Sept. 27, 1938. H. G. SCHWARZ 2,131,076

ALUMINUM ALLOY AND PROCESS FOR MAKING THE SAME, PISTON AND PISTON RING FORMED FROM SAID ALLOY

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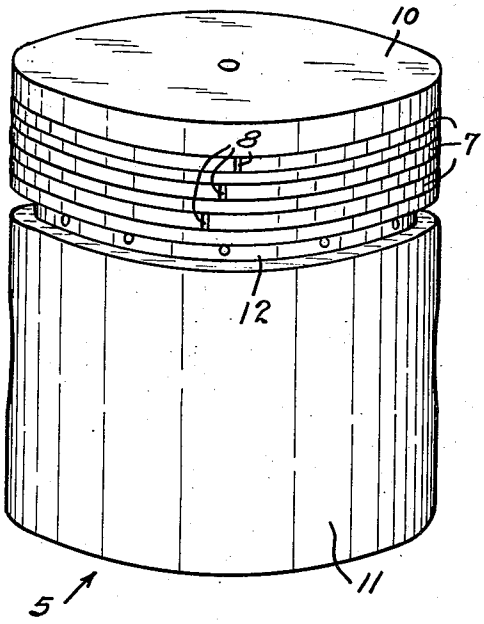



Fig. 1

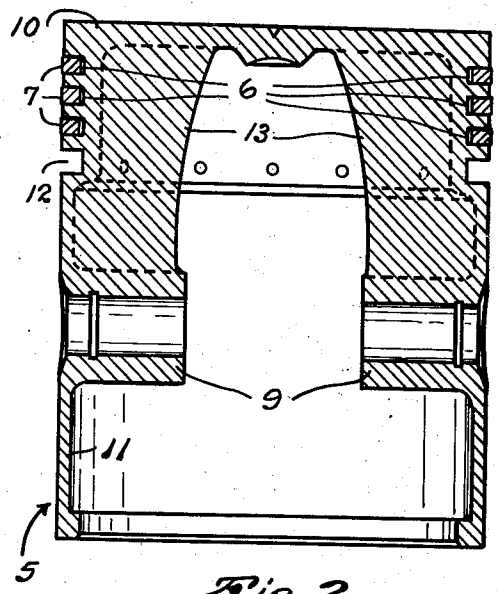



Fig. 2

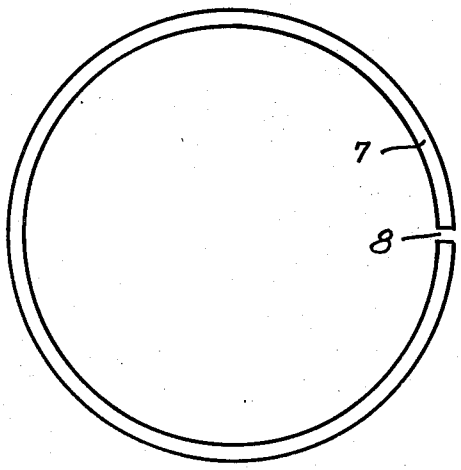



Fig. 3

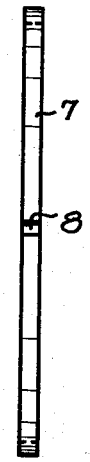



Fig. 4

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## ALUMINUM ALLOY AND PROCESS FOR MAKING THE SAME, PISTON AND PISTON RING FORMED FROM SAID ALLOY

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15 Claims. (Cl. 75—138)

My invention relates to a new aluminum alloy, piston and piston ring formed from said alloy.

More particularly, my invention relates to an alloy characterized by having a low coefficient of thermal expansion and is particularly adapted for use in the pistons and piston rings of internal combustion engines.

For purposes of illustration and definiteness of description, I will set forth my invention as applied to the manufacture of pistons and piston rings for internal combustion engines, but it is to be understood that my invention is not to be restricted to any such specific application, but is to extend to all uses where like problems or conditions in whole or in part obtain. It may be used for lubricated bearings and for heating surfaces in calendering or ironing equipment.

Ordinarily, as it is well known, engine blocks of internal combustion engines are made of cast iron. A great difficulty attending the use of aluminum alloys for pistons in such blocks arises from the great difference in the coefficient of thermal expansion of such aluminum alloys and cast iron, cast iron having a coefficient of approximately .000012 per degree C., while aluminum is almost double this, or .000023 per degree C. This, of course, means that if aluminum alloys having high coefficients are to be used as piston materials in internal combustion engines, provision must be made for compensating for the difference between the expansion of the piston and the cylinder wall. Such provision has been attempted by mechanical means, such as providing a split skirt for the piston.

The purpose of my invention is to provide an alloy of aluminum having a coefficient of expansion approximating that of cast iron, and to make unnecessary such mechanical contrivances as the split skirt. It is obvious that the providing of a split skirt weakens the structure as a whole.

It has been known that the addition of silicon to aluminum results in a marked decrease in the thermal expansion of the aluminum. Furthermore, this decrease is accentuated by the addition of other alloying elements, such as iron, nickel, and manganese. Such alloys, however, especially when high in contents of the alloying elements are subject to permanent volume growth when exposed to such temperatures as prevail in and about the piston during the operation of an internal combustion engine. Furthermore, when the silicon is used in relatively high percentages, it is known that the alloy becomes of an abrasive character, so that it injures the cylinder walls. Moreover, other properties are not retained at the high temperature involved.

All pistons have a tendency to wear eccentrically, due to the thrust not being vertical. The split skirt form of piston ordinarily in use at the present time (being formed of alloys having relatively high coefficient of expansion) is peculiarly subject to distortion, and, therefore, subject to eccentric wear. The split skirt, it will be understood, is provided in order to make allowance for the expansion. The wrist pin bosses being secured to the head, which is subject to high temperatures, tend to expand more than the rest of the skirt, and this also distorts the piston.

It is a further object of this invention to provide a piston ring formed from a cast, aluminum-base alloy, and has for its object a piston-ring which will follow inequalities of the cylinder wall at high speeds, and will have a higher thermal conductivity.

Heretofore, and at present, piston rings for internal combustion engines have been formed almost exclusively from cast iron. Such piston rings were satisfactory as long as engine speeds were comparatively low; for example at speeds of one-thousand revolutions per minute, a cast iron ring will follow the contour of a wall of a cylinder with a fair degree of faithfulness, even if the wall is badly worn. With the low working pressures previously used the possibility of "blow-by" or gas-leakage past the piston rings was slight if the rings follow the cylinder wall contours even fairly closely. Furthermore, at these low speeds the time factor is such that the thermal conductivity of the ring itself is not an element of great importance.

The present tendency in the design and construction of internal combustion engines, however, is toward higher and higher engine speeds and higher compression ratios. Accordingly, the thermal conductivity of the piston rings and their resiliency, i. e., the ability of the ring to follow the cylinder wall contours without increase in cylinder wall pressures is of increasing importance. Furthermore, it is well known that one of the limiting factors of the speed at which a spring can operate is the inertia of the spring material itself. As a piston ring is simply a spring which must expand and contract with every revolution of the engine to overcome any inequalities in the cylinder wall, it is evident that when the speed of the engine reaches the point where the elastic force can no longer overcome the inertia of the ring, the ring becomes

"paralyzed", or in other words, fails to follow the contour of the cylinder wall and gas leakage results. This phenomena is well recognized and many attempts have been made to overcome it. One means of increasing the elastic force of the ring consists in placing between it and the bottom of the ring grooves a steel ring. Another consists of building up a laminated ring from flat steel ring sections, the whole being backed by an inner spring ring. While these expedients decrease gas leakage, they also increase the pressure of the ring upon the cylinder wall with a resulting increase in frictional losses and an increase in cylinder wall wear. Also while it is possible to make a cast iron ring narrower and thus maintain the elastic force while decreasing the inertia of the ring, this change is necessarily accompanied by an increase in unit pressure with the resulting ring and cylinder wall wear.

The heat energy generated in the combustion chamber must be distributed and dissipated as quickly as possible to decrease detonation and to increase the ratio of mechanical energy to heat energy obtained from the engine. Accordingly it becomes increasingly important with higher engine speeds and compression ratios that the piston ring itself shall not block the movement of heat away from the piston head. This can be accomplished by making the rings of metal of higher heat conductivity but such rings do not have the other physical properties required.

I am aware that previous attempts have been made to use metals other than cast iron for piston rings for instance, brass and bronze rings backed up by steel springs have been used in steam engines, but these are far too bulky for use in high speed internal combustion engines. Attempts have also been made to use rolled bronze rings supported by steel springs but these were unsuccessful owing to their easy plastic deformation and to the fact that they tend to drag on the cylinder wall. Attempts have also been made to make aluminum alloy piston rings but these also have failed because they did not maintain the physical properties at elevated temperatures or because they were deformed by the hammering action of the ring lands.

Aluminum is recognized as a metal characterized by the property of relatively low elasticity. As pointed out above, the present attempts or practices are to provide piston rings with increased elasticity to meet the requirements of higher speed and compression ratio conditions. My solution of the problem proceeds substantially contrary to such practice. Instead of increasing the elasticity of the ring, I employ, as the base of my alloy, aluminum, which, as a metal, has relatively a low modulus of elasticity and find, however, that such elasticity, when coupled with relatively low inertia, operates surprisingly efficiently to provide a ring which follows at high speeds the inequalities of the cylinder wall.

This invention includes the discovery that my new aluminum base alloy when cast in the form of piston rings and when properly heat treated, provides rings which are characterized by properties which render them superior to any ring, which have heretofore been known to me, for high compression high speed engines. Rings of my invention have an elastic modulus of about 15,000,000 pounds per square inch and a specific gravity of 2.65 compared with a specific gravity of about 7.0 for cast iron. The inertia of the ring embodying my invention is therefore only about a third that of a similar cast iron ring. Furthermore the cast aluminum base alloy embodying my invention has a thermal conductivity three times that of cast iron and consequently the rate of flow of heat from the piston head to the cylinder wall is substantially increased, reducing the tendency to detonation and increasing the ratio of mechanical energy to heat energy obtained from the engine. In addition the cast piston rings embodying my invention cause a decrease in frictional loss because of the anti-frictional properties of my novel alloy. Piston rings made in accordance with my invention not only maintain their properties at high temperatures, but owing to the composition of the material and its cast structure, the material is such that the ring does not suffer plastic deformation.

Severe tests of piston rings embodying my invention in actual use under extreme conditions indicate that the ring completely fulfills all the requirements of rings for use in high speed engines and that for the first time a ring has been produced meeting the requirements herein specified.

In making piston rings embodying my invention the alloy is cast either in cylinders or in individual piston rings and is heat treated. This process involves heating castings made from the alloy to a temperature of approximately 516° C. (960° F.), depending upon the size and form of the casting, the period being longer for the larger than for the smaller casting, and holding at this temperature for a period from one to three hours, followed by rapid cooling in water or a blast of air at room temperature, and then "artificially aging" it from two to eight hours. In artificially aging it I raise the temperature to 121 to 255° C., (250 to 400° F.), depending upon the size and thickness of the casting. After holding the casting at this temperature from two to eight hours, it is allowed to cool at room temperature. I find that it is advantageous in providing the ring of my invention to give attention to the rate of cooling. The use of water as the quenching medium up to this time has been found preferable.

The above mentioned general objects of my invention, together with others inherent in the same, are attained by my alloy and method herein disclosed and by the devices illustrated in the following drawing, the same being preferred exemplary forms of embodiment of my invention, throughout which drawing like reference numerals indicate like parts:

Figure 1 is a perspective view of a piston embodying my invention, having rings in the grooves of the piston;

Fig. 2 is a vertical sectional view of said piston;

Fig. 3 is a view in front elevation of a ring embodying my invention, showing the same in compressed position; and

Fig. 4 is a view in side elevation of the ring shown in Fig. 3.

The piston 5 is provided with a plurality of grooves 6 into which the rings 7 may be operatively positioned. For the purpose of illustration, the groove 12 is shown without a ring, such as the usual oil ring. The rings 7 are shown in compressed position in which a gap, as gap 8, appears.

In providing an alloy with a relatively high silicon content, such as is provided by my present invention, ordinarily objection arises, owing to the high degree of porosity or badly gassed metal which results. The practice has been to take every step to prevent this condition of great porosity, and to this end special chemicals and

special methods of melting have been adopted in order to avoid such objections incident to a high gas content.

My invention goes contrary to this practice as I employ a highly gassed metal. The alloy which I provide, having a relatively high silicon content, is intentionally exposed, while being melted, to the absorption of gases. Accordingly, I purposely provide a product having uniform porosity, which I find to be exceedingly advantageous in absorbing oil or lubricants, so that the providing of a film of lubricant is directly facilitated by the nature of my alloy.

The results set forth are those which have been actually tested out under operative conditions as to temperatures, etc., and has proven successful. The type of piston employed was of the trunk type commonly used at the present time, comprising pin bosses 9 extending inwardly, head 10, skirt 11 and reinforcing members 13. Practically all of the aluminum alloy pistons of this type that are now commonly in use have the skirt split so as to allow for the thermal expansion of the skirt. However, the type of piston which I employ does not have the skirt split. The splitting of the skirt is usually unnecessary because the coefficient of thermal expansion of the alloy embodying my invention is low and nearly that of cast iron. While my alloy is primarily for use in the manufacture of pistons having a unitary or unsplit skirt I do not limit myself to its use in such pistons since pistons with split skirts can also be made satisfactorily from the alloy. By reason of this, I am enabled to avoid weakening the skirt by splitting it. The skirt of the piston formed of my alloy is one complete continuous annular wall which renders it exceedingly strong. This has the very great beneficial advantage also of maintaining the skirt in true circular form. In short, there is a direct relationship between the shape of the piston and the alloy. The increased strength of the skirt by forming it of the alloy, so as to avoid making provision for the thermal expansion, provides against distortion and thereby unequal wear, which is a very distinct advantage.

While the alloy embodying my invention has some 13% by weight of the total alloy in the form of colloidal eutectic silicon, it also has hyper-eutectic silicon to as high a degree as 37%, and such hyper-eutectic silicon is characterized as to its crystalline form, in that the particles are of a nonacicular form, so that it is free of an abrasive characteristic.

Another feature which was considered to render former alloys of high silicon content objectionable was that in casting such alloys, they were peculiarly subject to internal shrinkage. This objection especially arises in forming the solid piston pin bosses. The gate of the mold, which represents a considerable body of metal, is subject to this objection of internal shrinkage, which operates to form a cavity, as it were, that blocks off the metal to compensate for the shrinkage of the casting for points beyond the gate. However, I have discovered an alloy that avoids this objection, and the same can be cast in the semi-permanent mold by following practices well known to the molding art.

Furthermore, it is known that there is a certain segregation of the silicon element when there is a high percent of silicon present, silicon being lighter than the aluminum, which naturally tends to become more segregated on the top of the molten aluminum. However, on the percentages with which I am working, I have overcome the segregation difficulty in large measure by reason of the particular character of the alloy.

A primary purpose of my invention is to overcome the various objections herein set forth relating to previous aluminum alloys.

A further object of my invention is to provide an aluminum alloy having a coefficient of thermal expansion approximating that of cast iron, and at the same time obtaining the high thermal conductivity common to aluminum alloys, while at the same time, securing good properties which are retained at the elevated temperatures. Such properties include fair tensile strength, sufficient hardness, good impact property, high wear resistance and maintaining a porous character which will retain a film of lubricant, and at the same time have an alloy which is free from permanent volume growth. Also I purpose providing an alloy having hyper-eutectic silicon in nonacicular form.

The outstanding characteristics of the alloy embodying my invention are as follows: The first characteristic is its exceptionally low coefficient of thermal expansion. A piston formed of the alloy made according to my invention does not require the use of a design of piston with a split skirt. In itself this emphasizes very emphatically the low coefficient of expansion which characterizes the alloy of my invention. The coefficient of expansion of such new alloy is only slightly higher than that of cast iron. In actual computation the coefficient of expansion of my alloy is .000015 per degree C. as against .000012 to .000014 degree C. for cast iron.

A second characteristic of my alloy is that it lacks the permanent volume growth which characterizes the aluminum alloys as heretofore formed.

A third characteristic is its high thermal conductivity, a most important point in connection with the use of aluminum alloy for the manufacture of pistons. High thermal conductivity characterizes aluminum in general, but I have been able to provide an alloy possessing this high thermal conductivity, even though the coefficient of expansion has been reduced to the relatively negligible magnitude above indicated.

A fourth important characteristic of the alloy of my invention is that besides some 13% colloidal silicon, I provide hyper-eutectic silicon to the extent of 37% and this in the nonacicular form. This feature is of the utmost importance in a piston and piston ring products, in that it avoids cutting or scoring the cylinder walls, and thus promotes a low coefficient of friction. Providing the silicon in the nonacicular form, as just explained, not only avoids increasing the friction, but makes possible the use of a very hard alloy to form the piston member which is subject to the marked strains induced by its reciprocal operation at high speeds. It is obvious that if an object is formed of very hard material, and yet rounded in form, it will have a low coefficient of friction, while the same material with sharp elements would have a very high coefficient of friction. In other words, I have provided an alloy which contains very hard particles and yet of a character such that they present a smooth bearing surface. Thus, in making silicon available as a means of providing a low coefficient of friction, it was also necessary in my invention to make the silicon available in a form which would have a low coefficient of

friction, and this I have accomplished as just explained.

A fifth characteristic of the new aluminum alloy is that it has uniformly dispersed throughout its body pores or minute gas cavities. Heretofore, every effort has been made to eliminate the presence of any gas cavities. The elimination of such cavities has heretofore been considered a matter of great concern, and great care was taken to melt the metal without allowing the products of combustion of the heating means to reach or contact the metal, the same being carefully kept covered and out of all contact with the products of combustion. Contrary to all such practice I find that in my new alloy the presence of gas cavities uniformly distributed is of a decided importance, in that it facilitates lubrication by way of providing for the ready absorption of oil or other lubricants. This aids in the production of a low coefficient of friction, since a continuous film of oil over the surface of the piston is retained. In other words, while I provide for a very hard material for the forming of the piston, nevertheless, I provide a surface character which eliminates a high coefficient of friction by providing for the retention of the lubricating film.

A sixth characteristic of the alloy embodying my invention is its lightness. It is approximately ten percent lighter than the conventional piston alloy now commonly employed, i. e., the alloy having about 10% copper with other minor alloying constituents.

A seventh important and novel characteristic of my alloy is that in operation it provides a matrix, as it were, in which the very hard nonacicular particles of hyper-eutectic silicon are embedded. The matrix forms a yieldable mass in operation, so that it yieldingly holds the hard nonacicular particles of silicon, and thus again I facilitate the maintaining of a low coefficient of friction.

An eighth characteristic of the new alloy is that when fully heat treated it possesses a tensile strength in excess of 30,000 pounds per square inch. For all purposes involving low coefficient of expansion, as well as the other characteristics above indicated, it is not necessary to have such high tensile strength, but nevertheless, the alloy of my invention does have such strength. Furthermore, the new alloy is characterized by increased resiliency, making the metal adapted to uses where both lightness and resiliency are desirable.

A ninth characteristic of my alloy is that it has the property of high impact strength, that is, it is able to withstand the high impact stresses attendant to its use in forming pistons for use in internal combustion engines.

A tenth important characteristic of the alloy of my invention is its ability to retain all of the above mentioned listed properties at elevated temperatures. Many alloys may have the property of hardness at room temperature, but not at the elevated temperatures in which a piston or piston ring must operate in an internal combustion engine.

Some of the above characteristics will now be discussed in more detail. While the exact cause of permanent volume growth is not clear, it seems reasonably certain that by far the greater part of such changes may be accounted for by phase changes within the alloy, and by the relief of internal strains within the alloy. As both phase changes and strain relief take place at temperatures approximating those of a piston in operation, a means of controlling them would also be a means of controlling the growth of the piston.

The first cause, that of phase changes within the alloy, can be attributed mostly to copper. It is well known that in the ageing of a solution heat treated and quenched copper aluminum alloy, the density of the alloy decreases quite markedly when the ageing is carried out at temperatures from 150° to 400° C., (302° F. to 752° F.) and reaches a minimum when the ageing is carried out at a temperature of 265° C. (509° F.). This decrease in density is due to the precipitation of the copper aluminum compound ($CuAl_2$) from the copper-aluminum solid solution. The seriousness of permanent growth becomes evident when it is realized that this cause alone will bring about a unit expansion of 0.0015, or, in other words, would increase the diameter of a four-inch piston six-thousandths of an inch. I have found that by adding to the piston alloy only one percent of copper and double this amount or two percent of nickel, I can prevent the copper aluminum compound from being precipitated from the solid solution as such. That is, I find that the copper aluminum compound is not precipitated from the solution when there is sufficient nickel aluminum compound present to prevent the volume changes from taking place as a result of the phase change.

In the case of high silicon alloys, in which there is present not less than 15% of silicon, as is the case in my invention, the controlling or elimination of the second cause of permanent growth, viz., strain relief, is extremely important. It must be remembered that the limit of solid solubility of silicon in aluminum is low, being practically zero at room temperature and only 1.65 percent at the eutectic temperature of 577° C. (1071° F.). Furthermore, that the melting point of silicon is 1420° C. (2588° F.) against 661° C. (1222° F.) for aluminum, and that the coefficient of thermal expansion of silicon is only one-third that of aluminum. I believe, therefore, that the great tendency for these high silicon alloys to grow at elevated temperatures is due to the relief of the internal strains which are brought about by the freezing of the aluminum matrix around the non-yielding silicon particles. Since this is not greatly different from strain relief in a cold worked metal, any alloying element that will prevent recrystallization and grain growth in such a cold worked metal, and still have other advantages in a cast metal, will prevent permanent volume changes in this high silicon alloy.

In this connection, I have found that small quantities of metallic vanadium, when added to my alloy prevent this permanent growth. Furthermore, that small quantities of this element have beneficial effects on strained aluminum and aluminum alloys in general, as they increase the recrystallization temperature and decrease the rate of grain growth after the recrystallization temperature has been reached. Furthermore, I have found that the addition of small quantities of this element have the effect of decreasing the grain size of cast aluminum alloys. Decreasing the grain size of the alloy increases the tensile strength, yield point, and improves the physical characteristics generally. One of the reasons why it has been conceived as impossible heretofore to have aluminum alloys of silicon content of any extent beyond the eutectic point, is of the tremendous high internal stresses developed, so that even in some cases the alloy will fly apart. Accordingly, it is of the utmost importance to have an agent which will prevent and

overcome this characteristic, and I have found such an agent in vanadium.

As equivalents of metallic vanadium for the use here set forth, I cite vanadium tribromide, vanadium dichloride, vanadium trichloride, vanadium pentachloride, vanadium trifluoride, vanadium tetrafluoride, vanadium pentafluoride, vanadium silicide, and the two silicides of vanadium $VSi_2$ and $V_2Si$.

Thus, the vanadium and the nickel, respectively, operate independently to prevent permanent volume growth and are each permanent volume growth preventing agents.

Aside from its low coefficient of thermal expansion, cast iron has another advantage over the conventional aluminum piston alloys. Owing to its rather porous character it is capable of absorbing and maintaining a continuous film of oil over its working surface. Porosity in aluminum alloys has always been considered very disadvantageous, and a great deal of attention has been directed toward its prevention by foundrymen and metallurgists. However, I have found that very advantageous results may be obtained by going contrary to general and accepted practice and allowing my alloy, while in the melting and molten states, to be exposed, particularly when overheated, to such gases as carbon dioxide, carbon monoxide, water vapor and nitrogen arising from the combustion of a carbonaceous fuel in the melting furnace. By such exposure my alloy is allowed to freely absorb these gases and thereby simulate the porosity of cast iron. Thus a porous metal of great utility may be produced. Any carbonaceous fuel may be employed to heat the metal and provide products of combustion for such gassing of the metal. It is considered a fundamental rule in manufacturing an aluminum alloy not to allow the temperature, during the melting operation, to go beyond the point required for pouring into the particular molds employed, to prevent oxidation and gassing the metal. But in making my alloy, I find it advantageous to heat beyond this point required for pouring, in order to have the alloy absorb the various gases present in the products of the fuel combustion. Thus, by "overheating" I mean raising the temperature beyond that required for pouring. It is to be noted that the pouring temperature varies with the particular type of mold employed as is known in the art. For aluminum piston manufacture I find that a practical temperature to which the molten mass is to be raised is approximately 871° C. (1600° F.). In casting the piston from this molten alloy I allow the most highly stressed parts of the piston, viz., the hanger members, to solidify at such a rate as to allow the gas to escape during solidification. The parts of the piston, such as the bearing surfaces, are chilled sufficiently so that the gas cannot escape, but is entrapped in minute pores uniformly disseminated throughout these bearing portions of the piston. I find that due to the presence of these pores, the outermost of which are exposed during the machining of the piston, the surface is capable of absorbing and maintaining a continuous film of oil.

The alloy embodying my invention may be improved with respect to increased tensile strength, increased yield point, and increased hardness by a heat treating process. This process consists of heating castings made from the alloy to a temperature of approximately 516° C., (960° F.), depending upon the size and form of the casting, the period being longer for the larger than for the smaller casting, and holding at this temperature for a period from one to three hours, following by a rapid cooling in a blast of air at room temperature, and then "artificially ageing" it from two to eight hours. In artificially ageing I raise the temperature to 121 to 255° C., (250 to 400° F.), depending upon the form, size, thickness of section and nature of the casting. After holding the product at this temperature for two to eight hours, it is allowed to cool at room temperature.

I have stated in the above that I allow my alloy, while in the presence of the gaseous furnace products, to become overheated. While this is advantageous from the point of view of absorbing these gases, it has one disadvantage that can be readily appreciated by anyone skilled in the art. This disadvantage arises from the danger of oxygen becoming absorbed into the body of the molten alloy with the resultant formation of aluminum oxide. Since aluminum oxide is an abrasive material, its presence in a piston is very undesirable, both from a machining and an operating standpoint. I have found that by introducing antimony trichloride into the body of the molten alloy before pouring, I am able to greatly facilitate the removal of such aluminum oxide as it actually is formed. In explaining the mechanics of this oxide removal I will confine myself for the present to the action of the aluminum trichloride which is formed when the antimony trichloride is decomposed by the molten aluminum and will later describe the effect of the liberated antimony upon the silicon.

I can summarize the reaction into which the antimony trichloride enters with the aluminum as follows:

$$SbCl_3+Al \rightarrow Sb+AlCl_3$$

The aluminum trichloride which is formed in the above reaction is useful by virtue of the effect it has in reducing the surface tension of the aluminum-aluminum oxide interface, and thereby allowing the oxide to coagulate and rise to the surface where it may be skimmed off. The other useful gases, carbon monoxide, carbon dioxide, and nitrogen, are in solution in the molten alloy and are not greatly affected, or, at any rate, are not completely removed by the antimony trichloride treatment.

The antimony that is produced by the above reaction becomes uniformly disseminated throughout the molten alloy. I have found that metallic antimony, when introduced into a molten aluminum-silicon alloy, as antimony trichloride, has the property of "modifying" the alloy. Without attempting a necessarily lengthy explanation of the modifying process in aluminum-silicon alloys, or without confining myself to any one particular theory regarding modification, I will simply state that it is accompanied by the following phenomena (*a*) an increase in the eutectic composition from 11.6 per cent silicon to approximately 13 per cent silicon; (*b*) a decrease in the eutectic temperature from 577° C., (1071° F.) to approximately 565° C., (1049° F.); (*c*) a definite improvement in the physical properties of the alloy, including elongation; (*d*) a change in the microstructure of the hypoeutectic silicon itself from the acicular structure of the unmodified alloy to the colloidally dispersed silicon of the modified alloy. In forming binary aluminum silicon alloys, the customary agents used to bring about these changes are the alkali metals and their fluorides, hydroxides, chlorides, peroxides, and the fluorides and peroxides of the alkaline earth met-

als as well as various mixtures of these substances. It can be readily appreciated that a modifier that can be introduced into the body of the molten alloy, as I have succeeded in doing with the antimony by adding it as the trichloride in the form of a gas has very definite advantages owing to its uniform dispersion throughout the alloy. In the case of adding the customary agents in the form of salts, the uniformity of their dispersion depends upon the degree of mechanical mixing. In adding the antimony trichloride, I volatilize the same, and thereby it forms a very active dispersing agent in and of itself as contrasted with being mechanically dispersed throughout the mass. Also, the antimony has one further advantage that I have not dealt with, namely, that of increasing the resistance of aluminum alloys to corrosion, especially salt water corrosion. As equivalent of antimony trichloride I give the following: Antimony tribromide, antimony pentachloride, antimony trifluoride, and antimony pentafluoride.

The process by which I make my alloy follows. The weights given are sufficient for one hundred pounds of the finished alloy less a slight melting loss. I do not limit myself to the particular compositions of the starting materials that I described, but my invention includes the use of other materials that are known to those skilled in the art to be equal or equivalent. For example, I may add copper as the metal, in combination with aluminum in the form of an aluminum rich alloy, in combination with both nickel and aluminum as an aluminum rich ternary alloy, or in any other manner that will give the desired analysis in the finished alloy. This applies equally well to the other alloying ingredients. For example, I may add vanadium either as the ten per cent vanadium aluminum alloy, or by introducing a volatile salt of vanadium which will decompose to liberate vanadium. Further, it is to be understood that fifteen pounds of a thirty-three per cent silicon aluminum alloy is the equivalent of ten pounds of the fifty per cent alloy plus five pounds of substantially pure aluminum, etc.

In the crucible of a conventional oil-fired tilting crucible furnace, I melt together the following materials:

As one of the starting materials, an alloy consisting of fifty per cent silicon, the balance substantially pure aluminum—42 pounds.

Substantially pure aluminum—46 pounds.

An alloy consisting of twenty per cent nickel, ten per cent copper, and the balance substantially pure aluminum—10 pounds.

An alloy consisting of ten per cent vanadium, the balance substantially pure aluminum—1 pound.

After the above ingredients are thoroughly melted together, I add one pound of metallic magnesium.

I now allow the temperature of the molten alloy to increase to approximately 871° C., (1600° F.), while it is in the presence of the products of combustion of the fuel, so that it will absorb carbon monoxide, carbon dioxide and nitrogen. When this temperature is reached, I introduce antimony trichloride into the molten alloy as I have before described. When I have added about 0.2 pound of antimony trichloride, I allow the temperature to drop to about 816° C., (1500° F.), and the alloy is ready to be poured into pistons, piston rings, castings, or into ingots for remelting.

The aluminum alloy thus formed embodying my invention comprises 20 to 22% silicon, 2% nickel, 1% copper, 1% magnesium, 0.1% vanadium, 0.1% antimony, the balance substantially pure aluminum, i. e., aluminum plus impurities, other than silicon and copper.

For purposes where tensile strength can be sacrificed for better bearing qualities, as in the case where the alloy is to be used for a lightly stressed bearing, I provide an alloy having the following analysis: Silicon 25 to 35%, nickel 2%, copper 1%, magnesium 0.5%, vanadium 0.1%, antimony 0.1%, and the balance substantially pure aluminum, i. e., aluminum plus impurities, other than silicon and copper.

Relative limits of range of ingredients:

It is impractical for the alloy to contain silicon to more than 50% by weight of the total alloy, because such an alloy would have a very high melting point, and because the oxidization of aluminum at such high temperature would be so great as to be prohibitive. Below 15% the coefficient of expansion is so great as to render the alloy subject to the customary disadvantages of the alloys now commonly in use.

Nickel: This ingredient cannot be below 1% because no appreciable hardening of the matrix results. If more than 5% is added, segregation becomes too great and the alloy becomes brittle. From the point of view of economics, its cost at present prices would be prohibitive. The amount of nickel must be sufficient to prevent precipitation of any copper aluminum compound as such from the copper aluminum solid solution. The nickel serves two purposes (1), to provide hardening, and (2), to provide against permanent volume growth. The rule, therefore, for determining the amount of nickel to be employed in the alloy of my invention, characterized by having a relatively high silicon content, is that there must be just sufficient nickel to combine with the copper aluminum compound and precipitate as ternary copper nickel aluminum compound and prevent the precipitation of copper aluminum as such. The amount of nickel, therefore, is critical for the alloy embodying my invention.

Copper: There must be at least 0.5% present to get any hardening and strengthening of the matrix effect, and if there is present more than 2.5%, then there is an undue tendency for permanent volume growth. To be sure, if there should be present more than 2.5%, then it would require a sufficiently larger amount of nickel present to prevent precipitation, which would result in an alloy which would be too brittle.

Magnesium: At least 1% is required to obtain the necessary degree of hardness while above 3% excessive oxidization results.

Vanadium: A trace is necessary to get any effect, and serious segregation occurs over 1%. I have found that when the amount of vanadium is increased, a point may be reached where segregation of crystals of vanadium aluminum compound occurs. The segregation begins above about twenty-five one-hundredths of one per cent, and when the amount of vanadium reaches one per cent, segregation is serious. Amounts above twenty-five one hundredths of one per cent are increasingly disadvantageous for the reason of increasing segregation. One-tenth of one per cent has been found to give satisfactory results both economically and practically.

Antimony: Some effect is obtained with a trace and with more than 0.5% very coarse crystals of antimony are formed, which are objectionable because they weaken the alloy.

Aluminum—impurities: Balance of alloy is aluminum plus its impurities, other than silicon and copper.

The use of antimony as an alloying element in aluminum alloys is known for the purpose of increasing the corrosion resistance. I obtain the advantage of using antimony in the form of antimony trichloride to get the more intimate intermixing, but principally to get the effect of the chlorine which is liberated. The same advantage of intermixing is obtained with vanadium when it is employed in the form of its volatile salts.

This application is a continuation-in-part of my application Serial No. 746,422 filed October 1, 1934, and my application Serial No. 85,542 filed June 16, 1936.

Obviously, changes may be made in the forms, dimensions and arrangement of the parts of my invention, without departing from the principle thereof, the above setting forth only preferred forms of embodiment.

I claim:

1. An aluminum alloy comprising substantially silicon twenty to fifty per cent, nickel one to five per cent, copper five-tenths per cent to two and five tenths per cent, magnesium one to three per cent, vanadium in an effective amount up to 1%, antimony in an effective amount up to 1%, and the balance aluminum plus impurities.

2. The process of making an aluminum alloy characterized by having a low coefficient of expansion comprising the steps of (*a*) forming a hypereutectic aluminum silicon alloy containing nickel, copper, and vanadium; (*b*) adding magnesium to said alloy while in a molten state; and (*c*) superheating said composition in the presence of gases readily absorbable by said composition.

3. The process of making an aluminum alloy characterized by having a low coefficient of expansion comprising the steps of (*a*) forming an aluminum silicon alloy containing silicon 20 to 50%, nickel 1 to 5%, copper 0.5 to 2.5%, vanadium in an effective amount up to 1%, the balance aluminum plus impurities; (*b*) adding magnesium to said alloy while in a molten state in an amount of 1 to 3%; and (*c*) superheating said composition in the presence of gases readily absorbable by said composition.

4. The process of making an aluminum alloy characterized by having a low coefficient of expansion comprising the steps of (*a*) forming a hypereutectic aluminum silicon alloy containing nickel, copper, and vanadium; (*b*) adding magnesium to said alloy while in a molten state; and (*c*) superheating said composition to approximately 871° C. in the presence of gases readily absorbable by said composition.

5. The process of making an aluminum alloy characterized by having a low coefficient of expansion comprising the steps of (*a*) forming an aluminum silicon alloy containing silicon 20 to 50%, nickel 1 to 5%, copper 0.5 to 2.5%, vanadium in an effective amount up to 1%, and the balance substantially all aluminum; (*b*) adding magnesium to said alloy while in a molten state in an amount of 1 to 3%; and (*c*) superheating said composition to approximately 871° C. in the presence of gases readily absorbable by said composition.

6. An aluminum alloy comprising substantially silicon 20 to 50%, nickel 1 to 5%, copper 0.5 to 2.5%, magnesium 1 to 3%, vanadium in an effective amount up to 1% and the balance substantially all aluminum.

7. The process of making an aluminum alloy characterized by having a low coefficient of expansion comprising the steps of (*a*) forming a hypereutectic aluminum silicon alloy containing nickel, copper, and vanadium; (*b*) adding magnesium to said alloy while in a molten state; (*c*) adding antimony trichloride; and (*d*) superheating said composition in the presence of gases readily absorbable by said composition.

8. The method of dispersing silicon in an aluminum alloy, which consists in the step of adding to the aluminum mix antimony trichloride.

9. The method of dispersing silicon in an aluminum alloy, which consists in the step of adding to the aluminum mix antimony trichloride in effective amounts up to 1%.

10. The aluminum alloy containing from 20 to 22% of silicon, copper about 1%, nickel about twice the copper, magnesium about 1%, and vanadium in effective amount up to 1%, the remainder being essentialy aluminum.

11. The aluminum alloy containing from 20 to 22% of silicon, copper about 1%, nickel about twice the copper, magnesium about 1%, and vanadium about $\frac{1}{10}$ of 1%, the remainder being essentially aluminum.

12. A piston suitable for use in internal combustion engines, which piston is formed of a cast aluminum alloy containing silicon 20 to 50%, nickel 1 to 5%, copper 0.5 to 2.5%, vanadium in an effective amount up to 1%, magnesium 1 to 3% and the balance aluminum plus impurities.

13. A piston suitable for use in internal combustion engines, which piston is formed of a cast aluminum alloy containing from 20 to 22% of silicon, copper about 1%, nickel about twice the copper, magnesium about 1%, and vanadium in effective amount up to 1%, the remainder being essentially aluminum.

14. A piston ring for use in high speed, high compression internal combustion engines, which ring is formed of a cast aluminum alloy containing silicon 20 to 50%, nickel 1 to 5%, copper 0.5 to 2.5%, vanadium in an effective amount up to 1%, magnesium 1 to 3% and the balance aluminum plus impurities.

15. A piston ring for use in high speed, high compression internal combustion engines, which piston ring is formed of a cast aluminum alloy containing from 20 to 22% of silicon, copper about 1%, nickel about twice the copper, magnesium about 1%, and vanadium in effective amount up to 1%, the remainder being essentially aluminum.

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