An improved aluminum-silicon hypereutectic alloy cylinder is provided by the following steps: machining the sliding surface of the cylinder to given dimensions; finishing the sliding surface to a degree that the primary crystal grains of silicon clearly appear; subjecting the finished surface to acid pickling to remove to a given depth the eutectic aluminum solid solution surrounding the primary crystal grains of silicon; subjecting the thus treated finished surface to a pickling-activating treatment which does not substantially corrode the primary crystals of silicon but retains them intact; electroplating a metal or alloy onto the sliding surface to give a layer flush with the top finished surfaces of the primary crystal grains of silicon, the type of metal or alloy electroplated depending on the contemplated member mating, to thereby improve the sliding performance of the sliding surface; whereby the top surfaces of the primary crystal grains of silicon and the electroplated metal surfaces provide the desired sliding surface in combination.

8 Claims, 11 Drawing Figures
FIG. 4

FIG. 5
ALUMINUM ALLOY CYLINDER

FIELD OF INVENTION

The present invention relates to a cylinder having a sliding surface of an hypereutectic aluminum-silicon alloy.

BACKGROUND

In the past, in the utilization of hypereutectic aluminum-silicon alloys as internal combustion engine cylinders, there has been experienced scuffing or scoring of the sliding surface of the cylinder. This has been particularly noticeable when the cylinder has a plurality of ports in the sliding surface and is used for a two cycle engine or for a large sized engine dealing with a high load; in these cases there is apt to be caused thermal deformation in the cylinder during the break-in or run-in operation of the engine.

SUMMARY

It is, accordingly, an object of the present invention to provide an engine cylinder, which is long in service life, free from scuffing or scoring loss, both during the break-in or run-in operation of an engine and during its cold operation.

It is another object to provide an improved engine cylinder in which scuffing or scoring is avoided or minimized for a duration from the initial operation until the engine becomes broken-in and the piston and cylinder mate properly. The objects are achieved according to the present invention by subsequent operations after starting with a conventional aluminum-silicon hypereutectic alloy, which is used for the cylinder from the viewpoint of its superiority in abrasion resistance, and which is cast by a die casting method or by a low pressure die casting process to provide the engine cylinder.

In an air-cooled two cycle engine cylinder utilizing an oil-mixed fuel lubricating system and made of such an aluminum alloy, there arises a heterogeneous temperature distribution during operation due to a large number of ports (inlet port, exhaust port and scavenging ports) formed in the sliding surface thereof, resulting in thermal deformation of the sliding surface of a cylinder. This incurs local high intensity pressure which is exerted locally on the sliding surface, leading to scuffing or scoring loss.

Such phenomena would be inevitable even if the engine cylinder were designed and manufactured with consideration of the superior heat conductivity of the aluminum alloy, and the shape, number and position of air-cooling fins which could be provided around the outer periphery of a cylinder.

Particularly, a cylinder of a large sized, air-cooled two cycle engine dealing with a high load suffers from difficulty in lubrication of the over-all sliding surface during the initial stage cooling operation, resulting in scuffing or scoring loss on the sliding surface, coupled with a considerable degree of thermal deformation.

In cylinders formed of aluminum-silicon hypereutectic alloys, scuffing or scoring loss arising in the sliding surfaces thereof during the initial stage operation is attributable to various causes. The major reasons are due to the fact that a eutectic aluminum solid solution exists in the microstructure of aluminum-silicon hypereutectic alloy and this solid solution is soft and has a low melting point. If such a eutectic aluminum solid solution exists in a portion of the sliding surface which is subjected to local heating due to increase in local intensity of pressure exerted thereon, there will arise adhesion phenomenon in the aluminum solid solution such that there is a tendency of the mating member to adhere with the sliding surface. This causes scuffing and scoring in the sliding surface. In cases where the solubility between the eutectic aluminum solid solution and the metal member mating with the sliding surface is great at elevated temperatures, adhesion of the solid solution to the mating metal piston tends to increase.

The gist of the present invention lies in a principle wherein in a cylinder of aluminum-silicon hypereutectic alloy, the sliding surface thereof is subjected to pickling to remove therefrom eutectic aluminum solid solution to a given depth, and voids on the sliding surface resulting from removal of such eutectic aluminum solid solution are filled with an electroplated layer of other metals, thus affording an improved sliding characteristic to the sliding surface. Included among metals which are employable for such electroplating are lead, tin, copper, zinc, iron, nickel, silver, and alloys thereof.

Practically, the above metals and alloys are selected depending upon the material and shape of mating piston with the sliding surface as well as upon operational conditions. A metal used as the sliding surface of cylinder should be among those having high affinity to lubricating oil used, superior self-lubricating ability, and excellent mating characteristics for the sliding member. Thus, for selecting a metal for the sliding surface of a cylinder, those requirements should be taken into consideration.

On the sliding surface which has been subjected to pickling to remove eutectic aluminum solid solution therefrom, there remains only primary crystal grain silicon, each grain of which has been finished and flattened at its exposed top surface. Since these silicon grains have complicated side surfaces which define various small recesses among them, there may be obtained by the usual electroplating process an electroplated layer extremely adherent and highly resistant to being peeled off.

Thus, there is obtained an engine cylinder of aluminum-silicon hypereutectic alloy which is free from scuffing or scoring loss even during the break-in run operation and cooling run operation of an engine.

According to the present invention, a metal is selected as the aforesaid electroplating metal, which is superior in sliding performance and mating characteristic with the sliding piston surface, such that in case an electrodeposited metal is of a low shearing material, then there will be no necessity to apply a precise finishing treatment to the electro-deposited sliding surface, i.e., the electrodeposited sliding surface as deposited may be used as a sliding surface. Since the hardness of an electrodeposited metal or alloy is relatively low as compared with that of the primary crystal grains of silicon, portions of the electrodeposited layer which extend over the sliding surface may be readily finished to be substantially flush with the initially finished surfaces of the primary crystal grains of silicon.

FIG. 1 is a microphotograph showing the external appearance of a cylinder of a two-cycle engine having a sliding surface according to the present invention;
FIG. 2 is a microphotograph of 100 magnifications showing the sliding surface of a cylinder which has been subjected to finishing honing step.

FIG. 3 is a microphotograph of 100 magnifications showing the sliding surface of a cylinder, in which lead electroplating according to the present invention has been applied to the sliding surface of FIG. 2.

FIG. 4 is a microphotograph of 100 magnifications showing the sliding surface of a cylinder, in which iron electroplating according to the present invention has been applied to the sliding surface of FIG. 2.

FIG. 5 is a microphotograph of 100 magnifications showing the cross-section of the electroplated sliding surface of the cylinder of FIG. 4, taken perpendicularly to the electroplated sliding surface.

FIG. 6 is a route or trace showing the surface roughness of a cylinder of aluminum-silicon hypereutectic aluminum alloy, which has been subjected to the finishing honing step, but prior to the formation of a lead-electroplated sliding surface of FIG. 3.

FIG. 7 is a route or trace showing the roughness distribution of the surface of a cylinder, in which the surface of FIG. 6 has been subjected to pickling-activating treatment for removing eutectic aluminum solid solution therefrom.

FIG. 8 is a route or trace showing the roughness distribution of the surface of a cylinder, in which lead electroplating has been applied to the surface of FIG. 7.

FIG. 9 is a route or trace showing the roughness distribution of the surface of a cylinder of aluminum-silicon hypereutectic alloy of FIGS. 4 and 5, which has been subjected to the finishing honing step, but prior to the formation of iron-electroplated surface.

FIG. 10 is a route or trace showing the roughness distribution of the surface, when the surface of FIG. 9 has been subjected to pickling-activating treatment according to the present invention to remove aluminum solid solution therefrom; and

FIG. 11 is a route or trace showing the roughness distribution of the surface when iron electroplating has been applied to the surface of FIG. 10, i.e. surface of FIG. 4.

DETAILED DESCRIPTION OF EMBODIMENTS

A detailed description will now be given of the process of applying the electroplating layer to a cylinder made of aluminum-silicon hypereutectic alloy according to the present invention.

Prior to the application of electroplating to a cylinder, the sliding surface thereof is subjected to the normal finishing-honing step but to a degree that the primary crystal grains of silicon clearly appear on the sliding surface.

The electroplating treatment includes the following steps:

- Tricline degreasing → Electrolyte degreasing → Water rinsing → Pickling-activating treatment → Water rinsing → Zinc immersion treatment → Water rinsing → Copper striking → Water rinsing → Electroplating → Water rinsing → Drying

Each of these steps is known in the art.

Reference will be had to examples of the present invention, in which the sliding surface of a cylinder of aluminum-silicon hypereutectic alloy consists of silicon and lead or silicon and iron.

The engine cylinder, noting FIG. 1, is made of aluminum-silicon hypereutectic alloy formed according to a low pressure die casting process. The cylinder is for use in an air cooled, two cycle twin engine, whose total displacement is 440 c.c. and whose bore stroke is 66 × 64 mm. FIG. 1 shows the external appearance of the cylinder. The inner surface of a cylinder which has been subjected to boring is provided with a rough honing, followed by a finishing honing step. The primary crystal grains of silicon at this point clearly appear on the thus finished inner sliding surface of cylinder.

The first embodiment is an example of producing a cylinder of aluminum-silicon hypereutectic alloy, whose sliding surface consists of silicon and lead. FIG. 6 shows the surface roughness in the upper portion of a scavenging port of the cylinder, prior to application of the treatments of the present invention.

The surface was subjected to tricline degreasing, electrolyte degreasing and water rinsing, followed by pickling-activating treatment at 80°C in a solution containing 70 parts by weight of orthophosphoric acid (H₃PO₄), 20 parts of sulfuric acid (H₂SO₄), and 20 parts of nitric acid (HNO₃). FIG. 7 shows the surface roughness in the upper portion of a scavenging port which has been subjected to the pickling-activating treatment.

The sliding surface thus treated was subjected to water rinsing, followed by treatment at 20°C in the zinc substituted liquid containing 20gms/liter of zinc oxide (ZnO), 120gms/liter of sodium hydroxide (NaOH), 2gms/liter of ferric chloride (FeCl₃.6H₂O), 50gms/liter of Rochelle salt (KNaC₂H₄O₄), and 1gm/liter of sodium nitrate (NaNO₃). Water rinsing followed, after which the sliding surface was treated, at 25°C, with a copper striking liquid containing 15gms/liter of copper pyrophosphate (Cu₃P₂O₇), 120gms/liter of potassium pyrophosphate (K₃P₂O₇) and 10gms/liter of potassium oxalate (K₂C₂O₄·H₂O).

Then, the surface was subjected to water rinsing, followed by lead electroplating to a given thickness, at 25°C in a lead borofluoride bath containing 300gms/liter of lead borofluoride (Pb(BF₄)₂), 30gms/liter of borofluoric acid (HBF₄), 40gms/liter of boric acid (H₃BO₃) and 0.2gms/liter of glue, whereby the inner surface of cylinder provided a sliding surface consisting of silicon and lead, and thus the electroplating of the present invention was completed. There is shown in FIG. 8 the roughness on the finished inner surface of the upper portion of a scavenging port of the cylinder.

FIG. 2 shows a microphotograph of 100 magnifications showing the surface prior to subjecting it to the aforesaid electroplating, i.e. the surface which has been subjected to the machining process. Gray angular crystal grains appearing in the micrograph of FIG. 2 are the primary crystal silicon grains. The surfaces of those primary crystal silicon grains are smoothed to flat surfaces of a comparatively large area by the finishing honing treatment. Matrix surrounding those primary crystal grains of silicon is a eutectic crystal consisting of silicon and aluminum solid solution and presents a phase containing various but a small amount of inter-metallic compounds. FIG. 3 is a micrograph of 100 magnifications showing the sliding surface consisting of silicon and lead, which surface has been subjected to the aforesaid electroplating according to the present inven-
tion. White, angular crystals appearing in the micrograph are the primary crystal grains of silicon. The surfaces of those primary crystal grains of silicon have been smoothed by the finishing honing treatment prior to electroplating and those smoothed surfaces appear on the sliding surface. Black matrix surrounding those primary crystal grains of silicon are lead electrodeposited layers. Because the aforesaid lead electrodeposited layers are soft and difficult to polish, a clear micrograph of the cross-section of the embodiement described could not be obtained. The status of the cross-section will be seen from a second embodiment, which cross-section is substantially the same.

The second embodiment refers to FIGS. 4, 5, 9, 10, and 11. In the embodiment, aluminum solid solution existing in the sliding surface of cylinder of aluminum-silicon-crystal-hyper-eutectic aluminum alloy was substituted by iron, thereby providing a sliding surface consisting of silicon and iron. The thickness of the electrodeposited iron layer is approximately 10 μ.

FIG. 9 shows the roughness distribution of the surface of the upper portion of a scavenging port in the sliding surface of a cylinder, which has been subjected to the machining process, prior to the electroplating treatment according to the second embodiment.

Following the triethylene rinsing, electrolyte degreasing and water rinsing, the surface was subjected to pickling, pickling-activating treatment, after which the thus treated surface was subjected to pickling and pickling-activating treatments at 80°C in a solution containing 70 parts of orthophosphoric acid (H₃PO₄), 20 parts of sulfuric acid (H₂SO₄) and 20 parts of nitric acid (HNO₃). There is shown in FIG. 10 the surface roughness of the sliding surface of the upper portion of a scavenging port which had been subjected to water rinsing.

Following the preceding steps, the surface was treated with the zinc substitution liquid of the same composition as that of the first embodiment, which was maintained at 20°C. The zinc substituted liquid used consisted, likewise as in the first embodiment, of 20gms/liter of zinc oxide (ZnO), 120gms/liter of sodium hydroxide (NaOH), 2gms/liter of ferric chloride (FeCl₃·6H₂O), 50gms/liter of Rochelle salt (Na₂C₆H₄O₇·5H₂O), and 1gms/liter of sodium nitrate (NaNO₃).

Following zinc substitution, the surface was subjected to water rinsing and then treated at 25°C with the copper stripping liquid containing 15gms/liter of copper pyrophosphate, 120gms/liter of potassium phosphosphate and 10gms/liter of potassium oxalate (K₂C₂O₄·H₂O), followed by water rinsing.

Both the zinc-substitution treatment and the copper stripping treatment are preliminary treatments for obtaining an electroplated layer superior in adhesion.

Subsequently, iron electroplating was applied to the surface. In detail, the surface was treated at 25°C with an iron electroplating liquid containing 250gms/liter of ferrous sulfate (FeSO₄·7H₂O), 120gms/liter of ammonium sulfate (NH₄)₂SO₄ and several cc/liter of a surface active agent, whereby an electroplated iron layer of a given thickness was formed on the surface, thereby providing the sliding surface consisting of silicon and iron. The iron electroplating was effected for filling voids formed in the sliding surface resulting from the removal of aluminum solid solution therefrom due to the aforesaid pickling, pickling-activating treatment, so as to give a layer of iron whose surface is flush with the top surfaces of the primary crystal grains of silicon which remained intact without being corroded.

There is shown in FIG. 11 the surface roughness in the upper portion of a scavenging port of the inner surface of a cylinder after iron electroplating has been applied thereto.

The micrograph of the sliding surface consisting of silicon and iron shown in FIG. 11 is shown in FIG. 4, while the micrograph of the cross-section of the sliding surface taken perpendicularly thereto is shown in FIG. 5, both of which are micrographs of 100 magnifications. While, angular portions seen in FIG. 4 are the primary crystal grains of silicon, whose top surfaces are smoothed by the finishing honing treatment, while matrix surrounding those primary crystal grains of silicon is deposited by the aforesaid electroplating, and in which iron phase of minute, white eutectic crystal grains of silicon are admixed.

FIG. 5 shows a copper layer 1 which has been electroplated to a considerable thickness for the sake of obtaining a clear micrograph in order to show a clear section of the electroplated layer according to the present invention. The cylinder sliding surface 2 contains portions 3 of iron electroplated material and portions 4 of primary crystal grains of silicon.

The iron-electroplated layer 3 is formed by removing by the pickling treatment a certain amount of aluminum solid solution detrimental to the sliding motion of the piston of the light metallic alloy on the cylinder surface of aluminum-silicon-hyper-eutectic alloy, and by using the iron electroplated layer 3 in place of the aluminum solid solution removed. In the first embodiment, such a substituted layer is a lead layer, in consideration of operational conditions of the sliding members, for pistons of metals such as nickel or copper or copper-tin alloy or the like. In the second embodiment, an iron layer is utilized to avoid adhesion to the metal member mating with the sliding surface during the operation and to give an improved sliding performance, taking the operational conditions and the type of a metal member mating with the sliding surface into consideration.

The precise thickness of the electroplated layer is optional, since in any event the top surfaces are flattened by the finishing honing operation so that the top surfaces of the electroplated layer will be of even height with the crystal grains 4 of silicon. Such crystal grains 4 remain intact without being subjected to any substantial change in size either by the steps prior to the electroplating or by the electroplating step itself, since the crystal grains of silicon are of high hardness and have excellent resistance to wear.

Again referring to FIG. 5, a eutectic matrix 5 of silicon and aluminum solid solution surrounds the primary crystal grains 4 of silicon, such matrix 5 usually containing a small amount of inter-metallic compound. Also disposed beneath the surface are primary crystal grains 6 of silicon which, since they are below the sliding surface, do not undergo any processing, such primary crystal grains 6 of silicon being surrounded by the eutectic crystal matrix 5.

As is apparent from the foregoing, the present invention provides a cylinder having an improved sliding surface which provides a smooth sliding performance, by utilizing the characteristics of aluminum-silicon hyper-eutectic alloy, i.e., the good characteristics of which include superior heat radiation, light weight, low expan-
sion and high strength, as well as excellent wear resistance inherent in the primary crystal grains of silicon which are high in hardness and which are abundantly contained in the aluminum-silicon hypereutectic alloy.

According to the present invention, such requirements for the cylinder are all realized, by improving the mating characteristic of a metal member, such as a piston, mating with the sliding cylinder surface; imparting a self-lubricating property to the sliding surface, improving affinity to lubricating oil provided between the cylinder and the piston, improving the mating characteristic of the metal piston member with the cylinder sliding surface, and avoiding adhesion between mutually sliding metals.

As set forth in the foregoing, in the aluminum-silicon hypereutectic alloy, eutectic aluminum solid solution surrounding the primary crystal grains of silicon is removed by pickling to a given depth, and a metal or alloy suited for smoothing the sliding performance is electrodeposited in the voids formed in the sliding surface resulting from the removal of such an eutectic aluminum solid solution, so as to give a layer, whose surface is substantially flush with the smooth top surfaces of primary crystal grains of silicon, which remain intact without being corroded, whereby there is provided a cylinder having a sliding surface providing a smooth sliding performance as well as long service lift without any trouble.

What is claimed is:

1. In a process for providing an aluminum-silicon hypereutectic alloy cylinder, the improvements comprising the steps of:
machining and finishing the sliding surface of said cylinder to a given dimension so that finished primary crystal grains of silicon clearly appear on said sliding surface;
subjecting said finished surface to pickling activating treatment to remove eutectic aluminum solid solu-
tion surrounding the primary crystal grains of silicon to a given depth in the manner that said primary crystal grains of silicon are not substantially corroded and are left intact;
electroplating on said sliding surface having thus been treated by said pickling-activating treatment a metal or alloy which is capable of improving the sliding performance of said sliding surface in relation to a mating surface, said metal or alloy being selected from the group consisting of lead, tin, copper, zinc, iron, nickel, silver, and alloys thereof;
whereby said electroplated metal surfaces and the top finished surfaces of primary crystal grain silicon provide a desired sliding surface in combination.

2. A cylinder of aluminum alloy as defined in claim 1, wherein the cylinder has a sliding surface whose electroplated metal is lead.

3. A cylinder of aluminum alloy as defined in claim 1, wherein the cylinder has a sliding surface whose electroplated metal is copper.

4. A cylinder of aluminum alloy as defined in claim 1, wherein the cylinder has a sliding surface whose electroplated metal is zinc.

5. A cylinder of aluminum alloy as defined in claim 1, wherein the cylinder has a sliding surface whose electroplated metal is iron.

6. A cylinder of aluminum alloy as defined in claim 1, wherein the cylinder has a sliding surface whose electroplated metal is silver.

7. A cylinder of aluminum alloy as defined in claim 1, wherein the cylinder has a sliding surface whose electroplated metal is nickel.

8. A cylinder of aluminum alloy as defined in claim 1, wherein the cylinder has a sliding surface whose electroplated metal is tin.

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