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(54) **METHODS OF REDUCING SURFACE
ROUGHNESS AND IMPROVING OXIDE
COATING THICKNESS UNIFORMITY FOR
ANODIZED ALUMINUM-SILICON ALLOYS**

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(57) **ABSTRACT**

In one exemplary method, an anodized aluminum-silicon alloy work piece may be formed from an aluminum-silicon alloy substrate material by applying a friction stir processing treatment to the aluminum-silicon alloy substrate material to reduce an average particle size of a plurality of silicon particles contained within the substrate material while increasing a size uniformity of the plurality of silicon particles, and subsequently anodizing said aluminum-silicon alloy substrate material.

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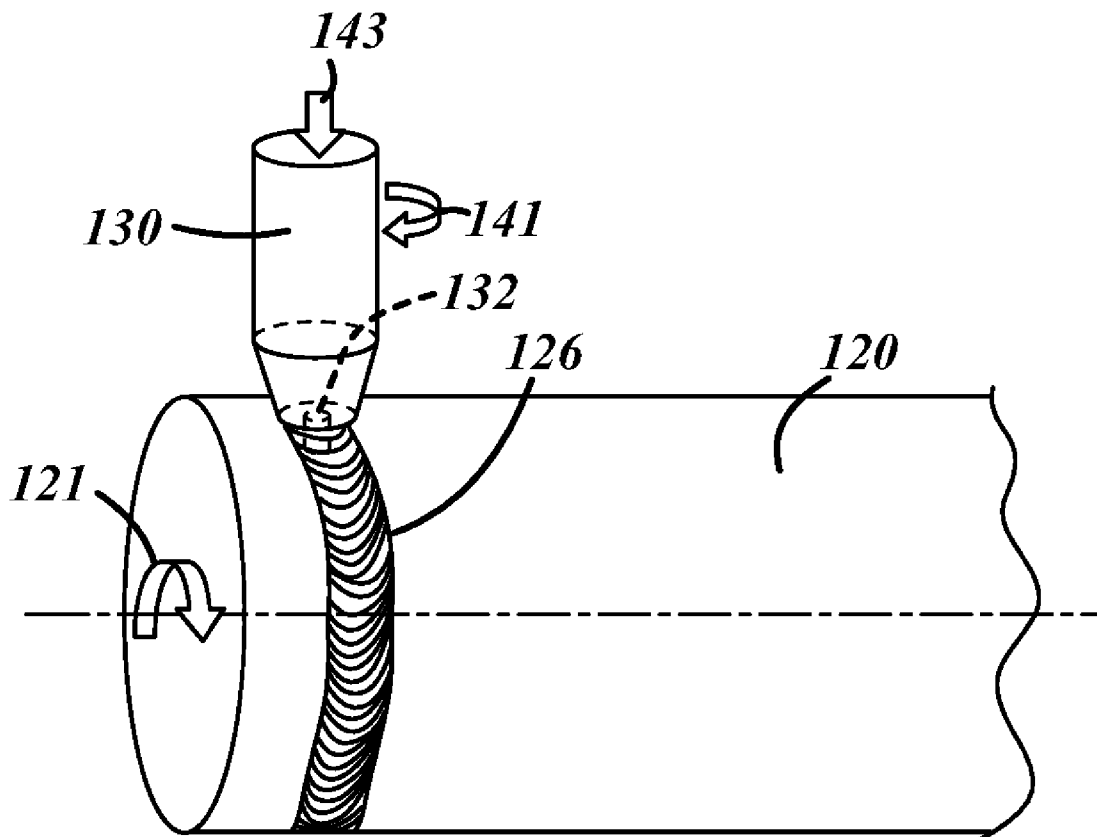


FIG. 1

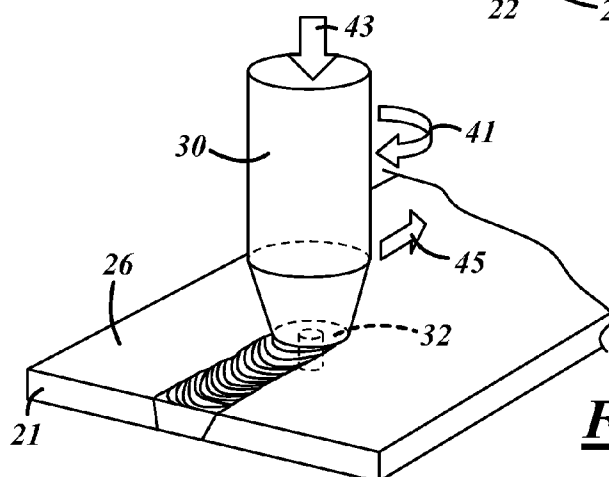
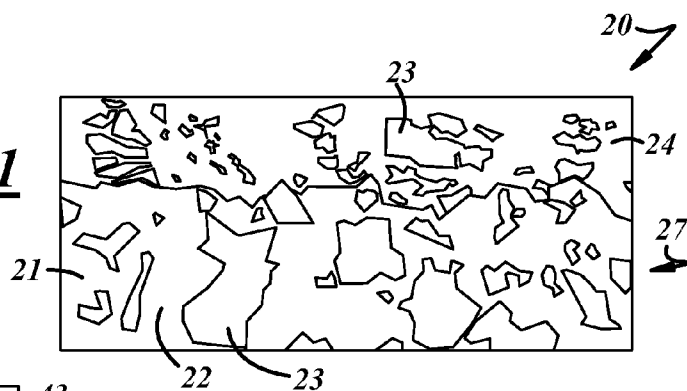


FIG. 2

FIG. 3

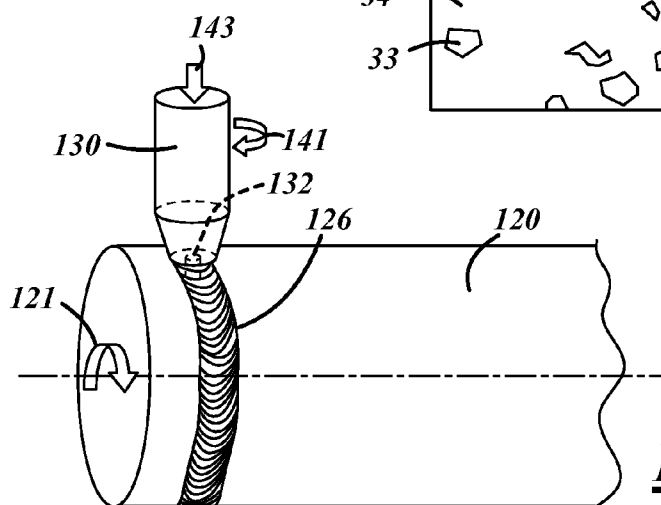
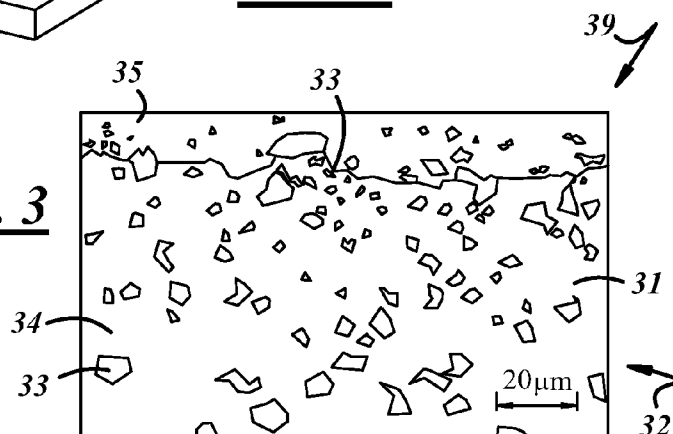


FIG. 4

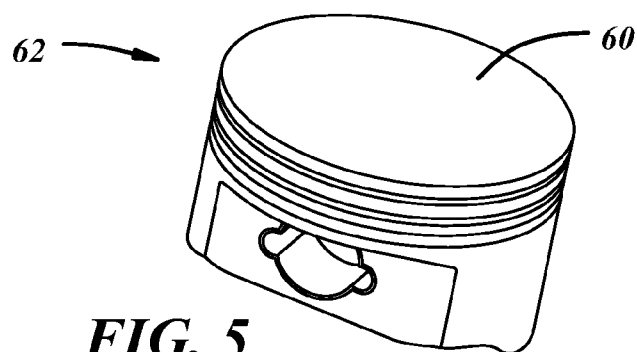


FIG. 5

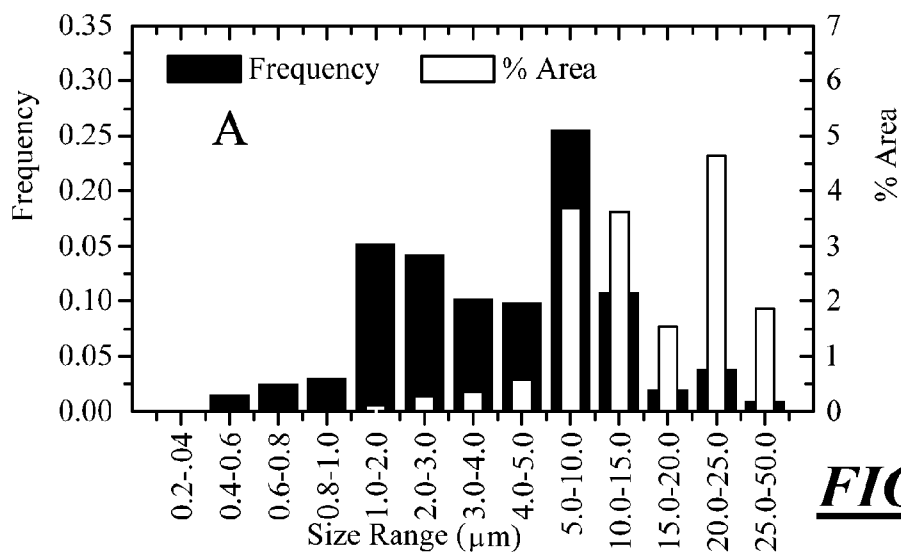


FIG. 6A

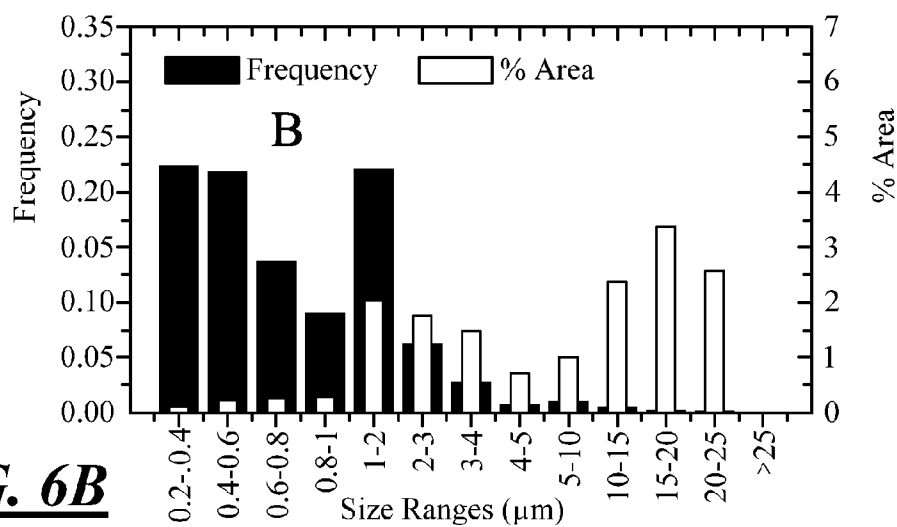


FIG. 6B

METHODS OF REDUCING SURFACE ROUGHNESS AND IMPROVING OXIDE COATING THICKNESS UNIFORMITY FOR ANODIZED ALUMINUM-SILICON ALLOYS

TECHNICAL FIELD

[0001] The field to which the disclosure generally relates includes surface treatment methods and more specifically relates to methods for reducing surface roughness and improving oxide coating thickness uniformity for anodized aluminum-silicon alloys.

BACKGROUND

[0002] Many pistons used today are made from hypoeutectic aluminum-silicon alloys like SAE 332 which contains 8½ to 10½ percent silicon, eutectic aluminum-silicon alloy pistons which have 11 to 12 percent silicon, or hypereutectic alloys that have 12½ to over 16 percent silicon (e.g. B390). Silicon improves high heat strength and reduces the coefficient of expansion so tighter tolerances can be held as temperatures change. The piston surface is often hard anodized to improve wear and scuffing resistance.

[0003] During anodizing, since silicon particles are non-reactive, the aluminum oxide coating grows around the silicon sites. Due to the large silicon particle size and non-uniform size distribution, the typical 15 to 20 micron thick coating has high surface roughness and non-uniform coating thickness, which may not be overcome by changing anodizing parameters. The combination of high surface roughness and non-uniform coating thickness are thought to contribute to decreased wear durability of the piston surface during use, and may contribute to premature piston failure.

SUMMARY OF EXEMPLARY EMBODIMENTS OF THE INVENTION

[0004] In one exemplary method, an anodized aluminum-silicon alloy work piece may be formed from a cast aluminum-silicon alloy substrate material by applying a friction stir processing (hereinafter referred to as FSP) treatment to the cast aluminum-silicon alloy substrate material to reduce an average particle size of a plurality of silicon particles contained within the substrate material while increasing a size uniformity of the plurality of silicon particles, and subsequently anodizing the FSP treated cast aluminum-silicon alloy substrate material.

[0005] Other exemplary embodiments of the invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while disclosing exemplary embodiments of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] Exemplary embodiments of the invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0007] FIG. 1 is a schematic representation of a cross-section of a relatively flat B390 aluminum alloy substrate material magnified to 20 micrometers after conventional anodization;

[0008] FIG. 2 is a perspective view of a friction stir process for modifying the surface of a relatively flat aluminum alloy work piece prior to anodization according to an exemplary embodiment;

[0009] FIG. 3 is a schematic representation of a cross-section of an B390 aluminum alloy substrate material magnified to 20 micrometers after friction stir processing according to FIG. 2 and anodization according to an exemplary embodiment;

[0010] FIG. 4 is a perspective view of a friction stir process for modifying the surface of a cylindrical aluminum alloy work piece prior to anodization according to another exemplary embodiment;

[0011] FIG. 5 is a perspective view of a piston having ring-grooves that are FSP treated and anodized in accordance with an exemplary method;

[0012] FIG. 6A is a graphical illustration plotting size range of silicon particles versus frequency for an anodized aluminum alloy piston without FSP treatment; and

[0013] FIG. 6B is a graphical illustration plotting size range of silicon particles versus frequency for an anodized aluminum alloy piston of similar composition having FSP treatment.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0014] The following description of the embodiment(s) is merely exemplary (illustrative) in nature and is in no way intended to limit the invention, its application, or uses.

[0015] The exemplary embodiments describe a method for reducing surface roughness in aluminum-silicon alloy work pieces in which a hard-anodized coating, preferably using either a Type II or Type III anodizing process, has been formed on the underlying substrate material to achieve hardness, high thermal insulation, corrosion resistance, decreased friction, and increased wear resistance.

[0016] Exemplary embodiments of aluminum-silicon alloys may include, but are not limited to, material such as a hypoeutectic aluminum-silicon alloy like SAE 332 which includes between about 8.5 and 10.5 percent silicon, a eutectic aluminum-silicon alloy which includes between about 11 to 12 percent silicon, or a hypereutectic aluminum-silicon alloy that includes between about 12.5 to over 16 percent silicon. One exemplary hypereutectic aluminum-silicon alloy that may be used as the substrate material, as shown below in FIGS. 1 and 3, is aluminum alloy B390, which includes silicon particles having a particle size of up to about 40 microns in diameter. However, additional alloying elements may be included in the aluminum-silicon alloys.

[0017] Referring first to FIG. 1, a magnified schematic representation of a prior art cast aluminum-silicon alloy work piece **20**, anodized with a Type II anodization process, may be illustrated as including a substrate layer **21** having a cast microstructure **27** that may include aluminum-containing portion **22** and silicon particles **23** of a predetermined size range having non-uniform size distribution. The silicon particles **23** may be classified as having larger particles, or primary particles, that may approach about 40 micrometers in diameter, and as having smaller particles, or secondary particles, that may include silicon flakes.

[0018] As one of ordinary skill recognizes, during a conventional anodizing process such as a Type II process, elemental aluminum and possibly other alloying elements of the aluminum-containing portion **22** close to the surface **26** of

the cast substrate material **21** may react with oxygen to form a barrier oxide layer, or oxide coating layer **24**, of varying thickness, depending upon the anodization conditions, but typically ranges between about 5-15 μm thick. Given the fact that the silicon particles **23** do not react in the anodization process, the resultant oxide coating layer **24** may therefore have non-uniform film thickness as a result of the random distribution of large (primary) and small (secondary) silicon particles **23**, and may also have high surface roughness. This high surface roughness and non-uniform film thickness is thought to contribute to reduced durability characteristics.

[0019] The exemplary embodiments utilize a friction stir processing (FSP) treatment prior to anodizing to reduce the average particle size of the silicon particles and provide a more uniform and narrow distribution of silicon particles, thereby reducing surface roughness and increasing the uniformity of film thickness for the oxide coating layer **24**. This is thought to improve the wear resistant properties of the resultant anodized work piece.

[0020] In a friction stir processing process (FSP), in accordance with one exemplary embodiment as shown in FIG. 2, a rotating friction stir tool **30** having a profiled pin **32** may be rotated at a predetermined rotational speed (signified by arrow **41**) and pressed into substrate material **21** of the cast work piece **20** at a predetermined force (shown by arrow **43**). In this exemplary process, the tool **30** may be held in place while the non-anodized substrate material **21** traverses (i.e. the non-anodized substrate material **21** is moved in a desired direction at a predetermined travel rate, shown by arrow **45**, to allow the profiled pin **32** to contact and penetrate the surface **26** of the substrate material **21** at any desired surface location for a desired amount of time). Alternatively, the rotating tool **30** may traverse across a stationary substrate **21**. The predetermined rotational speed and force of the friction stir action of the profiled pin **32**, coupled with the predetermined travel rate of the substrate material **21**, create heat, which in turn soften the surface **26** of the substrate material **21** and force it to flow, generally without melting the substrate **21**. The force may also break down the silicon particles **23** to smaller, and more uniformly distributed, silicon particles. The original microstructure **27** of the substrate material **21** may thereby be modified to a wrought microstructure (shown as **32** in FIG. 3) prior to anodization. The process that occurs in FIG. 2 to modify the microstructure may be done in a single pass or in multiple passes. In another exemplary process, multiple overlapping passes may be utilized.

[0021] The shape of the profiled pin **32** may vary to achieve a desired result, but generally may include a stepped spiral feature (not shown) including a shoulder at a particular pin height that may be preferred for silicon particle **23** breakdown. The pin height and shoulder diameter of the profiled pin **32** may be adjusted to achieve a desired depth with the surface **26** of the substrate material **21** to achieve the desired silicon particle breakdown at the given pin **32** rotational speed and substrate material traverse speed.

[0022] In the work piece **20** of FIG. 1, for example, the cast microstructure **27** of the substrate material **21** may be broken up and refined during FSP prior to anodization, resulting in a modified substrate material **31** having a wrought microstructure **39**, as shown in FIG. 3, which includes smaller and more uniformly distributed silicon particles **33**. Furthermore, the porosity is greatly reduced or eliminated in the resultant wrought microstructure **39** as compared to the microstructure **27** of the substrate material **21** of FIG. 1.

[0023] In one exemplary embodiment for transforming the cast microstructure **27**, as shown in FIG. 1 without FPS treatment after Type II anodization, to form the wrought microstructure **39**, as shown in FIG. 3 with FSP treatment and Type II anodization, the predetermined rotational speed for the friction stir tool **30** of FIG. 2 may be approximately 2000 rpm with a travel speed of about 6 mm/s. More preferably, a second overlapping pass in the same or opposite direction may be utilized to further reduce the silicon particle size and obtain more uniform microstructure. Further, in this example, the profiled pin **32** had a shoulder diameter of about 12 millimeters and a pin height of 2.5 millimeters.

[0024] The FSP-treated substrate **31** may then be anodized with a Type II sulfuric acid anodizing process (not shown), similar to that for the substrate material **21** of FIG. 1, to form an anodized work piece **39** having the oxide layer **35**, as shown in FIG. 3. The resultant oxide layer **35** may achieve decreased oxide surface roughness and increased oxide layer thickness consistency as compared with the oxide layer **24** of FIG. 1, wherein each work piece **20** or **39** was formed from similar starting materials, here a B390 aluminum-silicon alloy, and processed in the same manner with the exception of the afore-mentioned.

[0025] To confirm the results, both surface roughness and uniformity of the oxide layer **35** of FIG. 3 were measured and compared with the oxide layer **24** of FIG. 1 without FSP treatment. The FSP-treated anodized oxide layer **35** showed substantial improvement in both oxide layer thickness consistency and smoothness that is believed to be due to the refinement of the silicon particles in both size and size distribution. By reducing the oxide surface roughness and increasing the oxide thickness uniformity, an increase in wear resistant properties of the oxide coating layer **35** may be realized, as well as improvements of other properties such as corrosion resistance and thermal insulating ability.

[0026] Moreover, by adjusting the working parameters of the friction stir processing treatment and the ensuing anodization process, one can tailor the anodized coating property, in terms of the afore-mentioned material characteristics and material properties, including coating uniformity, roughness, corrosion resistance, and thermal insulation characteristics. Adjustments in working parameters to adjust these properties and characteristics include adjusting the tool design (such as the pin height, pin profile and shoulder diameter), adjusting the number of FSP passes and/or the rotational speed of the friction stir tool **30**, and/or adjusting the applied pressure (force) on the surface **26** of the substrate material **21** on any given pass or passes.

[0027] While the exemplary embodiments of FIGS. 1-3 may be illustrated for a relatively flat work piece, other exemplary embodiments may utilize other shaped work pieces. For example, as shown in FIG. 4, a cylindrical work piece **120** may be FSP treated and anodized in substantially the same manner as the work pieces **20**, **21** and **39** in FIGS. 1-3 respectively.

[0028] Referring now to FIG. 4, a cylindrical work piece **120** of the same composition as work piece **20** of FIG. 1 may be mounted on a rotating structure (not shown) and rotated at a predetermined rotational speed (as shown by arrows **121**). The mounted rotating friction stir tool **130** having a profiled pin **132** may be rotated at a predetermined rotational speed (signified by arrow **141**) and pressed into surface **126** of the cylindrical work piece **120** at a predetermined force (shown by arrow **143**). In the same manner described above with

respect to the flat work piece **20**, the microstructure of the cylindrical work piece **120** may be broken up and refined during FSP, resulting in a modified substrate material having a wrought microstructure, which includes smaller and more uniformly distributed silicon particles similar to particles **33** in FIG. **3**. Furthermore, the porosity in the resultant wrought microstructure of the FSP-treated anodized material may be greatly reduced or eliminated as compared to the microstructure of the non-FSP-treated anodized substrate material. Subsequent anodization of the cylindrical work piece **120** forms an oxide coating layer on the exterior of the cylindrical work piece, similar to oxide layer **35** in FIG. **3**, having reduced surface roughness and improved coating thickness uniformity as described above with respect to the anodized work piece **39** of FIG. **3**.

[0029] Exemplary products that may benefit from such a reduction in surface roughness and an increase in oxide layer thickness uniformity, that utilize cast aluminum-silicon alloy work pieces, include but are not limited to automotive parts such as pistons.

[0030] One exemplary product that may utilize the exemplary process described above in FIG. **3**, as shown in FIG. **5**, is a piston **60** having a ring groove area **62**. Here, the ring groove area **62** has been FSP-treated, ring grooves machined out and subsequently anodized using a Type II anodization technique as will be described in further detail below.

[0031] More specifically, in one exemplary embodiment, the piston **60**, being a cylindrical work piece similar in shape to the cylindrical work piece **120** of FIG. **4** and similar in composition to the substrate material **21** of FIGS. **1** and **3**, may be mounted on a rotating structure (not shown) and rotated at a desired rotational speed. A mounted rotating friction stir tool, similar to the friction stir tool **130** of FIG. **4** and having a profiled pin similar to the profiled pin **132** of FIG. **4**, may be rotated at a predetermined rotational speed and pressed into piston groove area **62**. The microstructure of the piston groove area **62** may be broken up and refined during the FSP treatment, resulting in a modified piston groove area **62** having a wrought microstructure with smaller and more narrowly uniformly distributed silicon particles, and is thus similar to the microstructure **39** of FIG. **3**.

[0032] In an alternative embodiment, the ring groove area **62** may be machined prior to the FSP treatment, and then finish-machined to remove the flash formed during the FSP treatment and obtain the desired ring groove geometry.

[0033] The surface of the piston groove area **62** may then be anodized through a Type III hard-anodizing process, resulting in a piston ring groove area **62** having reduced coating roughness and improved coating uniformity.

[0034] In a Type III anodizing process, the piston **60** is introduced to a room temperature bath containing 100 g/L sulfuric acid at a 20 volt applied voltage. An aluminum oxide coating of about 15 micrometers in thickness is achieved, having silicon particles with an average particle size of 2 micrometers or less with a relatively narrow size distribution. As one of ordinary skill recognizes, a Type II anodizing process utilizes lower bath temperatures, higher voltages, and lower concentrations of sulfuric acid than a conventional Type II anodizing process, and therein forms a barrier oxide layer **35** that is thicker (0.001-0.003 inches) than Type II anodized barrier layers **24**. In addition, Type II oxide barrier layers may penetrate approximately 0.001 inches into the underlying substrate material, therein forming an integral, harder barrier layer.

[0035] A comparison of an anodized piston **60**, with and without the FSP treatment and with a subsequent Type III anodization, showed silicon particle size reduction from about 6 micrometers to about 1.4 micrometers with the FSP treatment. In addition, as shown in FIGS. **6A** and **6B**, a comparison of the silicon particle size distribution without (FIG. **6A**) and with (FIG. **6B**) the FSP treatment followed by the Type III anodization confirmed a more uniform silicon particle distribution within the aluminum oxide layer when FSP treatment was utilized.

[0036] In either related embodiment, the piston **60** having the FSP-treated anodized piston groove area **62** may avoid or reduce microwelding that may occur between a piston ring and the piston **60**. In addition, the FSP anodized ring-groove **62** offered significantly improved durability as compared with a conventional anodized ring-groove, therein reducing piston failure and reducing costs associated with replacement or repair.

[0037] The above description of embodiments of the invention is merely exemplary in nature and, thus, variations thereof are not to be regarded as a departure from the spirit and scope of the invention.

1. A method for forming an anodized aluminum-silicon alloy work piece comprising:

providing a cast aluminum-silicon alloy substrate material having a plurality of silicon particles;

applying a friction stir processing treatment to said cast aluminum-silicon alloy substrate material to reduce an average particle size of said plurality of silicon particles while increasing a size uniformity of said plurality of silicon particles; and

subsequently anodizing said cast aluminum-silicon alloy substrate material to form an oxide coating layer on said aluminum-silicon alloy substrate material.

2. The method of claim 1, wherein said cast aluminum-silicon alloy substrate material comprises a cast hypoeutectic aluminum-silicon alloy substrate material.

3. The method of claim 1, wherein said cast aluminum-silicon alloy substrate material comprises a cast eutectic aluminum-silicon alloy substrate material.

4. The method of claim 1, wherein said cast aluminum-silicon alloy substrate material comprises a cast hypereutectic aluminum-silicon alloy substrate material.

5. The method of claim 1, wherein applying a friction stir processing treatment to said cast aluminum-silicon alloy substrate material comprises:

providing a friction stir tool having a profiled pin; rotating said friction stir tool at a desired rotational speed; and

plunging said rotating profiled pin into an outer surface of said cast aluminum-silicon alloy substrate material to alter a microstructure of said substrate material to reduce an average particle size of said plurality of silicon particles and to provide a narrower size distribution of said plurality of silicon particles.

6. The method of claim 5 further comprising:

traversing said cast aluminum-silicon alloy substrate material in a first direction at a first travel speed such that said rotating profiled pin friction stirs an additional portion of said outer surface.

7. The method of claim 5 further comprising:

rotating said cast aluminum-silicon alloy substrate material at a first rotational speed such that said rotating profiled pin friction stirs an additional portion of said

outer surface, wherein said cast aluminum-silicon alloy substrate material comprises a cylindrical cast aluminum-silicon alloy substrate material.

8. The method of claim **1**, wherein subsequently anodizing said aluminum-silicon alloy substrate material to form an oxide coating layer on said cast aluminum-silicon alloy substrate material comprises anodizing said aluminum-silicon alloy substrate material using a Type III anodizing process to form an oxide coating layer.

9. The method of claim **8**, wherein said average particle size of said plurality of silicon particles is about 2 micrometers.

10. The method of claim **1**, wherein subsequently anodizing said cast aluminum-silicon alloy substrate material to form an oxide coating layer on said aluminum-silicon alloy substrate material comprises anodizing said aluminum-silicon alloy substrate material using a Type II anodizing process to form an oxide coating layer.

11. A method for forming an anodized aluminum-silicon alloy piston comprising:

casting a piston having at least one ring groove area from an aluminum-silicon alloy material, said aluminum-silicon alloy material including a plurality of silicon particles; applying a friction stir processing treatment to said ring groove area to reduce an average particle size of said plurality silicon particles and to increase the size uniformity of said plurality of silicon particles; machining ring grooves in the ring groove area; and anodizing said ring groove area to form an oxide coating layer.

12. The method of claim **11**, wherein applying a friction stir processing treatment to said ring groove area comprises:

providing a friction stir tool having a profiled pin; rotating said friction stir tool at a desired rotational speed; coupling said piston to a rotating device; rotating said piston at a desired rotational rate; and plunging said rotating profiled pin into an outer surface layer of said ring groove area to alter a microstructure of said ring groove area to reduce an average particle size of said plurality of silicon particles and to provide a narrower size distribution of said plurality of silicon particles.

13. The method of claim **11**, wherein anodizing said ring groove comprises anodizing said ring groove using a Type II anodization process.

14. The method of claim **13**, wherein anodizing said ring groove using a Type II anodization process comprises:

introducing said piston to a room temperature sulfuric acid bath; and

applying a voltage to said room temperature sulfuric acid bath for a period of time sufficient to form a barrier oxide layer of a desired thickness on said ring groove.

15. The method of claim **14**, wherein said desired thickness is about 15 micrometers.

16. The method of claim **11**, wherein anodizing said ring groove comprises anodizing said ring groove using a Type II anodization process.

17. A method for reducing barrier oxide coating layer surface roughness and increasing barrier oxide coating layer thickness uniformity in an anodized aluminum-silicon alloy work piece, the method comprising:

providing a cast aluminum-silicon alloy substrate material having a cast microstructure, said cast microstructure including a plurality of silicon particles; and

applying a friction stir process to a surface of a cast aluminum-silicon alloy substrate material prior to anodization to transform said cast microstructure to a wrought microstructure, wherein said transformation also reduces an average particle size of said plurality of silicon particles within said wrought microstructure and narrows a size distribution of said plurality of silicon particles.

18. The method of claim **17**, wherein applying a friction stir processing treatment comprises:

providing a friction stir tool having a profiled pin; rotating said friction stir tool at a desired rotational speed; and

plunging said rotating profiled pin into an outer surface layer of said cast aluminum-silicon alloy substrate material at sufficient force to alter said cast microstructure to a wrought microstructure.

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