contain manganese and chromium in amounts not greater than about 0.3% each, although the amounts of any manganese and chromium present are advantageously kept as low as possible since these elements promote formation of detrimental coarse aluminides in the alloy. A small amount of zinc can be tolerated in the alloy but the zinc content should be as low as possible and must not be greater than 1%. Lead may be present in an amount up to about 1% for improving machinability, but the amount of lead is advantageously maintained as low as the minimum needed. All chemical composition percentages herein are by weight.

The composition of the alloy is closely controlled with regard to proportions of silicon, nickel, iron, magnesium and any copper present to thereby achieve the highly important combination of characteristics, including metallurgical stability and high strength at elevated temperature and adequate ductility at room temperature, which provides new and improved utility for the alloy. The silicon content must be at least about 11% and not greater than about 13% inasmuch as silicon contents either below about 11% or above about 13% do not produce the characteristics ternary microstructure of the alloy and are not satisfactory for obtaining the optimum castability, the high strength and stability at elevated temperature and/or the adequate room temperature ductility and toughness of the alloy. The alloy must contain at least 4.5% nickel and 0.5% iron in order to obtain the high elevated temperature strength and stability of the alloy; otherwise, if the amounts of nickel and/or iron are too low, the elevated temperature strength and stability of the alloy are not satisfactory. Amounts of nickel above about 5.5% have detrimental effects resulting in the formation of acicular primary nickel aluminides which are detrimental to room temperature ductility and toughness. Iron contents greater than about 0.85% detrimentally promote formation of coarse nickel-iron aluminides in the microstructure and are detrimental to room temperature ductility and toughness. In addition to silicon, nickel, iron and aluminum, the alloy must contain about 0.2% magnesium to provide adequate room temperature strength, but amounts of magnesium greater than 0.65% are detrimental to room temperature ductility. Copper, advantageously 0.5% to 1% copper, is beneficial for improving the room temperature strength of the alloy but is of little or no value for obtaining stable 600° F. temperature strength over prolonged periods.

For the purpose of giving those skilled in the art a better understanding of the invention and a better appreciation of the advantages of the invention, the following illustrative examples are given.

Three alloys in accordance with the invention, referred to herein as alloys No. 1, No. 2 and No. 3, were melted in an induction furnace, degassed by purging with a nitrogen-chlorine gas mixture and thereafter chill-cast by pouring at approximately 1350° F. into cast iron permanent molds which were preheated to about 500° F. Prior to

casting, the melts were inoculated with 0.1% sodium. Chemical compositions of alloys No. 1, No. 2 and No. 3 are set forth in Table I hereinafter.

TABLE I

Alloy No.	Percent Si	Percent Ni	Percent Fe	Percent Cu	Percent Mg	Al
1-----	11.5	5	0.6	0.9	0.25	Balance.
2-----	11.5	5	0.64	0.93	0.56	Do.
3-----	11.5	5	0.6	<0.03	0.24	Do.

Results of testing chill-cast, cast-to-size test bars (0.505-inch diameter, 2-inches reduced section) of alloys No. 1, No. 2 and No. 3 illustrate the high elevated temperature strength and adequate ductility, and also other useful desirable characteristics, of the alloy of the invention. The specimens for the room temperature test results in Table II were heat treated 8 hours at 350° F. to 400° F., alloys No. 1 and No. 2 being heat treated at 400° F. and alloy No. 3 being heat treated at 350° F. The tests at 600° F. referred to in Table II were made with specimens which had been heated at 600° F. for 1000 hours prior to testing. The room temperature ductility of the alloy is not decreased and is usually increased slightly after the alloy has been heated at 600° F.

TABLE II

Alloy No.	Tested at Room Temperature			Tested at 600° F.		
	U.T.S., p.s.i.	Y.S., p.s.i.	Elong., percent	U.T.S., p.s.i.	Y.S., p.s.i.	Elong., percent
1-----	31,800	26,800	0.3	13,100	7,100	9.5
2-----	30,400	28,500	0.3	13,500	7,400	8
3-----	31,200	26,600	0.3	12,600	7,700	5

NOTE.—U.T.S.=Ultimate Tensile Strength; Y.S.=Yield Strength at 0.2% offset; Elong.=Elongation in 2 inches; measured under load in room temperature tests; measured after fracture in 600° F. tests.

The alloy of the invention is characterized in the chill-cast condition, with or without heat treatment in accordance with the invention, by a ternary eutectic type microstructure comprising alpha aluminum, eutectic silicon and eutectic nickel aluminides. Inasmuch as the composition is of a eutectic nature, the alloy has especially good castability.

To further illustrate the new and improved characteristics and/or properties attributable to the specially controlled proportion of the cooperating elements iron, nickel, silicon and magnesium in the aluminum alloy of the invention and other novel unobvious features of the invention, a number of alloys and castings not in accordance with the invention were prepared and tested to compare the characteristics thereof with corresponding characteristics of embodiments of the present invention. Compositions of alloys not in accordance with the invention are set forth in Table III hereinafter and characteristics pertaining thereto are set forth in Table IV hereinafter. The techniques for preparing and testing the alloys referred to in Tables III and IV were the same as were employed with the alloys referred to in Tables I and II.

TABLE III

Alloy No.	Percent Si	Percent Ni	Percent Fe	Percent Cu	Percent Mg	Al
A-----	11.5	5	0.15	<0.03	0.26	Balance.
B-----	11.5	5	0.13	0.93	0.54	Do.
C-----	12	2.5	0.6	1	1	Do.
D-----	11.5	7.5	0.5	0.5	0.3	Do.

TABLE IV

Alloy No.	Tested at Room Temperature			Tested at 600° F.		
	U.T.S., p.s.i.	Y.S., p.s.i.	Elong., percent	U.T.S., p.s.i.	Y.S., p.s.i.	Elong., percent
A-----	34,400	23,100	1	9,300	5,400	18
B-----	33,100	28,100	0.4	11,400	6,400	6
C-----	36,000	25,000	0.5	11,700	5,900	9
D-----	26,900	(1)	<0.2			

¹ Fractured with sustaining a yield stress at 0.2% offset.

Each of the alloys set forth in Table III and referred to in Table IV is outside the scope of the composition of the alloy of the invention and fails to have satisfactory characteristics in at least one respect. For instance, the composition of alloy A contains only 0.15% iron, which is too low an iron content to be in accordance with the invention, and the yield strength of alloy A at 600° F., after being heated at 600° F. for about 1000 hours, was only 5400 p.s.i., which strength is not satisfactory. Also, alloy B has an iron content of only 0.13%, which is too low to be in accordance with the invention, and the elevated temperature yield strength of alloy B was unsatisfactorily low as compared to that of alloy No. 2 within the invention. The composition of alloy C is not in accordance with the invention, particularly in that alloy C contains only 2.5% nickel, and the elevated temperature yield strength of alloy C was also unsatisfactorily low. The nickel content of alloy D is too high, that is more than about 5.5%, and the room temperature tensile test result shows that alloy D, which was chill-cast and heat treated for 8 hours at 400° F., was not characterized by adequate ductility. Thus, the room temperature elongation of alloy D was less than 0.2% and the alloy could not sustain a load at 0.2% extension.

It is to be observed that the present invention also provides a new process for making a cast and heat treated aluminum-base alloy article characterized by high strength and metallurgical stability at elevated temperatures up to 600° F. and by adequate ductility at room temperature comprising providing a melt of an alloy containing about 11% to about 13% silicon, 4.5% to about 5.5% nickel, 0.5% to about 0.85% iron, about 0.2% to about 0.65% magnesium, up to about 1% copper, up to about 1% lead, up to about 0.5% titanium, up to about 0.1% sodium, up to about 0.03% boron with balance essentially aluminum, pouring said alloy into a chill mold, allowing the alloy to solidify to form a chill casting and thereafter heat treating the casting for about 7 hours to about 9 hours at about 350° F. to about 450° F. in order to obtain good combinations of room temperature yield strength and ductility. Advantageously, castings are heat treated about 7 hours to about 9 hours at about 350° F. to about 400° F.

The present invention is particularly applicable to the production of aluminum-base alloys for pistons, cylinder heads, engine blocks, marine hardware, valve bodies and bridge railing parts.

Although the present invention has been described in conjunction with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention, as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and appended claims.

I claim:

1. An alloy consisting essentially of about 11% to about 13% silicon, 4.5% to about 5.5% nickel, 0.5% to about 0.85% iron, about 0.2% to about 0.65% magnesium, up to about 1% copper and balance essentially aluminum.

2. A chill casting consisting essentially of about 11% to about 13% silicon, 4.5% to about 5.5% nickel, 0.5% to about 0.85% iron, about 0.2% to about 0.65% magnesium, up to about 1% copper with balance essentially aluminum and characterized by a ternary eutectic type microstructure comprising alpha aluminum, eutectic silicon and eutectic nickel aluminides.

3. An alloy consisting essentially of 11.5% to 12% silicon, 4.7% to 5.2% nickel, 0.55% to 0.7% iron, 0.25% to 0.6% magnesium, 0.5% to 1% copper and balance essentially aluminum.

4. An alloy consisting essentially of about 11.5% silicon, about 5% nickel, about 0.64% iron, about 0.56% magnesium, about 0.93% copper and balance essentially aluminum.

5. An alloy consisting essentially of about 11.5% silicon, about 5% nickel, about 0.6% iron, about 0.24% magnesium and balance essentially aluminum.

6. An alloy consisting essentially of about 11.5% silicon, about 5% nickel, about 0.6% iron, about 0.25% magnesium about 0.9% copper and balance essentially aluminum.

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RICHARD O. DEAN, *Primary Examiner*.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

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Frank A. Badia

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

Column 3, line 13, cancel "the". Column 4, line 45, "proportion" should read -- proportioning --; line 75, "with" should read -- without --.

Signed and sealed this 3rd day of February 1970.

(SEAL)

Attest:

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Commissioner of Patents