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ALUMINUM BASE ALLOY

Charles B. Criner, New Kensington, Pa., assignor to Aluminum Company of America, Pittsburgh, Pa., a corporation of Pennsylvania

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This invention is concerned with aluminum base alloys which are adapted for service at elevated temperatures, particularly such as required in certain parts of jet engines. An object of the invention is to provide an aluminum base alloy composition that possesses a combination of high strength and a high resistance to creep and fatigue at elevated temperatures.

Aluminum base alloys have long been used for such parts of internal combustion engines as pistons, cylinder heads and connecting rods and they have served quite satisfactorily for these purposes. Typical of the alloys that have been used for these parts are those which, in addition to aluminum, contain 4% copper, 1.5% magnesium and 2% nickel; 10% copper, 1.25% iron and 0.25% magnesium; or, 12% silicon, 1.2% magnesium, 2.5% nickel and 0.8% copper. With the advent of more powerful motors and auxiliary equipment, especially jet engines, it has been found that the above alloys do not possess the requisite properties for long time operation. The requirements for compressor parts in jet engines, for example, have demanded the utmost from aluminum base alloys. It has been learned that while some alloys may have a satisfactory strength at elevated temperatures their resistance to creep and fatigue are so low as to make them unacceptable. In other cases the alloys may have interesting properties at high temperatures but they are so difficult to cast and work as to remove them from consideration as practical materials. Effort has therefore been made to find an alloy which would possess both high strength and high resistance to creep and fatigue and still be amenable to fabrication by conventional methods.

My invention is based on the discovery that a highly satisfactory combination of strength and resistance to fatigue and creep at high temperatures is to be found in a magnesium-free aluminum base alloy containing copper as the chief added component and small amounts of manganese, vanadium and zirconium. More specifically the alloy should consist essentially of aluminum, from 5 to 13% copper, 0.15 to 1.7% manganese, 0.05 to .20% vanadium and 0.05 to 0.30% zirconium, the iron impurity not exceeding 0.75% and the silicon impurity being below 0.40%. Furthermore, the amount of manganese should be between 3 and 13% of the copper content. The presence of the small amount of manganese, vanadium and zirconium considerably modifies the properties of the binary aluminum-copper alloy at elevated temperatures. The precise manner in which these elements cooperate with each other and with the copper component is not understood but it has been found that the foregoing limits must be strictly observed to obtain the desired results. While the alloy exhibits improved properties in both the cast and worked conditions the improvement is more clearly evident where it receives a solution heat treatment with or without subsequent precipitation hardening treatment. The use of a solution heat treatment has the further advantage of homogenizing the alloy and insuring a more uniform product.

The alloy should contain no more than about 0.02% magnesium and hence it is here referred to as being "magnesium-free."

For optimum results the alloy should contain from 5 to 9% copper, 0.15 to 1.20% manganese, 0.05 to 0.15% vanadium and 0.05 to 0.25% zirconium, the silicon and iron impurities amounting to 0.05 to 0.30% silicon and 0.05 to 0.50% iron. The amount of manganese, of course, should be between 3 and 13% of the copper content as indicated hereinabove. It is also desirable that the alloy be given both solution and precipitation hardening treatments to produce the maximum properties. Alloys within the foregoing range which have received the prescribed thermal treatment may be expected to have at 400° F. a tensile strength after 100 hr. exposure of 39,000 p. s. i., a minimum creep rate of on the order of 0.00006 to 0.00016 in./in./hr. under a stress of 25,000 p. s. i., a stress for rupture in 1000 hours of 23,000 p. s. i. and to not fail in fatigue at a stress of 13000 p. s. i. in less than about 20 million cycles.

To obtain a finer grain size or enhance minor characteristics of the alloys it may be desirable to add 0.01 to 0.25% of one or more of the following elements: cobalt, nickel, molybdenum, tungsten, chromium, titanium, boron, tantalum and niobium, the total amount of such elements not exceeding 0.25%.

The thermal treatment that may be used to enhance the properties of my alloys should consist of heating them to a temperature between 960 and 1000° F. for a period of 2 to 24 hours followed by quenching, preferably in water at 70 to 160° F. The quenched alloys may then be reheated to 350 to 450° F. for a period of 1 to 50 hours.

My alloys may be used in the non-heat treated condition, if a maximum strength is not demanded, for even in that condition they represent an improvement over such well known alloys as one composed of aluminum, 4% copper, 1.5% magnesium and 2% nickel. For example, sand cast test bars of an aluminum, 6% copper, 0.3% manganese, 0.25% zirconium of 0.1% vanadium alloy had a tensile strength of 14,500 p. s. i., a yield strength of 9,600 p. s. i. and an elongation of 21% at 600° F. whereas the foregoing aluminum-copper-magnesium-nickel composition has a typical tensile strength of but 8,000 p. s. i. and a yield strength of 6,000 p. s. i. at 600° F.

The minimum creep rate values mentioned herein were obtained in the following manner. Standard ½ in. diameter bars were placed in small electrically heated air furnace and maintained under a constant load throughout the period of the test by means of a dead weight and lever system. The furnace temperature was automatically controlled. Measurements of extension or creep were made at regular intervals throughout the test period to the nearest 0.000005 in. To obtain the minimum creep rate, the measured values of creep were plotted against time on Cartesian coordinates and the minimum slope of the resulting curve determined. The minimum creep rate thus determined is also known as the secondary creep rate.

Stresses for specific creep rates were determined in customary manner from graphs in which the creep rates mentioned above were plotted logarithmically against stress. Stress rupture values were obtained in a similar manner by determining the time required for rupture at a given stress for each of several specimens under different stresses. By interpolation in the customary manner specific stresses were found which would be expected to cause rupture in specific times.

The alloys of my invention may be used in the cast state or they may be worked. This is of practical importance since it may be possible to use a single composition for both cast and wrought products.

The properties of cast and forged alloys made in accordance with my invention and one not so made are illustrated in the following examples. The alloys had the compositions given in the table below:

TABLE I

Percentage composition of alloys

Alloy	Cu	Mn	V	Zr	Fe	Si	Others
A	5.98	0.21	0.10	0.23	0.11	0.07	----------
B	6.20	0.28	0.14	0.22	0.20	0.20	----------
C	12.14	1.45	0.12	0.25	0.12	0.12	----------
D	6.16	------	0.13	0.23	0.19	0.19	----------
E	6.0	0.3	0.10	0.25	------	------	0.02 Ti 0.005 B

Forged 1" sq. bars of alloys A, B, C, and D were

given a solution heat treatment at 1000° F. for a period of 1 or 2 hours, followed by quenching in water and precipitation hardening at 375° F. for 12 hours. Cast-to-size test bars of alloy E were heat treated at 985° F., quenched and precipitation hardened by heating at 375° F. for 12 hours. Samples of the forged bars were heated to a temperature of 600° F. for a period of 100 hours, while the cast bars were heated to the same temperature for 48 hours and their tensile and yield strengths determined at that temperature. The tensile values obtained under this condition are given in Table II below:

TABLE II

Tensile properties at 600° F.

Alloy	Tensile Strength, p. s. i.	Yield Strength, p. s. i.	Percent Elongation
A	20,000	14,600	24
B	20,300	15,300	24
C	22,200	15,200	21
D	9,000	7,200	41
E	25,000	17,600	9

Comparing the values for alloys A, B and C with D it is apparent that the presence of manganese has an important effect upon the strength of the alloy for in its absence the tensile and yield strengths are considerably reduced. Also, the strength of the cast bars of alloy E is higher than that of the forged bars.

Typical values for the minimum creep rate and stress for rupture at 400 and 600° F. of forged, solution heat treated, quenched and precipitation hardened test bars of an alloy having a nominal composition of 6% copper, 0.3% manganese, 0.10% vanadium, 0.25% zirconium and balance aluminum plus impurities are given in Tables III and IV below:

TABLE III

Creep characteristics at 400 and 600° F.

At 400° F. Stress (p. s. i.) for minimum rate of—				At 600° F. Stress (p. s. i.) for minimum creep rate of—
0.000001 in./in./hr.	0.00001 in./in./hr.	0.0001 in./in./hr.	0.001 in./in./hr.	0.0001 in./in./hr.
20,000	23,000	25,000	28,000	10,000

TABLE IV

Stress rupture characteristics at 400° F. and 600° F.

At 400° F. Stress (p. s. i.) for rupture in—			At 600° F. Stress (p. s. i.) for rupture in—	
10 Hrs.	100 Hrs.	1,000 Hrs.	100 Hrs.	10,000 Hrs.
30,000	26,000	23,000	12,000	8,000

The fatigue values for tests at 400° F. on solution heat treated, quenched and precipitation hardened forged test bars of alloy A are given in Table V below:

TABLE V

Fatigue test results at 400° F.

Millions of Cycles for Failure at Stress of—		
12,000 p. s. i.	13,000 p. s. i.	17,000 p. s. i.
36.5	30.7	3.6

Having described my invention and certain embodiments thereof I claim:

1. A magnesium-free aluminum base alloy consisting of aluminum, 5 to 13% copper, 0.15 to 1.7% manganese, 0.05 to 0.20% vanadium, 0.05 to 0.30% zirconium, and 0.01 to 0.25% of at least one of the elements of the group consisting of cobalt, nickel, molybdenum, tungsten, chromium, titanium, boron, tantalum and niobium, the total amount of said elements of said group not exceeding 0.25% the iron impurity in the alloy not exceeding 0.75%, and the silicon impurity being not over 0.40%, the amount of manganese being between 3 and 13% of the copper content.

2. A magnesium-free aluminum base alloy consisting essentially of aluminum, 5 to 13% copper, 0.15 to 1.7% manganese, 0.05 to 0.20% vanadium, and 0.05 to 0.30% zirconium, the iron impurity in the alloy not exceeding 0.75% and the silicon impurity being not over 0.40%, the amount of manganese being between 3 and 13% of the copper content, said alloy having a higher tensile strength and resistance to creep at elevated temperatures, on the order of 400 and 600° F., than the same alloy devoid of said manganese, vanadium and zirconium components.

3. A magnesium-free aluminum base alloy consisting essentially of aluminum, 5 to 9% copper, 0.15 to 1.20% manganese, 0.05 to 0.15% vanadium and 0.05 to 0.25% zirconium, the iron impurity in the alloy not exceeding 0.50% and the silicon impurity being not over 0.30%, the amount of manganese being between 3 and 13% of the copper content, said alloy having a higher tensile strength and resistance to creep at elevated temperatures, on the order of 400 and 600° F., than the same alloy devoid of said manganese, vanadium and zirconium components.

4. A solution heat treated and precipitation hardened magnesium-free aluminum base alloy consisting essentially of aluminum, 5 to 13% copper, 0.15 to 1.7% manganese, 0.05 to 0.20% vanadium and 0.05 to 0.30% zirconium, the iron impurity in the alloy not exceeding 0.75% and the silicon impurity being not over 0.40%, the amount of manganese being between 3 and 13% of the copper content, said alloy having the internal structure developed by a solution heat treatment at 960 to 1000° F. for a period of 2 to 24 hours and a precipitation hardening treatment at 350 to 450° F. for a period of 1 to 50 hours, said solution heat treated and precipitation hardened alloy having a higher tensile strength and resistance to creep at elevated temperatures, on the order of 400 and 600° F., than the same alloy devoid of said manganese, vanadium and zirconium components.

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