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ALUMINIUM BASE ALLOY

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This invention relates to a form of aluminium base alloy which possesses a high stress-to-fracture characteristic at 300° C. combined with the ability to form sound castings when poured into a sand mould and to be forgeable from cast ingots.

This application is a continuation-in-part of copending application Serial No. 173,244, filed July 11, 1950, now abandoned.

The compressor casings of internal combustion turbine engine are usually cast in two halves, each half being a very large and complicated casting. The compressor rotor blades run at very high speed in closely spaced relation to elements of the casing. A typical structure involved is illustrated in U. S. Patent No. 2,543,355. Such a casing structure in practice may be of the order of 2 ft. 6 ins. in diameter and 2 ft. 6 ins. in length. To cast an article of this kind, the mould must be of extremely intricate shape and it is essential to successful production that the alloy should, among other things, have the property of completely filling such a mould without formation of blow holes, hot tears or shrinkage cavities in the casting. The blades used in such rotors are, at least in their profile portion, commonly forged to size in order to avoid machining, and it is essential that the alloy used for such blades should have good forging characteristics, that is, ductility and hot-workability without loss of high-temperature properties.

Prior to the making of the present invention, successive changes and improvements in the design of internal combustion turbine engines have increased the stress upon the casing and the blades, and raised the running temperature of the compressed air to temperatures of 300° C. and above. Since the compressor casing comprises a major portion of the mass of an internal combustion turbine engine, it has been deemed important that such casing be made of a light metal, preferably aluminium or an aluminium base alloy having the requisite life at high temperature. For this purpose aluminium base alloys have been developed, having in varying degrees some of the desired properties.

When internal combustion turbine engines for aircraft propulsion purposes were first developed, the compressor casings were made of an aluminium base alloy generally as described in the Hall Patent No. 1,782,300 of 1930, which alloy had originally been developed for use in automobile cylinder heads and had excellent casting properties. However, this alloy could not be used when the running temperature of the compressor in internal combustion turbine engines was raised above about 200° C. Commercial specimens of this alloy have a stress-to-fracture characteristic (in 100 hours at 300° C.) of about 4000 lbs. per square inch.

Modern compressors running at about 300° C. require a stress-to-fracture characteristic in both casing and blades of at least 9000 lbs. per square inch, and no aluminium base alloy having this characteristic has heretofore been known. Accordingly, for some years, and until the present invention was made, certain compressor casings designed to run at temperatures upwards of 200° C. were made with a forward and cooler portion of aluminium or aluminium base alloy, and an aft and hotter portion of steel or the like. This construction adds materially to the weight of the engine for a given horsepower and introduces problems of differential expansion at the joint between the two portions of the casing.

So far as blades were concerned, the problem of life at elevated temperature was partially met by use of the aluminium base alloy in the particular heat-treated and direct chill-cast condition described in Hall Patent No. 2,522,575 dating from 1948, but that alloy does not possess the castability required for making complicated sand-cast compressor casings. Furthermore, blades made of the last-mentioned alloy do not have a sufficiently high stress-to-fracture characteristic at 300° C. to permit their use throughout all the rotor stages of modern compressors.

The object of the present invention is to produce an aluminium base alloy having a stress-to-fracture characteristic (in 100 hours at 300° C.) in excess of 9000 lbs. per sq. inch and possessing the smooth flowing characteristics which produce in the mould a sound casting free of blow holes, hot shortness and shrinkage cavities, thus enabling the two halves of compressor casings to be made in a single piece from front to rear of the compressor casing, which simplifies manufacture and avoids questions of differential expansion.

Alloys according to the present invention have a stress-to-fracture characteristic (in 100 hours at 300° C.) in excess of 9000 lbs. per sq. inch and may be produced having such characteristic at 9500 lbs. per sq. inch and higher, such alloy possessing both of the qualities of ease of castability and of forgeability. According to a modification of the invention, in which zirconium is added, the stress-to-fracture characteristics of the alloy may be increased to more than 11,000 lbs. per sq. inch.

A further object of the present invention is to produce an aluminium base alloy having a stress-to-fracture characteristic (in 100 hours at 300° C.) in excess of 9000 lbs. per sq. inch, and also possessing good forging characteristics thus enabling compressor blades to be forged to size in at least their profile portion. Such blade meet the design requirements for compressor blading in later stages of modern compressors.

All ranges given throughout this specification are percentages by weight of the alloy. Where it is specified that the alloy consist of certain named ingredients with the balance "essentially aluminium" the intention is to include, in addition to pure aluminium, such impurities and other ingredients as do not materially affect the physical characteristics of the alloy and to exclude those which markedly alter the said physical characteristics especially its high temperature stress-to-fracture properties and its ability to produce in a sand mould a sound casting normally free of the defects mentioned above.

A good casting alloy, according to the present invention, may be found within the following range:

	Approximately, percent
Copper	4.9 to 6.2
Nickel	0.90 to 1.2
Titanium	0.10 to 0.25
Manganese	0.20 to 0.30
Silicon	Not exceeding 0.25
Cobalt	0.20 to 0.30
Antimony	Optional up to 0.30
Aluminium	Balance except for impurities

Among the impurities which may be present without detriment to the performance of the alloy are up to about 2% zinc, up to about 0.30% bismuth, up to about 0.20% magnesium, and up to about 1.5% iron.

This alloy may be used in the as cast and aged condition. When solution heat treated after casting, for example at 530° to 535° or 545° C. for ½ to 20 hours, then quenched in boiling water or oil at 80° C. and finally aged at 200° to 300° C., this alloy has excellent stress-to-fracture characteristics at high temperature, as shown by the examples below.

The alloy may also be forged, and after forging should be solution heat treated, for example at 530° to 565° C. for ½ to 20 hours, and then aged.

The amounts of the several ingredients of the composition may be varied above or below the amounts specified above, with the results indicated generally as follows:

Copper.—While copper is preferably kept above about 4.9%, it may be used in slightly lesser amounts in alloys intended for use in the as cast condition. Below about 4.5% there is some detectable reduction in the stress-to-fracture characteristic though it remains good for some purposes down to about 3.5%. When the copper exceeds about 6.2%, there is a liability to segregation when the alloy is used in ordinary sand casting though, if the alloy is to be direct chill-cast and then forged, copper can go up to 7% without serious segregation. In alloys for forging, the copper can safely be as high as 7% if desired. The preferred amounts are between about 4.9% and 6.2%.

Nickel.—While for some purposes nickel may be used in amounts less than about 0.90%, a loss in the stress-to-fracture characteristic begins to be detectable below about 0.90%, though the alloy remains useful for some purposes down to about 0.50%. When nickel is more than about 1.5%, the alloy has a tendency to become brittle, i. e., less ductile when cold. But if some brittleness can be tolerated, the nickel can go up to as much as 2%, at which level the stress-to-fracture characteristic is still very good. The preferred amounts are between about 0.90% and 1.2%.

Titanium.—The presence of titanium is essential for the development of a high stress-to-fracture characteristic. It also serves as a cleanser and refiner. However, titanium cannot be used in amounts exceeding about 0.30%, owing to a tendency to segregation. The preferred amounts are between about 0.10% and 0.25%.

Manganese.—Manganese is essential for high stress-to-fracture characteristics. When used in amounts exceeding approximately 0.60%, there is a tendency to embrittlement and segregation. The preferred amounts are between about 0.20% and 0.30%.

Silicon.—Silicon, in the amount contemplated here, is a normal impurity. It should be kept as low as possible, preferably at or below about 0.20%. In amounts above about 0.45% of silicon, there is a serious falling off in the stress-to-fracture characteristic of alloy. It is to be noted that the normal amount of silicon, around 1.5% to 2%, heretofore commonly used in aluminium base alloys because of its ability to make the alloy smooth-flowing and castable, is not used for this purpose at all in the alloy according to the present invention.

Cobalt.—Cobalt is an essential ingredient in alloys of the present invention, serving both as replacement for silicon in prior known aluminium base alloys, in which capacity it appears to confer upon the alloy the property of completely filling a sand mould without formation of blow holes, hot tears, or shrinkage cavities, and also serving as the means by which the stress-to-fracture characteristic of the alloy (in 100 hours at 300° C.) is raised to and above 9000 lbs. per sq. inch. Cobalt should preferably be present in amounts between about 0.20% and 0.30%, but may be present in amounts up to about 0.50% without detriment to the qualities of the alloy.

Antimony.—Antimony is an optional addition which

may be included with cobalt, and is preferably so included in alloys intended for use in sand castings, since it appears to improve somewhat the casting properties of the alloy containing it in the amounts here specified. Antimony should preferably be present in amounts between about 0.10% and 0.30%, but may be present in amounts up to about 0.50%. If both cobalt and antimony are present, their sum should not in any event exceed about 0.60%, since above this amount there is a tendency to segregation, embrittlement and loss of stress-to-fracture characteristic. The preferred amount is about 0.25% of cobalt and 0.25% of antimony, though excellent results have been obtained with 0.30% of cobalt alone in alloys used for forging.

Iron.—Iron is a normal impurity which may be tolerated in small amounts. It has no apparent effect upon the alloy if present up to about 1%. In amounts between 1% and 1.5%, there is a tendency to embrittlement and loss of ductility. Not more than about 1.5% of iron can be tolerated. It should be kept around 0.20%.

Magnesium.—Magnesium, which has heretofore often been included in amounts of about 1.5% to 2% in aluminium base alloys, is according to the present invention regarded as an impurity to be kept as low as possible, preferably below 0.20%, and preferably omitted altogether.

An example of an alloy especially suitable for casting, according to the present invention, is as follows:

Example 1

	Percent
Copper	4.75
Nickel	1.0
Titanium	0.20
Manganese	0.25
Iron	0.20
Silicon	0.20
Cobalt	0.25
Antimony	0.25

Aluminium—the remainder (except for impurities).

This alloy when poured in an intricate mould possessed excellent casting qualities free of blow holes and shrinkage cavities. After the heat treatment above described it was found to have a stress-to-fracture characteristic (in 100 hours at 300° C.) of about 4.3 long tons (9632 lbs.) per square inch.

Example 2

	Percent
Copper	5.5
Nickel	0.90
Titanium	0.21
Manganese	0.25
Iron	trace
Silicon	0.21
Cobalt	0.30
Antimony	0

Aluminium—the remainder (except for impurities).

Heat-treated as above, this alloy was found to have about the same stress-to-fracture characteristic as Example 1 above (that is, 4.3 long tons), and to possess good forging properties.

As a modification of the foregoing invention, small quantities of zirconium, from about 0.03% to 0.40% (but in any event the total content of zirconium plus titanium should not exceed about 0.50%), may be added to the alloy. The preferred amount of zirconium is about 0.20%. By such addition, a substantial gain in stress-to-fracture characteristic is achieved over the alloy hereinabove described. The use of zirconium has, however, certain disadvantages. It is difficult to remelt the stock ingot material, apparently because complex compounds are formed which are not readily soluble and hence the beneficial effects of this element are lost. Zirconium should therefore be added to the ladle immediately before casting. It appears to reduce slightly the castability of the alloy.

The following examples include zirconium:

Example 3

	Percent
Copper	4.75
Nickel	1.0
Titanium	0.20
Manganese	0.25
Iron	0.20
Silicon	0.20
Cobalt	0.25
Antimony	0.25
Zirconium	0.20

Aluminium—the remainder (except for impurities).

After the heat-treatment above described, this alloy was found to have stress-to-fracture characteristics (in 100 hours at 300° C.) of about 5.5 long tons (11,200 lbs.) per square inch. Its castability was not quite as good as that of Example 1, but complex sand castings can nevertheless be satisfactorily made of this alloy.

Example 4

	Percent
Copper	4.92
Nickel	0.94
Titanium	0.12
Manganese	0.25
Iron	trace
Silicon	0.21
Cobalt	0.23
Antimony	0.16
Zirconium	0.07

Aluminium—the remainder (except for impurities).

After the heat-treatment above described, this alloy was found to have a stress-to-fracture characteristic, under the conditions stated, of about 4.5 long tons (10,080 lbs.) per square inch, and to possess good forging properties.

What is claimed is:

1. A forgeable and castable alloy having a stress-to-fracture characteristic in 100 hours at 300° C. in excess of 9000 pounds per square inch, and consisting by weight of about 4.9% to 6.2% copper, about 0.90% to 1.2% nickel, about 0.10% to 0.25% titanium, about 0.20% to 0.30% manganese, about 0.20% to 0.30% cobalt and the balance essentially aluminium.

2. A forgeable and castable alloy having a stress-to-fracture characteristic in 100 hours at 300° C. in excess of 9000 pounds per square inch, and consisting by weight of about 4.9% to 6.2% copper, about 0.90% to 1.2% nickel, about 0.10% to 0.25% titanium, about 0.20% to 0.30% manganese, about 0.20% to 0.30% cobalt, about 0.10% to 0.30% antimony, and the balance essentially aluminium.

3. A forgeable and castable alloy having a stress-to-fracture characteristic in 100 hours at 300° C. in excess of 9000 pounds per square inch, and consisting by weight of about 4.9% to 6.2% copper, about 0.90% to 1.2% nickel, about 0.10% to 0.25% titanium, about 0.20% to 0.30% manganese, about 0.20% to 0.30% cobalt, about 0.03% to 0.40% zirconium, and the balance essentially aluminium.

4. A forgeable and castable alloy having a stress-to-fracture characteristic in 100 hours at 300° C. in excess of 9000 pounds per square inch, and consisting by weight of about 4.9% to 6.2% copper, about 0.90% to 1.2% nickel, about 0.10% to 0.25% titanium, about 0.20% to 0.30% manganese, about 0.20% to 0.30% cobalt, about 0.10% to 0.30% antimony, about 0.03% to 0.40% zirconium, and the balance essentially aluminium.

5. An alloy useful for casting and having a stress-to-fracture characteristic in 100 hours at 300° C. of about 4.3 long tons per square inch, consisting by weight of about 4.75% copper, about 1% nickel, about 0.20% titanium, about 0.25% manganese, iron and silicon each not exceeding about 0.20%, about 0.25% cobalt, about 0.25% antimony, and the balance essentially aluminium.

6. An alloy useful for forging and having a stress-to-fracture characteristic in 100 hours at 300° C. of about 4.3 long tons per square inch, consisting by weight of about 5.5% copper, about 0.90% nickel, about 0.21% titanium, about 0.25% manganese, about 0.21% silicon, about 0.30% cobalt, and the balance essentially aluminium.

7. An alloy useful for casting and having a stress-to-fracture characteristic in 100 hours at 300° C. of about 5.5 long tons per square inch, consisting by weight of about 4.75% copper, about 1% nickel, about 0.20% titanium, about 0.25% manganese, iron and silicon each not exceeding about 0.20%, about 0.25% cobalt, about 0.25% antimony, about 0.20% zirconium, and the balance essentially aluminium.

8. An alloy useful for forging and having a stress-to-fracture characteristic in 100 hours at 300° C. of about 4.5 long tons per square inch, consisting by weight of about 4.92% copper, about 0.94% nickel, about 0.12% titanium, about 0.25% manganese, about 0.21% silicon, about 0.23% cobalt, about 0.16% antimony, about 0.07% zirconium, and the balance essentially aluminium.

9. A forgeable and castable alloy having a stress-to-fracture characteristic in 100 hours at 300° C. in excess of 9000 pounds per square inch, and consisting by weight of about 3.5% to 7% copper, about 0.5% to 2% nickel, about 0.10% to 0.30% titanium, about 0.20% to 0.60% manganese, about 0.20% to 0.50% cobalt and the balance essentially aluminium.

10. An alloy as described in claim 9 containing in replacement of a like amount of aluminium about 0.10% to 0.50% antimony but in any event not more than about 0.60% of cobalt plus antimony.

11. An alloy as described in claim 9 containing in replacement of a like amount of aluminium about 0.03% to 0.40% zirconium, but in any event not more than about 0.50% of zirconium plus titanium.

12. An alloy as described in claim 9 containing in replacement of a like amount of aluminium about 0.10% to 0.50% antimony and about 0.03% to 0.40% zirconium, but in any event not more than about 0.60% of cobalt plus antimony and not more than about 0.50% of zirconium plus titanium.

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