



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
30.12.2009 Bulletin 2009/53

(51) Int Cl.:
F02F 1/20 (2006.01)

(21) Application number: **09006877.6**

(22) Date of filing: **22.05.2009**

(84) Designated Contracting States:
**AT BE BG CH CY CZ DE DK EE ES FI FR GB GR
HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL
PT RO SE SI SK TR**

(30) Priority: **27.06.2008 JP 2008168687**

(71) Applicant: **Yamaha Hatsudoki Kabushiki Kaisha
Iwata-shi, Shizuoka 438-8501 (JP)**

(72) Inventors:
• **Iwasaki, Shinya
Iwata-shi
Shizuoka 438-8501
(JP)**

• **Yamagata, Hiroshi
Iwata-shi
Shizuoka 438-8501
(JP)**
• **Kurita, Hirotaka
Iwata-shi
Shizuoka 438-8501
(JP)**

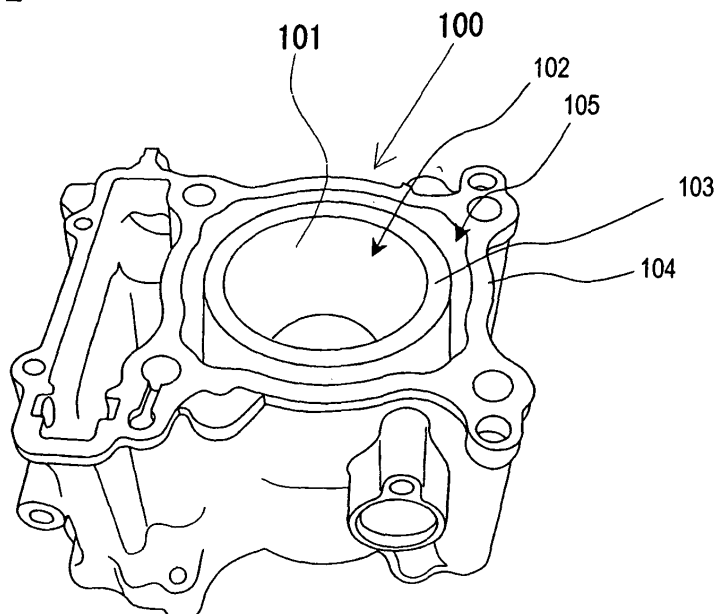
(74) Representative: **Schoppe, Fritz et al
Schoppe, Zimmermann, Stöckeler & Zinkler
Patentanwälte
Postfach 246
82043 Pullach bei München (DE)**

(54) **Cylinder block, internal combustion engine, transportation apparatus, and method for producing cylinder block**

(57) The cylinder block according to the present invention is a cylinder block composed of an aluminum alloy containing silicon, the cylinder block including a cylinder wall having a slide surface. The cylinder block according to the present invention includes a plurality of

silicon crystal grains on the slide surface, such that the ten point-average roughness Rz_{JIS} of the slide surface and the load length ratio $Rmr(30)$ of the slide surface at a cut level of 30% are larger in the upper 1/4 portion of the slide surface than in the lower 1/4 portion of the slide surface.

FIG. 1



Description

BACKGROUND OF THE INVENTION

1. Field of the Invention:

[0001] The present invention relates to a cylinder block and a production method thereof, and in particular to a cylinder block that is made of an aluminum alloy which includes silicon and a production method thereof. The present invention also relates to an internal combustion engine and a transportation apparatus incorporating such a cylinder block.

2. Description of the Related Art:

[0002] In recent years, in an attempt to reduce the weight of internal combustion engines, there has been a trend to use an aluminum alloy for cylinder blocks. Since a cylinder block is required to have a high strength and high abrasion resistance, aluminum alloys which contain a large amount of silicon, i.e., aluminum-silicon alloys having a hypereutectic composition, are expected to be promising aluminum alloys for cylinder blocks.

[0003] In a cylinder block composed of an aluminum-silicon alloy, silicon crystal grains located on the slide surface will contribute to the improvement of strength and abrasion resistance. An example of a technique for obtaining silicon crystal grains exposed on the surface of an alloy base metal is a honing process for allowing silicon crystal grains to remain jutting (called "emboss honing"). Moreover, Japanese Patent No. 2885407 discloses a technique of performing an etching process for allowing silicon crystal grains to remain jutting on the surface of an aluminum-silicon alloy, and thereafter performing an anodic oxidation to form an oxide layer, and further flame spraying a fluoroplastic onto this oxide layer to form a fluoroplastic resin layer.

[0004] As a lubricant is retained in between the silicon crystal grains which remain jutting on the slide surface (i.e., in the recesses between the silicon crystal grains functioning as oil puddles), an improved lubricity is obtained when a piston slides within the cylinder, whereby the abrasion resistance and seizing resistance of the cylinder block are improved.

[0005] However, further improvements in abrasion resistance and seizing resistance become necessary when using the above-described aluminum-alloy cylinder block for certain types of internal combustion engines.

[0006] Conventionally, aluminum-alloy cylinder blocks have been used in internal combustion engines that are mounted in four-wheeled automobiles. In a four-wheeled automobile, a mechanism (e.g., an oil pump) for compulsorily supplying a lubricant for the cylinder block and piston is provided in the internal combustion engine, and the internal combustion engine is operated at a relatively low revolution speed (specifically, under a maximum revolution speed of 7500 rpm or less), in which case the aforementioned problems will not occur. However, in an internal combustion engine which is operated at a relatively high revolution speed (specifically, under a maximum revolution speed of 8000 rpm or more), or in an internal combustion engine in which a lubricant is supplied to the cylinder only by way of splashing of the lubricant associated with crankshaft rotation (i.e., the oil pump is omitted, as in the case of an internal combustion engine that is mounted in a motorcycle), the aluminum-alloy cylinder block may experience seizing and/or significant abrasion. Moreover, when a piston made of an aluminum alloy is used in order to achieve a further weight reduction of the entire internal combustion engine, sliding occurs between the aluminum alloy surfaces, so that there is an increased likelihood of seizing.

[0007] In order to further improve the abrasion resistance and seizing resistance of the cylinder block, it is necessary to improve the lubricity at the start of the internal combustion engine, which requires good retention of lubricant on the slide surface. The inventors have found through their study that a cylinder block which has been subjected to the aforementioned emboss honing process or etching process cannot achieve a sufficient lubricant retention, so that less than adequate lubricity exists when a high-speed operation is reached immediately after the start of the internal combustion engine.

[0008] Therefore, the inventors have proposed in Japanese Patent Application No. 2007-329164 a technique of improving the ability of a slide surface to retain lubricant. In this technique, as a parameter representing the surface roughness of a slide surface, a ten point-average roughness Rz_{JIS} and a load length ratio Rmr are paid attention to. By setting these parameters within a specific range, a slide surface is realized on which a large number of fine silicon crystal grains remain jutting, thus contributing to lubricant retention. As a result, a cylinder block having an excellent abrasion resistance and seizing resistance can be obtained.

[0009] However, the inventors have conducted a further study to find that, when using the technique disclosed in Japanese Patent Application No. 2007-329164, the slide surface is immersed in an etchant, thus causing the entire slide surface to be uniformly etched. As a result, although the abrasion resistance and seizing resistance of the cylinder block are improved in an upper (near the top dead center) portion of the slide surface, a new problem occurs in that, in a lower portion of the slide surface, the fine silicon crystal grains which remain jutting on the slide surface get caught during the piston sliding, thus increasing the friction loss.

SUMMARY OF THE INVENTION

[0010] The present invention has been made in view of the aforementioned problems, and an objective thereof is to provide a cylinder block having an excellent abrasion resistance and seizing resistance and having a small friction loss, as well as a production method thereof.

[0011] A cylinder block according to the present invention is a cylinder block composed of an aluminum alloy containing silicon, comprising: a cylinder wall having a slide surface on which a piston slides; and a plurality of silicon crystal grains on the slide surface, wherein a ten point-average roughness Rz_{JIS} of the slide surface and a load length ratio $Rmr(30)$ of the slide surface at a cut level of 30% are larger in an upper 1/4 portion of the slide surface than in a lower 1/4 portion of the slide surface.

[0012] In a preferred embodiment, in the upper 1/4 portion of the slide surface, the ten point-average roughness Rz_{JIS} is 0.54 μm or more and the load length ratio $Rmr(30)$ at a cut level of 30% is 20% or more.

[0013] In a preferred embodiment, in the upper 1/4 portion of the slide surface, the ten point-average roughness Rz_{JIS} is 2.0 μm or less.

[0014] In a preferred embodiment, in the upper 1/4 portion of the slide surface, the load length ratio $Rmr(30)$ at a cut level of 30% is 55% or less.

[0015] In a preferred embodiment, in the lower 1/4 portion of the slide surface, the ten point-average roughness Rz_{JIS} is less than 0.54 μm and the load length ratio $Rmr(30)$ at a cut level of 30% is 15% or less.

[0016] In a preferred embodiment, the slide surface has been subjected to an etching process.

[0017] Another cylinder block according to the present invention is a cylinder block composed of an aluminum alloy containing silicon, comprising: a cylinder wall having a slide surface on which a piston slides; and a plurality of silicon crystal grains on the slide surface, wherein, in an upper 1/4 portion of the slide surface, a ten point-average roughness Rz_{JIS} of the slide surface is 0.54 μm or more and a load length ratio $Rmr(30)$ of the slide surface at a cut level of 30% is 20% or more; and a coating is provided on at least a lower 1/4 portion of the slide surface.

[0018] In a preferred embodiment, in the upper 1/4 portion of the slide surface, the ten point-average roughness Rz_{JIS} is 2.0 μm or less.

[0019] In a preferred embodiment, in the upper 1/4 portion of the slide surface, the load length ratio $Rmr(30)$ at a cut level of 30% is 55% or less.

[0020] In a preferred embodiment, the plurality of silicon crystal grains include a plurality of primary crystal silicon grains and a plurality of eutectic silicon grains.

[0021] In a preferred embodiment, the plurality of primary crystal silicon grains have an average crystal grain size of no less than 12 μm and no more than 50 μm .

[0022] In a preferred embodiment, the plurality of eutectic silicon grains have an average crystal grain size of 7.5 μm or less.

[0023] In a preferred embodiment, the plurality of silicon crystal grains have a grain size distribution having a first peak existing in a crystal grain size range of no less than 1 μm and no more than 7.5 μm and a second peak existing in a crystal grain size range of no less than 12 μm and no more than 50 μm .

[0024] In a preferred embodiment, a frequency at the first peak is at least five times greater than a frequency at the second peak.

[0025] In a preferred embodiment, the aluminum alloy contains: no less than 73.4 mass% and no more than 79.6 mass% of aluminum; no less than 16 mass% and no more than 22 mass% of silicon; and no less than 2.0 mass% and no more than 5.0 mass% of copper.

[0026] In a preferred embodiment, the aluminum alloy contains no less than 50 mass ppm and no more than 200 mass ppm of phosphorus and no more than 0.01 mass% of calcium.

[0027] An internal combustion engine according to the present invention comprises: the cylinder block of the above construction; and a piston which slides while being in contact with the slide surface of the cylinder block.

[0028] In a preferred embodiment, the piston is composed of an aluminum alloy.

[0029] A transportation apparatus according to the present invention comprises an internal combustion engine of the above construction.

[0030] A method for producing a cylinder block according to the present invention is a method for producing a cylinder block including a cylinder wall, the cylinder wall having a slide surface on which a piston slides, the method comprising: a step of providing a molding which is composed of an aluminum alloy containing silicon; a step of polishing a region of the surface of the molding to become the slide surface by using a hone having a grit number of # 1500 or more; and a first etching step of etching only a portion of the polished region.

[0031] In a preferred embodiment, the method for producing a cylinder block according to the present invention further comprises, after the first etching step, a second etching step of etching the entire region.

[0032] In a preferred embodiment of the method for producing a cylinder block according to the present invention, no further etching step of etching the region is performed after the first etching step.

[0033] Another method for producing a cylinder block according to the present invention is a method for producing a cylinder block including a cylinder wall, the cylinder wall having a slide surface on which a piston slides, the method comprising: a step of providing a molding which is composed of an aluminum alloy containing silicon; a step of polishing a region of the surface of the molding to become the slide surface by using a hone having a grit number of # 1500 or more; an etching step of etching the polished region; and a step of providing a coating in only a portion of the etched region.

[0034] Hereinafter, the functions and effects of the present invention will be described.

[0035] In a cylinder block according to the present invention, the ten point-average roughness Rz_{JIS} of the slide surface and the load length ratio $Rmr(30)$ of the slide surface at a cut level of 30% are larger in the upper 1/4 portion of the slide surface than in the lower 1/4 portion. As a result, it is possible to increase the lubricant retaining ability of the slide surface in the upper 1/4 portion of the slide surface while decreasing the friction coefficient in the lower 1/4 portion of the slide surface. Therefore, the friction loss can be reduced while ensuring an excellent abrasion resistance and seizing resistance.

[0036] In order to sufficiently enhance the lubricant retaining ability to realize an excellent abrasion resistance and seizing resistance, it is preferable that, in the upper 1/4 portion of the slide surface, the ten point-average roughness Rz_{JIS} is $0.54\text{ }\mu\text{m}$ or more and that the load length ratio $Rmr(30)$ at a cut level of 30% is 20% or more.

[0037] However, from the standpoint of preventing drop-off of the silicon crystal grains and any significant abrasion of the counterpart (piston ring and/or piston) due to the silicon crystal grains which remain jutting, it is preferable that the ten point-average roughness Rz_{JIS} is $2.0\text{ }\mu\text{m}$ or less in the upper 1/4 portion of the slide surface.

[0038] Moreover, from the standpoint of reducing the damage and abrasion of the counterpart, it is preferable that the load length ratio $Rmr(30)$ is 55% or less in the upper 1/4 portion of the slide surface.

[0039] Moreover, in order to sufficiently reduce the friction loss by sufficiently decreasing the friction coefficient, it is preferable that the ten point-average roughness Rz_{JIS} is less than $0.54\text{ }\mu\text{m}$ and that the load length ratio $Rmr(30)$ at a cut level of 30% is 15% or less in the lower 1/4 portion of the slide surface.

[0040] The slide surface of the cylinder block according to the present invention typically has been subjected to an etching process (chemical etching).

[0041] In another cylinder block according to the present invention, in the upper 1/4 portion of the slide surface, the ten point-average roughness Rz_{JIS} is $0.54\text{ }\mu\text{m}$ or more and the load length ratio $Rmr(30)$ at a cut level of 30% is 20% or more, and furthermore, coating is provided on at least a lower 1/4 portion of the slide surface. As a result, it is possible to increase the lubricant retaining ability of the slide surface in the upper 1/4 portion of the slide surface while decreasing the friction coefficient in the lower 1/4 portion of the slide surface. Therefore, the friction loss can be reduced while ensuring an excellent abrasion resistance and seizing resistance.

[0042] From the standpoint of preventing drop-off of the silicon crystal grains and any significant abrasion of the counterpart (piston ring and/or piston) due to the silicon crystal grains which remain jutting, it is preferable that the ten point-average roughness Rz_{JIS} is $2.0\text{ }\mu\text{m}$ or less in the upper 1/4 portion of the slide surface.

[0043] Moreover, from the standpoint of reducing the damage and abrasion of the counterpart, it is preferable that the load length ratio $Rmr(30)$ is 55% or less in the upper 1/4 portion of the slide surface.

[0044] The plurality of silicon crystal grains typically include a plurality of primary crystal silicon grains and a plurality of eutectic silicon grains. Thus, since not only primary crystal silicon grains but also eutectic silicon grains remain jutting on the slide surface, the ten point-average roughness Rz_{JIS} and load length ratio $Rmr(30)$ can be sufficiently increased.

[0045] From the standpoint of improving the abrasion resistance and strength of the cylinder block, it is preferable that the average crystal grain size of the plurality of primary crystal silicon grains is no less than $12\text{ }\mu\text{m}$ and no more than $50\text{ }\mu\text{m}$, and that the average crystal grain size of the plurality of eutectic silicon grains is $7.5\text{ }\mu\text{m}$ or less. Moreover, it is preferable that the plurality of silicon crystal grains have a grain size distribution having a first peak existing in a crystal grain size range of no less than $1\text{ }\mu\text{m}$ and no more than $7.5\text{ }\mu\text{m}$ and a second peak existing in a crystal grain size range of no less than $12\text{ }\mu\text{m}$ and no more than $50\text{ }\mu\text{m}$, and it is further preferable that the frequency at the first peak is at least five times greater than the frequency at the second peak.

[0046] In order to sufficiently increase the abrasion resistance and strength of the cylinder block, it is preferable that the aluminum alloy contains: no less than 73.4 mass% and no more than 79.6 mass% of aluminum; no less than 16 mass% and no more than 22 mass% of silicon; and no less than 2.0 mass% and no more than 5.0 mass% of copper.

[0047] Moreover, it is preferable that the aluminum alloy contains no less than 50 mass ppm and no more than 200 mass ppm of phosphorus, and no more than 0.01 mass% of calcium. When the aluminum alloy contains no less than 50 mass ppm and no more than 200 mass ppm of phosphorus, it is possible to reduce the tendency of the silicon crystal grains to become gigantic, thus allowing for uniform dispersion of the silicon crystal grains within the alloy. On the other hand, when the calcium content in the ensuring aluminum alloy is 0.01 mass% or less, the effect of providing fine silicon crystal grains due to phosphorus is secured, and a metallurgical structure with abrasion resistance can be obtained.

[0048] A cylinder block according to the present invention can be suitably used in the internal combustion engines for various types of transportation apparatuses, and particularly suitably used in an internal combustion engine whose piston is made of an aluminum alloy for the sake of weight reduction.

[0049] In a method for producing a cylinder block according to the present invention, after performing a step of polishing

a region of the surface of a molding to become a slide surface by using a hone having a grit number of #1500 or more, a first etching step of etching only a portion of the polished region is performed. As a result, the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ can both be made different between the portion which is etched through the first etching step and the other portion. Therefore, the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ of the slide surface can be made larger in the upper 1/4 portion than in the lower 1/4 portion, whereby a cylinder block having an excellent abrasion resistance and seizing resistance and a small friction loss can be produced.

[0050] After the first etching step, a second etching step of etching the entire region to become the slide surface may be performed. When such a second etching step is performed, the entire slide surface will have been subjected to an etching process (although the portion which is etched through the first etching step will experience a large etching amount than will the other portion). As a result, recesses between silicon crystal grains (which function as oil puddles for retaining the lubricant) are suitably formed across the entire slide surface, thus further improving the abrasion resistance and seizing resistance of the entire slide surface.

[0051] Alternatively, after the first etching step, no further etching step of etching the region to become the slide surface may be performed. In the case where such a further etching step is omitted, the number of steps is reduced, whereby the production cost can be reduced and the production steps can be simplified.

[0052] In another method for producing a cylinder block according to the present invention, after performing a step of polishing a region of the surface of a molding to become a slide surface by using a hone having a grit number of #1500 or more, an etching step of etching the polished region is performed, after which a step of providing a coating on only a portion of the etched region is further performed. As a result, the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ can both be made different between the coated portion and the other portion. Therefore, the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ of the slide surface can be made larger in the upper 1/4 portion than in the lower 1/4 portion, whereby a cylinder block having an excellent abrasion resistance and seizing resistance and a small friction loss can be produced.

[0053] In any of the production methods described above, a region of the surface of a molding to become a slide surface is polished by using a hone having a grit number of #1500 or more, and thereafter at least a portion of the polished region is etched. As a result, in the etched portion, a surface is created where not only a large number of primary crystal silicon grains but also a large number of eutectic silicon grains remain jutting (protruding), and oil puddles having sufficient depths are formed with a fine pitch. Therefore, the abrasion resistance and seizing resistance in a portion of the slide surface can be significantly improved.

[0054] According to the present invention, there is provided a cylinder block having an excellent abrasion resistance and seizing resistance and having a small friction loss, as well as a production method thereof. Moreover, according to the present invention, an internal combustion engine and a transportation apparatus incorporating such a cylinder block are also provided.

[0055] Other features, elements, processes, steps, characteristics and advantages of the present invention will become more apparent from the following detailed description of preferred embodiments of the present invention with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0056] FIG. 1 is a perspective view schematically showing a cylinder block 100 according to a preferred embodiment of the present invention.

[0057] FIG. 2 is a cross-sectional view schematically showing a cylinder block 100 according to a preferred embodiment of the present invention.

[0058] FIG. 3 is a plan view schematically showing an enlarged image of a slide surface of the cylinder block 100.

[0059] FIG. 4 is a cross-sectional view schematically showing an enlarged image of a slide surface of the cylinder block 100.

[0060] FIG. 5 is a diagram for explaining a ten point-average roughness Rz_{JIS} .

[0061] FIG. 6 is a diagram for explaining a load length ratio $Rmr(c)$.

[0062] FIG. 7 is a graph showing an exemplary relationship between a crank angle (deg) and a gas pressure (MPa) and a frictional force (N) in a conventional internal combustion engine.

[0063] FIGS. 8A and 8B are diagrams for explaining a reason why the frictional force acting on a slide surface becomes greatest immediately after explosion.

[0064] FIG. 9 is a flowchart showing production steps for the cylinder block 100.

[0065] FIG. 10 is a flowchart showing production steps for the cylinder block 100.

[0066] FIGS. 11A to 11E are step-by-step cross-sectional views schematically showing, partly, the production steps for the cylinder block 100.

[0067] FIGS. 12A and 12B are step-by-step cross-sectional view schematically showing, partly, the production steps for the cylinder block 100.

[0068] FIG. 13 is a flowchart showing the production steps for the cylinder block 100.

[0069] FIG. 14 is a step cross-sectional view schematically showing a part of the production steps for the cylinder block 100.

[0070] FIG. 15 is a flowchart showing the production steps for the cylinder block 100.

[0071] FIGS. 16A to 16C are step-by-step cross-sectional views schematically showing, partly, the production steps for the cylinder block 100.

[0072] FIGS. 17A to 17C are diagrams for explaining a reason why eutectic silicon grains do not contribute to lubricant retention when an emboss honing process is performed.

[0073] FIGS. 18A to 18C are diagrams for explaining a reason why eutectic silicon grains do not contribute to lubricant retention when an etching process is performed without first performing a mirror-finish honing process.

[0074] FIG. 19 is a diagram schematically showing a scratch test machine 30 which is used for measuring a friction coefficient.

[0075] FIG. 20 is a graph in which Examples 1 to 3 and Comparative Examples 1 to 11 are plotted, on a horizontal axis representing a ten point-average roughness Rz_{JIS} and a vertical axis representing a load length ratio $Rmr(30)$ at a cut level of 30%, with respect to an upper 1/4 portion of the slide surface.

[0076] FIG. 21 is a cross-sectional view schematically showing a slide surface on which not only primary-crystal silicon grains but also eutectic silicon grains remain jutting.

[0077] FIG. 22 is a cross-sectional view schematically showing a slide surface on which substantially nothing but primary-crystal silicon grains remain jutting.

[0078] FIG. 23 is a diagram for explaining a reason why a constant emboss height cannot be obtained when an emboss honing process is employed.

[0079] FIG. 24 is a diagram for explaining a reason why a constant emboss height is obtained when an etching process is employed.

[0080] FIG. 25 is a graph in which Examples 1 to 3 and Comparative Examples 1 to 11 are plotted, on a horizontal axis representing a ten point-average roughness Rz_{JIS} and a vertical axis representing a load length ratio $Rmr(30)$ at a cut level of 30%, with respect to a lower 1/4 portion of the slide surface.

[0081] FIG. 26 is a graph showing an example of a preferable grain size distribution of silicon crystal grains.

[0082] FIG. 27 is a cross-sectional view schematically showing an internal combustion engine 150 having the cylinder block 100.

[0083] FIG. 28 is a side view schematically showing a motorcycle incorporating the internal combustion engine 150 shown in FIG. 27.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0084] Hereinafter, embodiments of the present invention will be described with reference to the drawings. Although the following descriptions will be directed to a cylinder block for an internal combustion engine of the water-cooling type as an example, the present invention is not limited thereto. The present invention is also suitably used in a cylinder block for an internal combustion engine of the air cooling type.

[0085] FIG. 1 and FIG. 2 show a cylinder block according to the present embodiment (which may also be referred to as a "cylinder body") 100. FIG. 1 and FIG. 2 are a perspective view and a cross-sectional view schematically showing the cylinder block 100. The cylinder block 100 is made of an aluminum alloy which contains silicon, and more specifically, an aluminum-silicon alloy of a hypereutectic composition containing a large amount of silicon.

[0086] As shown in FIG. 1 and FIG. 2, the cylinder block 100 includes: a wall portion (referred to as a "cylinder wall") 103 defining a cylinder bore 102; and a wall portion (referred to as a "outer wall") 104 surrounding the cylinder wall 103 and defining the outer contour of the cylinder block 100. Between the cylinder wall 103 and the outer wall 104, a water jacket 105 for retaining a coolant is provided. Although the present embodiment illustrates a single-cylindere cylinder block 100, the cylinder block 100 may be multi-cylindere.

[0087] A surface 101 of the cylinder wall 103 facing the cylinder bore 102 (i.e., the inner peripheral surface) defines a slide surface on which a piston slides (i.e., the slide surface is in contact with a piston). The slide surface 101 is shown enlarged in FIG. 3. FIG. 3 is a plan view schematically showing the slide surface 101.

[0088] As shown in FIG. 3, the cylinder block 100 having the cylinder wall 103 having the slide surface 101 includes a plurality of silicon crystal grains 1 and 2 on the slide surface 101. These silicon crystal grains 1 and 2 are present, in a dispersed manner, in a matrix (alloy base metal) 3 of solid solution which contains aluminum.

[0089] The silicon crystal grains which are the first to be formed when a melt of an aluminum-silicon alloy which has a hypereutectic composition are referred to as "primary-crystal silicon grains". The silicon crystal grains which are then formed are referred to as "eutectic silicon grains". Among the silicon crystal grains 1 and 2 shown in FIG. 2, the relatively large silicon crystal grains 1 are the primary-crystal silicon grains. The relatively small silicon crystal grains 2 present between the primary-crystal silicon grains are the eutectic silicon grains.

[0090] FIG. 4 shows a cross-sectional structure of the slide surface 101. As shown in FIG. 4, the plurality of silicon crystal grains 1 and 2, including the primary-crystal silicon grains 1 and eutectic silicon grains 2, protrude (i.e., remain jutting) from a matrix 3. Recesses 4 formed between the silicon crystal grains 1 and 2 function as oil puddles in which a lubricant will be retained.

[0091] The inventors have studied the reasons why the conventional emboss honing process or etching process cannot realize a sufficient lubricant retaining ability. Thus, it has been found that most of the eutectic silicon grains are actually removed from the slide surface according to these conventional techniques, such that hardly any contribution of eutectic silicon grains to lubricant retention is obtained, thus resulting in a low lubricant retaining ability.

[0092] Accordingly, as parameters representing the surface roughness of the slide surface 101, the inventors have paid attention to a ten point-average roughness Rz_{JIS} and a load length ratio $Rmr(30)$ at a cut level of 30%, and discovered that setting these parameters to be within specific ranges can greatly improve the ability of the slide surface 101 to retain a lubricant.

[0093] The ten point-average roughness Rz_{JIS} is, with respect to a portion taken from a cross-sectional profile, the portion extending a reference length L (as shown in FIG. 5), a difference between an average value of heights $R1$, $R3$, $R5$, $R7$, and $R9$ of the five highest apices and an average value of the heights $R2$, $R4$, $R6$, $R8$, and $R10$ of the five lowest troughs, as expressed by eq. 1 below. Therefore, a large ten point-average roughness Rz_{JIS} means that the oil puddles 4 have a sufficient depth.

eq. 1

$$Rz_{JIS} = \frac{(R1+R3+R5+R7+R9)-(R2+R4+R6+R8+R10)}{5}$$

[0094] A load length ratio $Rmr(c)$ at a given cut level c is, with respect to a portion taken from a roughness profile, the portion extending an evaluation length ln (as shown in FIG. 6), a ratio of the sum of cut lengths when the roughness profile is cut at a cut level c which is parallel to a line connecting the apices (i.e., load length) $M1(c)$ to the evaluation length ln , as expressed by eq. 2 below.

eq. 2

$$Rmr(c) = \frac{100}{ln} \sum_{i=1}^m Ml(c)i \quad (\%)$$

[0095] Therefore, the load length ratio $Rmr(c)$ is an index indicating how many silicon grains 1 and 2 remain jutting on the slide surface 101. A large load length ratio $Rmr(c)$ means that a large number of silicon grains 1, 2 (and in particular the eutectic silicon grains 2) remain jutting. In an early stage of operation of an internal combustion engine, the outermost surface of the slide surface 101 is abraded (expressed as "fitness"), approximately to a depth corresponding to a cut level of 30%. Therefore, it can be said that a load length ratio $Rmr(30)$ at a cut level of 30% serves as a parameter indicating how many or few eutectic silicon grains 2 remain jutting during an actual operation.

[0096] As mentioned above, a large ten point-average roughness Rz_{JIS} means that the oil puddles 4 have a sufficient depth, and a large load length ratio $Rmr(30)$ means that a large number of silicon grains 1, 2 remain jutting on the slide surface 101 (i.e., remaining without dropping off). Therefore, by ensuring that the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ of the slide surface 101 are greater than certain levels, the lubricant retaining ability of the slide surface 101 can be improved. However, if the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ of the slide surface 101 are increased in a simple manner, i.e., uniformly over the entire the slide surface 101, the large number of eutectic silicon grains 2 which remain jutting on the slide surface 101 will induce a large friction loss.

[0097] In the cylinder block 100 of the present embodiment, the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ at a cut level of 30% each differ between an upper 1/4 portion 101a and a lower 1/4 portion 101b of the slide surface 101 (see FIG. 2). Specifically, the ten point-average roughness Rz_{JIS} of the slide surface 101 and the load length ratio $Rmr(30)$ of the slide surface 101 at a cut level of 30% are larger in the upper 1/4 portion 101a of the slide surface 101 than in the lower 1/4 portion 101b of the slide surface 101. Since the surface roughness of the slide surface 101 has such a distribution, the friction loss can be reduced while ensuring an excellent abrasion resistance and seizing resistance. Hereinafter, the reasons thereof will be described.

[0098] Needless to say, the "upper side" of the slide surface 101 means the cylinder head side (i.e., the top dead

center side), whereas the "lower side" of the slide surface **101** means the crankcase side (i.e., the bottom dead center side). Specifically, when the entire slide surface **101** is equally divided into four parts along the direction of piston slide (the central axis direction of the cylinder bore **102**), the upper 1/4 portion **101a** of the slide surface **101** refers to a region that is the closest to the cylinder head, whereas the lower 1/4 portion **101b** of the slide surface **101** refers to a region that is the closest to the crankcase.

[0099] FIG. 7 shows an exemplary relationship, in a conventional 4 stroke internal combustion engine, between the crank angle, the gas pressure (pressure within the cylinder), and the frictional force occurring between a piston (including a piston ring) and the slide surface of the cylinder block. Note that, as for the crank angle, the top dead center of compression is defined as 0° . As for the frictional force, any frictional force occurring in the opposite direction to the forward rotation direction of the crankshaft is indicated with a positive value. When considering the influence of a frictional force occurring between the piston and the slide surface of the cylinder block, only the absolute value of the frictional force shown in FIG. 7 needs to be considered. The reason why the frictional force is substantially 0 at crank angles $\pm 360^\circ$, $\pm 180^\circ$, 0° is that, when the crank angle is near any of these angles, the piston motion is very small relative to changes in the crank angle, so that hardly any frictional force occurs.

[0100] As shown in FIG. 7, during the intake step, the frictional force occurring between the side face of the piston and the slide surface of the cylinder block is substantially constant, such that the frictional force is largest near a crank angle of -270° , where the sliding speed increases. Similarly during the compression step, the frictional force is substantially constant, such that the frictional force is largest near a crank angle of -90° , where the sliding speed increases.

[0101] On the other hand, during the explosion step, the frictional force acting on the slide surface of the cylinder block varies greatly, such that the frictional force takes the largest value throughout all four steps near a crank angle of 0° , where the gas pressure becomes maximum (a region **R1** surrounded by a dotted line in FIG. 7). In other words, immediately after explosion, the frictional force is largest, and the slide surface of the cylinder block and the piston (more specifically, the piston ring and piston skirt) come into strong, direct contact. One reason why the frictional force becomes large immediately after explosion is that, as shown in FIG. 8A, the combustion gas comes between the piston and the piston ring due to the explosion pressure (firing pressure), thus pressing the piston ring against the slide surface of the cylinder block. Another reason is that, as shown in FIG. 8B, the piston is tilted with respect to the cylinder bore immediately after explosion. In this state, the piston ring is strongly pressed against the slide surface of the cylinder block (region **A** surrounded by a broken line in FIG. 8B), so that the piston skirt is strongly pressed against the slide surface of the cylinder block (region **B** surrounded by a broken line in FIG. 8B). As a result, a large frictional force occurs not only between the piston ring and the slide surface of the cylinder block, but also between the piston skirt and the slide surface of the cylinder block. Furthermore, when the piston and the slide surface of the cylinder block strongly rub against each other, the relative moving speed of the piston against the slide surface becomes small, so that appropriate retention of an oil film for reducing the frictional force does not occur at the surface of the slide surface, thus further increasing the frictional force.

[0102] On the other hand, once the gas pressure decreases thereafter, the frictional force is decreased (region **R2** surrounded by a dotted line in FIG. 7). In other words, except for the very early stage of the explosion step, the contact pressure between the slide surface of the cylinder block and the piston is low.

[0103] Therefore, within the slide surface of the cylinder block, any portion that comes into contact with the piston near the top dead center of compression (specifically a crank angle range from -45° to $+45^\circ$) needs to have a high abrasion resistance and seizing resistance. With respect to the other portions, smoothness of the surface, i.e., having a small friction coefficient, is more important than having an excessive abrasion resistance and seizing resistance.

[0104] In the cylinder block **100** of the present embodiment, the ten point-average roughness Rz_{JIS} of the slide surface **101** and the load length ratio $Rmr(30)$ of the slide surface **101** at a cut level of 30% are larger in the upper 1/4 portion **101a** of the slide surface **101** than in the lower 1/4 portion **101b** of the slide surface **101**. As a result, it is possible to increase the lubricant retaining ability of the slide surface **101** in the upper 1/4 portion **101a** of the slide surface **101** while decreasing the friction coefficient in the lower 1/4 portion **101b** of the slide surface **101**. Therefore, the friction loss can be reduced while ensuring an excellent abrasion resistance and seizing resistance.

[0105] In order to realize an excellent abrasion resistance and seizing resistance by sufficiently enhancing the lubricant retaining ability (i.e., allowing the eutectic silicon grains **2** on the slide surface **101** to sufficiently contribute to lubricant retention), it is preferable that the ten point-average roughness Rz_{JIS} is $0.54 \mu\text{m}$ or more and the load length ratio $Rmr(30)$ at a cut level of 30% is 20% or more in the upper 1/4 portion **101a** of the slide surface **101**. However, in the case of producing the cylinder block **100** by a production method which involves an etching process as will be described later, the large amount of silicon crystal grains which remain jutting may cause a significant damage or abrasion on the counterpart (piston ring and/or piston) if the load length ratio $Rmr(30)$ exceeds 55%, and therefore the load length ratio $Rmr(30)$ is preferably 55% or less. Moreover, from the standpoint of further increasing the lubricant retaining ability, it is more preferable that the ten point-average roughness Rz_{JIS} is $0.7 \mu\text{m}$ or more, and from the standpoint of preventing drop-off of the eutectic silicon grains **2** and any significant abrasion of the counterpart, it is preferable that the ten point-average roughness Rz_{JIS} is $2.0 \mu\text{m}$ or less.

[0106] Moreover, in order to sufficiently reduce the friction loss by sufficiently decreasing the friction coefficient, it is preferable that the ten point-average roughness Rz_{JIS} is less than $0.54\ \mu\text{m}$ and the load length ratio $Rmr(30)$ at a cut level of 30% is 15% or less in the lower 1/4 portion **101b** of the slide surface **101**. Note that, from the standpoint of further reducing the friction loss, the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ are more preferably within the aforementioned numerical ranges in the lower 1/2 portion of the slide surface **101**, and still more preferably within the aforementioned numerical ranges in the lower 3/4 portion of the slide surface **101**.

[0107] As described above, in the cylinder block **100** of the present embodiment, the surface roughness of the slide surface **101** has a distribution. On the other hand, in a conventional cylinder block, substantially the same surface roughness exists across the entire slide surface. In other words, the present invention has been made based on an entirely new concept of purposely introducing a difference in surface roughness (specifically, the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ at a cut level of 30%) between one portion and another portion of the slide surface **101**.

[0108] A method for producing the cylinder block **100** of the present embodiment will be described with reference to FIG. 9 to FIG. 12B. FIG. 9 and FIG. 10 are flowcharts showing production steps for the cylinder block 100. FIGS. 11A to 11E and FIGS. 12A and 12B are cross-sectional views schematically showing, partly, the production steps.

[0109] First, a molding which is made of an aluminum alloy containing silicon is provided (step **S1**). This molding includes primary-crystal silicon grains and eutectic silicon grains near the surface. The step **S1** of providing the molding may include, for example, steps **S1a** to **S1e** shown in FIG. 10.

[0110] First, a silicon-containing aluminum alloy is prepared (step **S1a**). In order to ensure a sufficient abrasion resistance and strength of the cylinder block **100**, it is preferable to use an aluminum alloy which contains: no less than 73.4 mass% and no more than 79.6 mass% of aluminum; no less than 16 mass% and no more than 22 mass% of silicon; and no less than 2.0 mass% and no more than 5.0 mass% of copper.

[0111] Next, the prepared aluminum alloy is heated and melted in a melting furnace, whereby a melt is formed (step **S1b**). It is preferable that about 100 mass ppm of phosphorus be added to the aluminum alloy before melting or to the melt. If the aluminum alloy contains no less than 50 mass ppm and no more than 200 mass ppm of phosphorus, it becomes possible to reduce the tendency of the silicon crystal grains to become gigantic, thus allowing for uniform dispersion of the silicon crystal grains within the alloy. On the other hand, if the calcium content in the aluminum alloy is 0.01 mass% or less, the effect of providing fine silicon crystal grains due to phosphorus is secured, and a metallurgical structure with excellent abrasion resistance can be obtained. In other words, the aluminum alloy preferably contains no less than 50 mass ppm and no more than 200 mass ppm of phosphorus, and no more than 0.01 mass% of calcium.

[0112] Next, casting is performed by using the aluminum alloy melt (step **S1c**). In other words, the melt is cooled within a mold to form a molding. At this time, the portion to become the slide surface 101 of the cylinder wall 103 is cooled at a large cooling rate (e.g., no less than $4^\circ\text{C}/\text{sec}$ and no more than $50^\circ\text{C}/\text{sec}$), whereby a molding is obtained which includes silicon crystal grains contributing to abrasion resistance near its surface. This casting step **S1c** can be performed by using, for example, a casting apparatus which is disclosed in the pamphlet of International Publication No. 2004/002658.

[0113] Next, the molding which has been taken out of the mold is subjected to one of the heat treatments commonly known as "T5", "T6", and "T7" (step **S1d**). A T5 treatment is a treatment in which the molding is rapidly cooled (with water or the like) immediately after being taken out of the mold, and thereafter subjected to artificial aging at a predetermined temperature for a predetermined period of time to obtain improved mechanical properties and dimensional stability, followed by air cooling. A T6 treatment is a treatment in which the molding is subjected to a solution treatment at a predetermined temperature for a predetermined period after being taken out of the mold, then cooled with water, and thereafter subjected to artificial aging at a predetermined temperature for a predetermined period of time, followed by air cooling. A T7 treatment is a treatment for causing a stronger degree of aging than in the T6 treatment; although the T7 treatment can ensure better dimensional stability than does the T6 treatment, the resultant hardness will be lower than that obtained from the T6 treatment.

[0114] Next, predetermined machining is performed for the molding (step **S1e**). Specifically, a surface abutting with a cylinder head and a surface abutting with a crankcase are subjected to grinding or the like.

[0115] After the molding is prepared as described above, as shown in FIG. 11A, the surface of the molding, specifically, the inner peripheral surface of the cylinder wall **103** (i.e., the surface to become the slide surface 101) is subjected to a fine boring process for dimensional accuracy adjustment (step **S2**).

[0116] Next, as shown in FIG. 11B, the surface which has undergone a fine boring process is subjected to a coarse honing process (step **S3**). In other words, the surface to become the slide surface **101** is polished by using a hone having a relatively small grit number (specifically, with a grit number of no less than #600 and no more than #1000). This coarse honing process can be performed by using a honing apparatus disclosed in Japanese Laid-Open Patent Publication No. 2004-268179, for example.

[0117] Next, as shown in FIG. 11C, a mirror-finish honing process is performed (step **S4**). In other words, the region of the surface of the molding to become the slide surface **101** is polished by using a hone having a relatively large grit

number (specifically, with a grit number of #1500 or more). This mirror-finish honing process can also be performed by using a honing apparatus such as that disclosed in Japanese Laid-Open Patent Publication No. 2004-268179.

[0118] Next, as shown in FIG. 11D, only a portion of the polished region is etched (step **S5**). In the portion which has been subjected to the etching process (e.g., an alkaline etching process), the matrix **3** near the surface is removed to a predetermined thickness, whereby recesses are formed in between the primary crystal silicon grains **1** and the eutectic silicon grains **2**. As shown in FIG. 12A, this local etching step is performed by placing a cylindrical member **11** within the cylinder bore **102** of a molding **100'** which is placed in an inverted position (i.e., upside down with respect to how it will be placed when an internal combustion engine is assembled), the cylindrical member **11** having a smaller diameter than that of the cylinder bore **102**; in this state, an etchant **12** is used to fill between the outer peripheral surface of the cylindrical member **11** and the inner peripheral surface of the cylinder wall **103**, up to a predetermined height. Note that the etching process in this local etching step is to be performed for at least the upper 1/4 portion of the region to become the slide surface **101** (in FIG. 12A, this portion corresponds to the lower 1/4 portion of the inner peripheral surface of the cylinder wall **103**, since the molding **100'** is in an inverted position).

[0119] Thereafter, as shown in FIG. 11E, the entire region to become the slide surface **101** is etched (step **S6**). Through the etching process, in the entire region to become the slide surface **101**, the matrix **3** near the surface is removed to a predetermined thickness, whereby the slide surface **101** having the primary crystal silicon grains **1** and the eutectic silicon grains **2** protruding therefrom is formed. The recesses **4** between the primary crystal silicon grains **1** and the eutectic silicon grains **2** function as oil puddles. As shown in FIG. 12B, this overall etching step is performed by adding more etchant **12** to fill between the outer peripheral surface of the cylindrical member **11** and the inner peripheral surface of the cylinder wall **103** with the etchant **12**, up to a height such that the entire inner peripheral surface of the cylinder wall **103** is immersed in the etchant **12** (i.e., the maximum height). The upper end of the cylindrical member **11** is opened, thus allowing the etchant **12** to be collected through the inside of the cylindrical member **11** and circulate.

[0120] Note that the sizing steps to be performed before the mirror-finish honing process (step **S4**) are not limited to the two steps exemplified above, i.e., a fine boring process (step **S2**) and a coarse honing process (step **S3**). Sizing may be performed through a single step, or sizing may be performed through three or more steps.

[0121] According to the production method of the present embodiment, after performing a local etching (first etching) step of only etching a portion of the region to become the slide surface **101**, an overall etching (second etching) step of etching the entire region to become the slide surface **101** is performed. As a result, while a portion of the region to become the slide surface **101** is subjected to two etching processes, the other portion is subjected to only one etching process. Therefore, a distribution can be introduced to the size of the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ within the slide surface **101**, and therefore the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ of the slide surface **101** can each be made different between the upper 1/4 portion **101a** and the lower 1/4 portion **101b** of the slide surface **101**. As a result, the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ of the slide surface **101** can be made larger in the upper 1/4 portion **101a** than in the lower 1/4 portion **101b**.

[0122] The ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ of the portion which is subjected to one etching process and the portion which is subjected to two etching processes can each be adjusted based on the concentration and temperature of the etchant, etching time (immersion time), and the like, of the local etching step and the overall etching step.

[0123] Note that, as shown in FIG. 13, the overall etching step may be omitted. In other words, after the local etching (first etching) step **S5**, there is no need to perform a further etching step of etching the region to become the slide surface **101**. In this case, as shown in FIG. 14, the local etching step is performed by using a cylindrical member **11** which is lower than the cylindrical member **11** shown in FIG. 12, and via an opened upper end of the cylindrical member **11**, the etchant **12** is collected through the inside of the cylindrical member **11** and allowed to circulate.

[0124] Even when the overall etching step is omitted, the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ can each be made different between the portion which is subjected to an etching process in the local etching step and the other portion which is subjected to no etching process at all. Therefore, the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ of the slide surface **101** can be made larger in the upper 1/4 portion **101** than in the lower 1/4 portion **101b**. However, in the case where the overall etching step is omitted, it is preferable to adjust the etching amount in the local etching step so that the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ of the slide surface **101** become sufficiently large through the etching process of the local etching step alone.

[0125] Moreover, the cylinder block **100** of the present embodiment can also be produced by using a production method shown in FIG. 15, which does not include a local etching step. The production method shown in FIG. 15 is identical to the production methods shown in FIG. 9 and FIG. 13 up to the mirror-finish honing step (step **S4**). In the production method shown in FIG. 15, after the mirror-finish honing step, as shown in FIG. 16A, an overall etching step of etching the region to become the slide surface **101** (the entire region) is performed (step **S7**). Thereafter, a coating is provided only on a portion of the etched region (step **S8**).

[0126] In this partial coating step, first, as shown in FIG. 16B, a cylindrical masking member **14** having substantially the same diameter as that of the cylinder bore **102** is placed within the cylinder bore **102**. Thereafter, as shown in FIG.

16C, an inner gun **16** is inserted in the cylinder bore **102**, and a coating material is flame-sprayed from the inner gun **16**, thus providing a coating on the unmasked portion of the inner peripheral surface of the cylinder wall **103**. The coating is provided on at least the lower 1/4 portion of the region to become the slide surface **101** (which corresponds to the upper 1/4 portion of the inner peripheral surface of the cylinder wall **103** in FIG. **16C** because the molding **100'** is in an inverted position).

[0127] By performing a partial coating step after an overall etching step, it can be ensured that the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ are each different between the coated portion and the uncoated portion. Specifically, the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ can both be made smaller in the coated portion than in the uncoated portion. Thus, the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ of the slide surface **101** can be made larger in the upper 1/4 portion **101a** than in the lower 1/4 portion **101b**.

[0128] As the coating material, a broad range of materials which are unlikely to adhere to the material of the piston and which have an excellent lubricity can be used. A mixture of polyamide imide and molybdenum disulfide is suitably used as the coating material because it excels in thermal resistance, low-frictionness, and seizing resistance upon direct contact. It will be appreciated that the coating material is not limited thereto; for example, ceramics (cemented carbide, etc.) may be used.

[0129] In any of the above-described production methods, an etching is performed after a polish using a hone having a grit number of #1500 or more. In other words, a surface smoothing process (through a mirror-finish honing process) is first performed, and then a chemical grinding (through etching) is performed, whereby the recesses **4** to become oil puddles are formed. By forming the slide surface **101** in this manner (i.e., the slide surface **101** is a slide surface having experienced an etching process), the eutectic silicon grains **2** are allowed to remain on the slide surface **101** without dropping off, so that the eutectic silicon grains **2** can sufficiently contribute to lubricant retention. In other words, the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ in the portion (upper 1/4 portion) of the slide surface **101** where a high abrasion resistance and seizing resistance is required can be made sufficiently large. On the other hand, with a conventional emboss honing process and etching process, it is difficult to make the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ sufficiently large. Hereinafter, the reasons behind this will be described.

[0130] In the case where an emboss honing process is employed to form the slide surface **101**, a molding having primary-crystal silicon grains and eutectic silicon grains near its surface is prepared first (same step as the step **S1** shown in FIG. **9**), and then the surface of the molding is subjected to a fine boring process, as shown in FIG. **17A**. Then, after performing a coarse honing process as shown in FIG. **17B**, an emboss honing process is performed as shown in FIG. **17C**. The emboss honing process is performed by using a resin brush on which abrasive grains are adhered, and is performed in such a manner that mainly the matrix **3** will be cut. However, the emboss honing process, which is a mechanical grinding process, will inevitably remove a portion of the eutectic silicon grains **2** together with the matrix **3**, as schematically shown in FIG. **17C**. Therefore, the eutectic silicon grains **2** do not contribute much to lubricant retention.

[0131] On the other hand, in the case where the slide surface **101** is formed through an etching process which is not preceded by a mirror-finish honing process, a molding having primary-crystal silicon grains and eutectic silicon grains near its surface is prepared first (same step as the step **S1** shown in FIG. **9**), and then the surface of the molding is subjected to a fine boring process as shown in FIG. **18A**. Next, a coarse honing process is performed as shown in FIG. **18B**, and thereafter an etching process is performed as shown in FIG. **18C**. In this case, those eutectic silicon grains **2** whose surfaces have been damaged through the coarse honing process (i.e., cracked or broken) will remain jutting. Such eutectic silicon grains **2** will eventually drop off the slide surface as schematically shown in FIG. **18C**. Therefore, the eutectic silicon grains **2** do not contribute much to lubricant retention.

[0132] In the present embodiment, a mirror-finish honing process is performed before an etching process, in which case the etching process (which is a chemical grinding process) does not remove the eutectic silicon grains **2** together with the matrix **3**, unlike in the emboss honing process (which is a mechanical grinding). Moreover, since the surface is smoothed through a mirror-finish honing process (which also encompasses the surface of the eutectic silicon grains **2**) before the etching process, drop-off of the eutectic silicon grains **2** occurs less frequently than in the case where the etching process is performed immediately after a coarse honing process. Therefore, the eutectic silicon grains **2** sufficiently contribute to lubricant retention.

[0133] Note that, in all of the aforementioned methods, the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ of the resultant slide surface **101** vary in two steps, from the upper side toward the lower side. However, the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ of the slide surface **101** may vary in a greater number of steps, or vary gradually (e.g. linearly).

[0134] Next, results of actually prototyping the cylinder blocks **100** according to the present embodiment and subjecting them to an seizing resistance evaluation test and friction coefficient measurements will be described.

[0135] Using an aluminum alloy of the composition shown in Table 1, a molding to become a cylinder block **100** was produced by a high-pressure die-casting technique like that disclosed in the pamphlet of International Publication No. 2004/002658.

Table 1

Si	Cu	Mg
22.0 mass%	2.5 mass%	0.50 mass%
Fe	P	Al
0.3 mass%	0.01 mass%	balance

[0136] By using the produced moldings, cylinder blocks 100 were produced by the respective production methods which have been described with reference to FIG. 9, FIG. 13, and FIG. 15 (Examples 1 to 3).

[0137] The honing processes (coarse honing process and mirror-finish honing process) were performed by using a honing apparatus as disclosed in Japanese Laid-Open Patent Publication No. 2004-268179, while supplying cooling oil onto the surface to be polished (i.e., wet honing). A hone with a grit number of #600 was used for the coarse honing process, whereas a hone with a grit number of #2000 was used for the mirror-finish honing process. Note that a higher grit number indicates that the hone has finer abrasive grains and therefore the polished surface will attain a higher smoothness. However, as the abrasive grains become finer, the speed of cutting will decrease, thus resulting in a longer processing time and lower producibility. In other words, the production method according to the present embodiment dares to perform the mirror-finish honing process which is disadvantageous in terms of producibility.

[0138] In both of the local etching step and the overall etching step, the etching process was performed by using a 5 mass% sodium hydroxide solution, under conditions such that the temperature of the solution was 70°C. The etching amount (etching depth) was adjusted by varying the immersion time.

[0139] An internal combustion engine was assembled by using the cylinder block 100 as well as an aluminum-alloy piston which was separately produced by forging. Immediately after a state where the internal combustion engine was still cold and the lubricant had not permeated the cylinder, this internal combustion engine was operated for 5 minutes at a revolution speed of 8000 rpm, and scratches occurring on the upper 1/4 portion 101a of the slide surface 101 (i.e., scuffing) were observed through visual inspection to determine whether the cylinder block would qualify for use. The results (i.e., seizing resistance evaluation results) are shown in Table 2 below.

[0140] Table 2 also shows results of measuring the friction coefficient in the lower 1/4 portion 101b of the slide surface 101. The friction coefficient measurements were taken by employing a scratch test machine 30 as shown in FIG. 19. The scratch test machine 30 includes a stylus 31, an acoustic emission (AE) sensor 32, a pressing depth sensor (not shown), and the like. While applying a predetermined vertical load F_N to the stylus 31, a sample 35 is moved horizontally, as a result of which the stylus 31 scratches on the surface of the sample 35. Thus, the frictional force F_T is detected, and the friction coefficient can be measured. Herein, a SUJ2 ball was used as the stylus 31, and a small piece which had been cut out from the cylinder block 100 was used as the sample 35. The measurements were taken while dropping oil onto the surface of the sample 35.

[0141] Furthermore, Table 3 shows a ten point-average roughness Rz_{JIS} and a load length ratio $Rmr(30)$ at a cut level of 30% of the slide surface 101, as measured by using SURFCOM 1400D manufactured by TOKYO SEIMITSU CO., LTD, with respect to the upper 1/4 portion 101a and the lower 1/4 portion 101b of the slide surface 101. As has already been described, the ten point-average roughness Rz_{JIS} is a parameter that can be used for evaluating the depth of the oil puddles 4, whereas the load length ratio $Rmr(30)$ is a parameter that can be used for evaluating the number of eutectic silicon grains 2 that remain jutting (i.e., remaining without dropping off) on the slide surface 101.

Table 2

	step	upper 1/4	lower 1/4
		seizing resistance evaluation	friction coefficient
Example 1	#600⇒#2000⇒ local etching ⇒ overall etching	OK	0.15
Example 2	#600⇒#2000⇒ local etching	OK	0.1
Example 3	#600⇒#2000⇒ overall etching ⇒ partial coating	OK	0.05
Comparative Example 1	#600⇒#2000	NG	0.1
Comparative Example 2	#600⇒#2000⇒ emboss honing	NG	0.1
Comparative Example 3	#600⇒#2000⇒ emboss honing	NG	0.1

(continued)

	step	upper 1/4	lower 1/4
		seizing resistance evaluation	friction coefficient
Comparative Example 4	#600⇒#2000⇒ emboss honing	NG	0.1
Comparative Example 5	#600⇒#2000⇒ emboss honing	NG	0.1
Comparative Example 6	#600⇒#2000⇒ alkaline etching	NG	0.2
Comparative Example 7	#600⇒#2000⇒ alkaline etching	OK	0.2
Comparative Example 8	#600⇒#2000⇒ alkaline etching	OK	0.3
Comparative Example 9	#600⇒#2000⇒ alkaline etching	OK	0.3
Comparative Example 10	#600⇒#2000⇒ alkaline etching	OK	0.3
Comparative Example 11	#600⇒#2000⇒ alkaline etching	OK	0.3

Table 3

	upper 1/4		lower 1/4	
	Rz _{JIS} [μm]	Rmr(30) [%]	Rz _{JIS} [μm]	Rmr(30) [%]
Example 1	1.34	43	0.39	15
Example 2	1.28	43	0.28	10
Example 3	1.53	53	0.25	8
Comparative Example 1	0.28	8	0.28	7
Comparative Example 2	0.43	15	0.46	15
Comparative Example 3	0.45	12	0.49	10
Comparative Example 4	0.43	5	0.40	7
Comparative Example 5	0.76	3	0.76	3
Comparative Example 6	0.40	50	0.38	53
Comparative Example 7	0.54	40	0.50	40
Comparative Example 8	1.32	45	1.29	44
Comparative Example 9	0.82	30	0.79	29
Comparative Example 10	1.10	50	1.22	48
Comparative Example 11	2.76	20	2.54	18

[0142] Moreover, Table 2 and Table 3 also show results of taking similar evaluations and measurements for cylinder blocks which were produced as Comparative Examples. In Comparative Example 1, after a coarse honing process and a mirror-finish honing process, neither an etching process nor an emboss honing process was performed. In Comparative Examples 2 to 5, an emboss honing process was performed after a coarse honing process and a mirror-finish honing process. In Comparative Examples 6 to 11, the entire slide surface was subjected to an etching process after a coarse honing process and a mirror-finish honing process.

[0143] As can be seen from Table 2 and Table 3, in all of Examples 1 to 3, the ten point-average roughness Rz_{JIS} of the slide surface **101** and the load length ratio Rmr(30) of the slide surface **101** at a cut level of 30% are larger in the upper 1/4 portion **101a** of the slide surface **101** than in the lower 1/4 portion **101b**, whereby an excellent seizing resistance and a reduction of friction loss (herein, to a friction coefficient of 0.15 or less) are realized.

[0144] Moreover, with respect to all of Examples 1 to 3, the ten point-average roughness Rz_{JIS} is 0.54 μm or more and the load length ratio Rmr(30) is 20% or more in the upper 1/4 portion **101a** of the slide surface **101**. This indicates that, in order to realize an excellent seizing resistance, it is preferable that the ten point-average roughness Rz_{JIS} is 0.54 μm or more and the load length ratio Rmr(30) is 20% or more in the upper 1/4 portion **101a** of the slide surface **101**.

[0145] Furthermore, in all of Examples 1 to 3, the ten point-average roughness Rz_{JIS} is less than $0.54\text{ }\mu\text{m}$ and the load length ratio $Rmr(30)$ is 15% or less in the lower 1/4 portion **101b** of the slide surface **101**. This indicates that, in order to realize a sufficient reduction of friction loss (herein, to a friction coefficient of 0.15 or less), it is preferable that the ten point-average roughness Rz_{JIS} is less than $0.54\text{ }\mu\text{m}$ and the load length ratio $Rmr(30)$ is 15% or less in the lower 1/4 portion **101b** of the slide surface **101**.

[0146] In all of Comparative Examples 1 to 11, the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ at a cut level of 30% of the slide surface are substantially the same across the entire slide surface, thus being substantially the same between the upper 1/4 portion and the lower 1/4 portion of the slide surface. Therefore, an inferior seizing resistance and/or a larger friction loss (herein, a friction coefficient of 0.2 or more) were obtained.

[0147] Specifically, in Comparative Example 1 where neither an etching process nor an emboss honing process was performed after a mirror-finish honing process and in Comparative Examples 2 to 5 where an emboss honing process was performed after a mirror-finish honing process, the friction coefficient was small, but scuffing occurred.

[0148] Moreover, in Comparative Examples 7 to 11 where the entire slide surface was subjected to an etching process after a mirror-finish honing process, no scuffing occurred but the friction coefficient was large. Furthermore, in Comparative Example 6, where the entire slide surface was subjected to an etching process after a mirror-finish honing process but a for shorter etching time than in Comparative Examples 7 to 11, scuffing occurred and the friction coefficient was also large.

[0149] FIG. 20 is a graph in which Examples 1 to 3 and Comparative Examples 1 to 11 are plotted on a horizontal axis representing the ten point-average roughness Rz_{JIS} and a vertical axis representing the load length ratio $Rmr(30)$, with respect to the upper 1/4 portion of the slide surface.

[0150] As can be seen from FIG. 20, in Examples 1 to 3 and Comparative Examples 7 to 11, where no scuffing occurred, the ten point-average roughness Rz_{JIS} was $0.54\text{ }\mu\text{m}$ or more and the load length ratio $Rmr(30)$ was 20% or more. On the other hand, in Comparative Examples 1 to 6 which suffered scuffing, at least one of the ten point-average roughness Rz_{JIS} and load length ratio $Rmr(30)$ falls outside the aforementioned numerical range(s). Therefore, it can be seen that the lubricant retaining ability in the upper 1/4 portion **101a** of the slide surface **101** is improved and scuffing is prevented under the conditions that the ten point-average roughness Rz_{JIS} is $0.54\text{ }\mu\text{m}$ or more and the load length ratio $Rmr(30)$ at a cut level of 30% is 20% or more. Note that, when the ten point-average roughness Rz_{JIS} is significantly large (specifically, exceeding $4.0\text{ }\mu\text{m}$), significant drop-off of the fine eutectic silicon grains **2** may occur so that the fine voids for retaining lubricant (oil puddles **4** with a fine pitch) may decrease. Therefore, the ten point-average roughness Rz_{JIS} is preferably $4.0\text{ }\mu\text{m}$ or less, and more preferably $2.0\text{ }\mu\text{m}$ or less.

[0151] As has been described above, a high lubricant retaining ability is obtained when not only primary-crystal silicon grains **1** but also a large number of eutectic silicon grains **2** remain jutting on the slide surface **101**. As schematically shown in FIG. 21, oil puddles **4** of sufficient depth are formed with a fine pitch when a large number of eutectic silicon grains **2** remain jutting, whereby the lubricant retaining ability is enhanced and the seizing resistance is improved. Since a large number of eutectic silicon grains **2** remain jutting, the area of the portions which actually come in contact with a piston ring **122a** is increased as compared to the case where only the primary-crystal silicon grains **1** remain jutting. As a result, the load per unit area that is applied during a slide is reduced, whereby an improved abrasion resistance is obtained.

[0152] On the other hand, as schematically shown in FIG. 22, when substantially nothing but the primary-crystal silicon grains **1** remain jutting, the oil puddles **4** are formed with a coarse pitch, resulting in a lower lubricant retaining ability and seizing resistance. Since hardly any eutectic silicon grains **2** remain jutting, the area of the portions which actually come in contact with the piston ring **122a** is small, thus resulting in a low abrasion resistance.

[0153] As has already been described above, with the conventional emboss honing process, it is difficult to sufficiently increase the ten point-average roughness Rz_{JIS} and load length ratio $Rmr(30)$. The reason thereof will be described with reference to FIG. 23.

[0154] In an emboss honing process which is a mechanical grinding process, the grinding amount differs between regions where the silicon crystal grains **1** and **2** are sparse and regions where they are dense. Specifically, as shown at the right-hand side in FIG. 23, deep grinding occurs in a region where the silicon crystal grains **1** and **2** are sparse, thus resulting in a large emboss height h . However, as shown in at the left-hand side in FIG. 23, only shallow grinding occurs in a region where the silicon crystal grains **1** and **2** are dense, thus resulting in a small emboss height h . Therefore, it is difficult to obtain a large ten point-average roughness Rz_{JIS} over the entire slide surface **101**. Moreover, since the eutectic silicon grains **2** will be ground together with the matrix **3**, it is also difficult to obtain a large load length ratio $Rmr(30)$. Furthermore, since an emboss honing process is a mechanical grinding process, relative to the apex of each silicon crystal grain **1** or **2**, it is difficult to deeply gouge the aluminum alloy (matrix **3**) that is present around each silicon crystal grain **1** or **2**. Therefore, around each silicon crystal grain **1** or **2**, aluminum alloy exists to a height which is not much different from the apex thereof, thus resulting in a lubricant retaining ability which is lower than in the case of performing an etching process.

[0155] On the other hand, in an etching process (which is a chemical grinding process), as shown in FIG. 24, grinding

occurs down to a constant depth regardless of whether the silicon crystal grains **1** and **2** are sparse or dense, so that a constant emboss height **h** is obtained. Therefore, by adjusting the concentration and temperature of the etchant and the etching time, the ten point-average roughness Rz_{JIS} can be easily increased. Moreover, since the eutectic silicon grains **2** will not be ground together with the matrix **3**, the load length ratio $Rmr(30)$ can be easily increased.

[0156] FIG. **25** is a graph in which Examples 1 to 3 and Comparative Examples 1 to 11 are plotted, on a horizontal axis representing the ten point-average roughness Rz_{JIS} and a vertical axis representing the load length ratio $Rmr(30)$, with respect to the lower 1/4 portion of the slide surface.

[0157] As can also be seen from FIG. **25**, in all of Examples 1 to 3 and Comparative Examples 1 to 4, which showed a small friction coefficient (0.15 or less), the ten point-average roughness Rz_{JIS} is less than $0.54\text{ }\mu\text{m}$ and the load length ratio $Rmr(30)$ is 15% or less. On the other hand, in Comparative Examples 6 to 11, which showed a large friction coefficient (0.2 or more), at least one of the ten point-average roughness Rz_{JIS} and the load length ratio $Rmr(30)$ falls outside the aforementioned numerical range(s). This indicates that, by ensuring that the ten point-average roughness Rz_{JIS} is less than $0.54\text{ }\mu\text{m}$ and that the load length ratio $Rmr(30)$ at a cut level of 30% is 15% or less, the friction coefficient in the lower 1/4 portion **101b** of the slide surface **101** can be made sufficiently small, and the friction loss can be further reduced. Note that, in Comparative Example 5, the friction coefficient is small although the ten point-average roughness Rz_{JIS} is $0.54\text{ }\mu\text{m}$ or more. This is because the load length ratio $Rmr(30)$ is so small as 3%.

[0158] Moreover, it can be seen from Table 2 that the friction coefficient in the lower 1/4 portion **101b** of the slide surface **101** is the smallest (and hence the friction loss is the smallest) in Example 3, followed by Example 2 and then by Example 1. Therefore, from the standpoint of reducing friction losses, it is preferable to employ the production method described with reference to FIG. **15**, i.e., a production method in which a partial coating step is performed after an overall etching step.

[0159] In the case where the production method described with reference to FIG. **13** is used, i.e., a production method where no further etching step is conducted after performing a local etching step, the number of steps is reduced. Therefore, a reduction in production cost and simplification of production steps are possible.

[0160] In the case where the production method described with reference to FIG. **9** is used, i.e., a production method where an overall etching step is conducted after performing a local etching step, the entire slide surface **101** is subjected to an etching process (although the etching amount is non-constant), so that the lubricant retaining ability of the entire slide surface **101** is improved. Thus, a high effect of improving the abrasion resistance and seizing resistance across the entire slide surface **101** is obtained.

[0161] Next, preferable average crystal grain sizes and preferable grain size distributions of the silicon crystal grains **1** and **2** on the slide surface **101** will be described. The inventors have conducted a detailed study on the relationship between the specific deployment of the silicon crystal grains **1** and **2** on the slide surface **101** and the abrasion resistance and strength of the cylinder block **100**. As a result, it has been found that the abrasion resistance and strength can be greatly improved by setting the average crystal grain sizes of the silicon crystal grains **1** and **2** within specific ranges, and/or prescribing specific grain size distributions for the silicon crystal grains **1** and **2**.

[0162] First, by setting the average crystal grain size of the primary-crystal silicon grains **1** to be within the range of no less than $12\text{ }\mu\text{m}$ and no more than $50\text{ }\mu\text{m}$, the abrasion resistance of the cylinder block **100** can be improved.

[0163] If the average crystal grain size of the primary-crystal silicon grains **1** exceeds $50\text{ }\mu\text{m}$, the number of primary-crystal silicon grains **1** per unit area of the slide surface **101** becomes small. Therefore, a large load will be applied to each primary-crystal silicon grain **1** during operation of the internal combustion engine, so that the primary-crystal silicon grains **1** may be destroyed. The debris of the destroyed primary-crystal silicon grains **1** will act as abrasive particles, possibly causing a considerable abrasion of the slide surface **101**.

[0164] If the average crystal grain size of the primary-crystal silicon grains **1** is less than $12\text{ }\mu\text{m}$, the portion of each primary-crystal silicon grain **1** that is buried within the matrix **3** will be small. Therefore, drop-off of the primary-crystal silicon grains **1** is likely to occur during operation of the internal combustion engine. The primary-crystal silicon grains **1** having dropped off will act as abrasive particles, possibly causing a considerable abrasion of the slide surface **101**.

[0165] On the other hand, when the average crystal grain size of the primary-crystal silicon grains **1** is no less than $12\text{ }\mu\text{m}$ and no more than $50\text{ }\mu\text{m}$, a sufficient number of primary-crystal silicon grains **1** exist per unit area of the slide surface **101**. Therefore, the load applied to each primary-crystal silicon grain **1** during operation of the internal combustion engine will be relatively small, whereby destruction of the primary-crystal silicon grains **1** is suppressed. Since the portion of each primary-crystal silicon grain **1** that is buried within the matrix **3** is sufficiently large, drop-off of the primary-crystal silicon grains **1** is reduced, whereby the abrasion of the slide surface **101** due to primary-crystal silicon grains **1** having dropped off is also suppressed.

[0166] Moreover, the eutectic silicon grains **2** serve the function of reinforcing the matrix **3**. Therefore, by providing fine eutectic silicon grains **2**, the abrasion resistance and strength of the cylinder block **100** can be improved. Specifically, by ensuring that the eutectic silicon grains **2** have an average crystal grain size of $7.5\text{ }\mu\text{m}$ or less, an effect of improving the abrasion resistance and strength is obtained.

[0167] Furthermore, by prescribing grain size distributions for the silicon crystal grains **1** and **2** such that the silicon

crystal grains have a peak in a crystal grain size range of no less than 1 μm and no more than 7.5 μm and have an another peak in a crystal grain size range of no less than 12 μm and no more than 50 μm , the abrasion resistance and strength of the cylinder block **100** can be greatly improved. FIG. **26** shows an example of preferable grain size distributions. The silicon crystal grains whose crystal grain sizes fall within the range of no less than 1 μm and no more than 7.5 μm are eutectic silicon grains **2**, whereas the silicon crystal grains whose crystal grain sizes fall within the range of no less than 12 μm and no more than 50 μm are primary-crystal silicon grains **1**. Moreover, from the standpoint of allowing more eutectic silicon grains **2** to contribute to creation of oil puddles **4**, as is also shown in FIG. **26**, it is preferable that the frequency at a first peak existing in the crystal grain size range of no less than 1 μm and no more than 7.5 μm (i. e. , the peak associated with the eutectic silicon grains **2**) is at least five times greater than the frequency at a second peak existing in the crystal grain size range of no less than 12 μm and no more than 50 μm (i.e., the peak associated with the primary-crystal silicon grains **1**).

[0168] In order to control the average crystal grain sizes of the primary-crystal silicon grains **1** and the eutectic silicon grains **2**, the cooling rate of the portion to become the slide surface **101** may be adjusted in the step of casting the molding (the step **S1c** shown in FIG. **10**). Specifically, by performing the aforementioned casting so that the portion to become the slide surface **101** is cooled at a cooling rate of no less than 4°C/second and no more than 50°C/second, the silicon crystal grains **1** and **2** will be deposited in such a manner that the primary-crystal silicon grains **1** have an average crystal grain size of no less than 12 μm and no more than 50 μm and that the eutectic silicon grains **2** have an average crystal grain size of 7.5 μm or less.

[0169] As described above, the cylinder block **100** of the present embodiment has an excellent abrasion resistance and seizing resistance, as well as a small friction loss, and therefore can be suitably used in the internal combustion engines of various types of transportation apparatuses. In particular, the cylinder block **100** is suitably used in any internal combustion engine that is operated at a high revolution speed (specifically, under a maximum revolution speed of 8000 rpm or more), e.g., an internal combustion engine of a motorcycle, whereby the durability of the internal combustion engine can be greatly improved.

[0170] FIG. **27** shows an exemplary internal combustion engine **150** incorporating the cylinder block **100** according to the present invention. The internal combustion engine **150** includes a crankcase **110**, a cylinder block **100**, and a cylinder head **130**.

[0171] A crankshaft **111** is accommodated within the crankcase **110**. The crankshaft **111** includes a crankpin **112** and a crank web **113**.

[0172] The cylinder block **100** is provided above the crankcase **110**. A piston **122** is inserted in a cylinder bore **102** of the cylinder block **100**. The piston **122** slides within the cylinder bore **102** while in contact with the slide surface **101** of the cylinder block **100**. The piston **122** is made of an aluminum alloy (typically, a silicon-containing aluminum alloy). The piston **122** can be formed by forging, as is disclosed in e.g. the specification of USP No. 6205836.

[0173] No cylinder sleeve is inserted in the cylinder bore **102**, and no plating is provided on the inner surface of the cylinder wall **103** of the cylinder block **100**. In other words, the primary-crystal silicon grains **1** and the eutectic silicon grains **2** are exposed on the inner surface, i.e., the slide surface **101**, of the cylinder bore wall **103**.

[0174] A cylinder head **130** is provided above the cylinder block **100**. Together with the piston **122** in the cylinder block **100**, the cylinder head **130** defines a combustion chamber **131**. The cylinder head **130** includes an intake port **132** and an exhaust port **133**. An intake valve **134** for supplying fuel-air mixture into the combustion chamber **131** is provided in the intake port **132**, and an exhaust valve **135** for performing evacuation of the combustion chamber **131** is provided in the exhaust port **133**.

[0175] The piston **122** and the crankshaft **111** are linked via a connecting rod **140**. Specifically, a piston pin **123** of the piston **122** is inserted in a throughhole in a small end **142** of the connecting rod **140**, and the crankpin **112** of the crankshaft **111** is inserted in a throughhole in a big end **144**, whereby the piston **122** and the crankshaft **111** are linked to each other. Roller bearings **114** are provided between the inner peripheral surface of the throughhole of the big end **144** and the crankpin **112**.

[0176] The internal combustion engine **150** shown in FIG. **27** has excellent durability because the cylinder block **100** of the present embodiment is incorporated, although lacking an oil pump for compulsorily supplying a lubricant. Since the cylinder block **100** of the present embodiment is characterized by a high abrasion resistance of the slide surface **101**, there is no need for a cylinder sleeve. Therefore, the production steps of the internal combustion engine **150** can be simplified, the weight of the internal combustion engine **150** can be reduced, and the cooling performance can be improved. Furthermore, since it is unnecessary to perform plating for the inner surface of the cylinder bore wall **103**, it is also possible to reduce production cost. Moreover, because the internal combustion engine **150** includes the cylinder block **100** of the present embodiment, a reduced the friction loss is obtained, and hence an improved fuel consumption.

[0177] FIG. **28** shows a motorcycle which incorporates the internal combustion engine **150** shown in FIG. **27**. In a motorcycle, the internal combustion engine **150** will be operated at a high revolution speed.

[0178] In the motorcycle shown in FIG. **28**, a head pipe **302** is provided at the front end of a body frame **301**. To the head pipe **302**, a front fork **303** is attached so as to be capable of swinging in the right-left direction of the vehicle. At

the lower end of the front fork **303**, a front wheel **304** is supported so as to be capable of rotating.

[0179] A seat rail **306** is attached at an upper portion of the rear end of the body frame **301** so as to extend in the rear direction. A fuel tank **307** is provided on the body frame **301**, and a main seat **308a** and a tandem seat **308b** are provided on the seat rail **306**.

[0180] Rear arms **309** extending in the rear direction are attached to the rear end of the body frame **301**. At the rear end of the rear arms **309**, a rear wheel **310** is supported so as to be capable of rotating.

[0181] At the central portion of the body frame **301**, the internal combustion engine **150** shown in FIG. **27** is held. The cylinder block **100** of the present embodiment is used for the internal combustion engine **150**. A radiator **311** is provided in front of the internal combustion engine **150**. An exhaust pipe **312** is connected to an exhaust port of the internal combustion engine **150**, and a muffler **313** is attached to the rear end of the exhaust pipe **312**.

[0182] A transmission **315** is linked to the internal combustion engine **150**. Driving sprockets **317** are attached on an output axis **316** of the transmission **315**. Via a chain **318**, the driving sprockets **317** are linked to rear wheel sprockets **319** of the rear wheel **310**. The transmission **315** and the chain **318** function as a transmitting mechanism for transmitting the motive power generated in the internal combustion engine **150** to the driving wheel.

[0183] According to the present invention, there is provided a cylinder block having an excellent abrasion resistance and seizing resistance and having a small friction loss, as well as a production method thereof.

[0184] The cylinder block according to the present invention can be suitably used in the internal combustion engines for various types of transportation apparatuses, and can be particularly suitably used for internal combustion engines which are operated at high revolution speeds and for internal combustion engines in which lubricant is not compulsorily supplied to a cylinder by means of a pump.

[0185] While the present invention has been described with respect to preferred embodiments thereof, it will be apparent to those skilled in the art that the disclosed invention may be modified in numerous ways and may assume many embodiments other than those specifically described above. Accordingly, it is intended by the appended claims to cover all modifications of the invention that fall within the true spirit and scope of the invention.

Claims

1. A cylinder block composed of an aluminum alloy containing silicon, comprising: a cylinder wall having a slide surface on which a piston slides; and a plurality of silicon crystal grains on the slide surface, wherein a ten point-average roughness Rz_{JIS} of the slide surface and a load length ratio $Rmr(30)$ of the slide surface at a cut level of 30% are larger in an upper 1/4 portion of the slide surface than in a lower 1/4 portion of the slide surface.
2. The cylinder block of claim 1, wherein, in the upper 1/4 portion of the slide surface, the ten point-average roughness Rz_{JIS} is 0.54 μm or more and the load length ratio $Rmr(30)$ at a cut level of 30% is 20% or more.
3. The cylinder block of claim 2, wherein, in the upper 1/4 portion of the slide surface, the ten point-average roughness Rz_{JIS} is 2.0 μm or less.
4. The cylinder block of claim 2 or 3, wherein, in the upper 1/4 portion of the slide surface, the load length ratio $Rmr(30)$ at a cut level of 30% is 55% or less.
5. The cylinder block of any of claims 1 to 4, wherein, in the lower 1/4 portion of the slide surface, the ten point-average roughness Rz_{JIS} is less than 0.54 μm and the load length ratio $Rmr(30)$ at a cut level of 30% is 15% or less.
6. The cylinder block of any of claims 1 to 5, wherein the slide surface has been subjected to an etching process.
7. A cylinder block composed of an aluminum alloy containing silicon, comprising: a cylinder wall having a slide surface on which a piston slides; and a plurality of silicon crystal grains on the slide surface, wherein, in an upper 1/4 portion of the slide surface, a ten point-average roughness Rz_{JIS} of the slide surface is 0.54 μm or more and a load length ratio $Rmr(30)$ of the slide surface at a cut level of 30% is 20% or more; and a coating is provided on at least a lower 1/4 portion of the slide surface.
8. The cylinder block of claim 7, wherein, in the upper 1/4 portion of the slide surface, the ten point-average roughness Rz_{JIS} is 2.0 μm or less.
9. The cylinder block of claim 7 or 8, wherein, in the upper 1/4 portion of the slide surface, the load length ratio $Rmr(30)$ at a cut level of 30% is 55% or less.

10. An internal combustion engine comprising:

the cylinder block of any of claims 1 to 9; and
a piston which slides while being in contact with the slide surface of the cylinder block.

5

11. The internal combustion engine of claim 10, wherein the piston is composed of an aluminum alloy.

12. A transportation apparatus comprising the internal combustion engine of claim 10 or 11.

10 13. A method for producing a cylinder block including a cylinder wall, the cylinder wall having a slide surface on which a piston slides, the method comprising:

a step of providing a molding which is composed of an aluminum alloy containing silicon;
a step of polishing a region of the surface of the molding to become the slide surface by using a hone having
a grit number of #1500 or more; and
a first etching step of etching only a portion of the polished region.

15

14. The method for producing a cylinder block of claim 13, further comprising, after the first etching step, a second etching step of etching the entire region.

20

15. The method for producing a cylinder block of claim 13, wherein no further etching step of etching the region is performed after the first etching step.

16. A method for producing a cylinder block including a cylinder wall, the cylinder wall having a slide surface on which a piston slides, the method comprising:

25

a step of providing a molding which is composed of an aluminum alloy containing silicon;
a step of polishing a region of the surface of the molding to become the slide surface by using a hone having
a grit number of #1500 or more;
an etching step of etching the polished region; and
a step of providing a coating in only a portion of the etched region.

30

35

40

45

50

55

FIG. 1

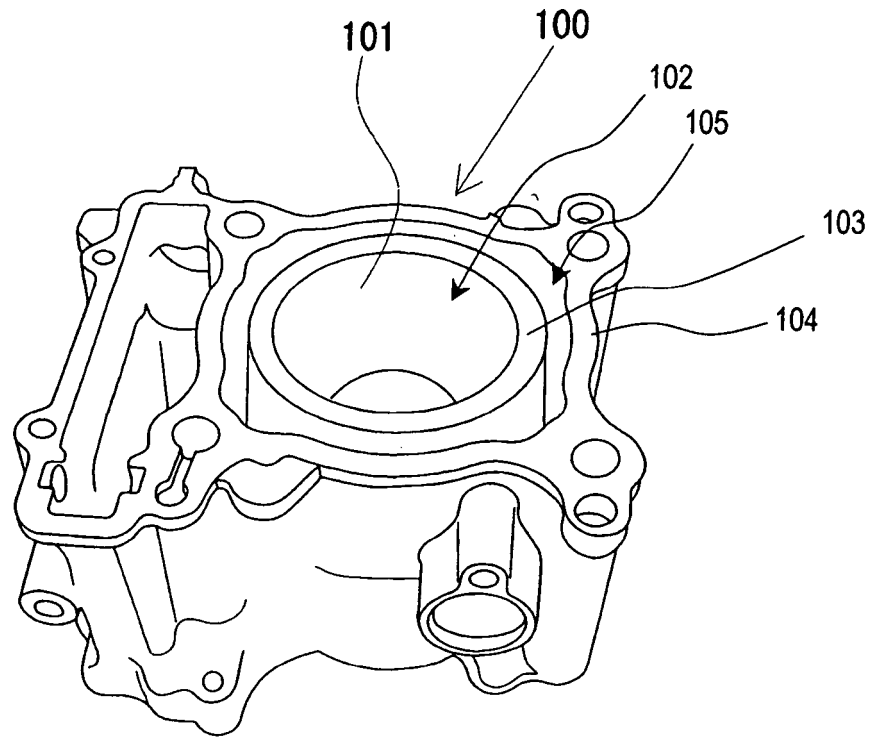


FIG. 2

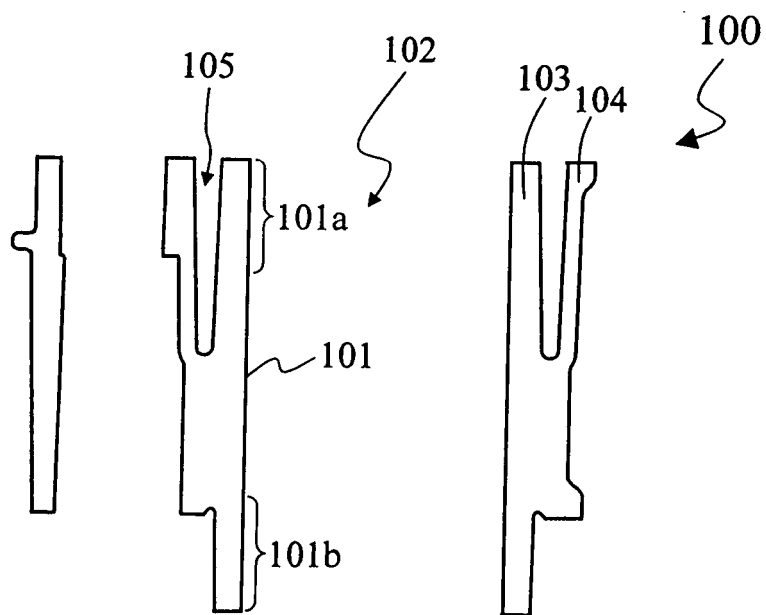


FIG. 3

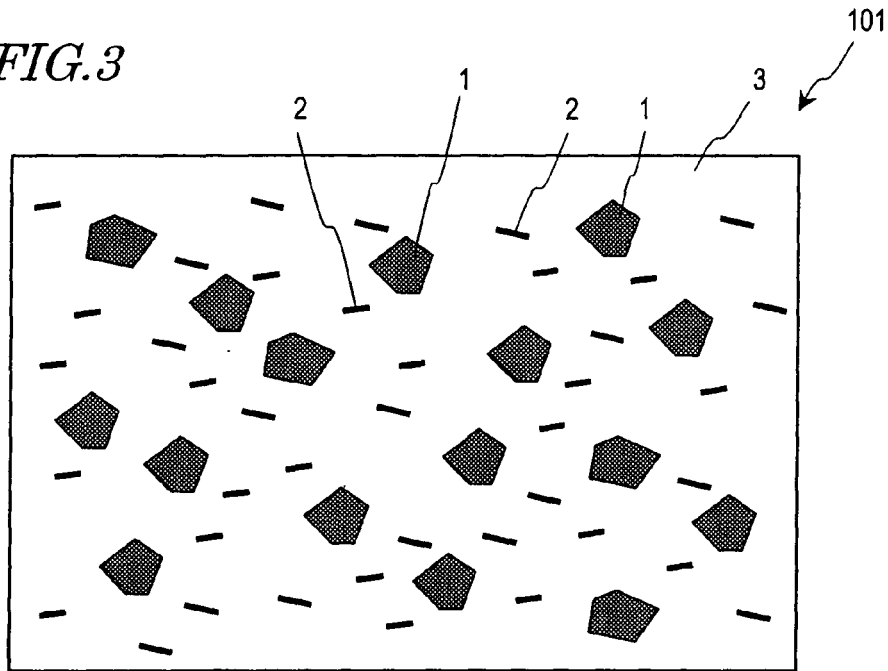


FIG. 4

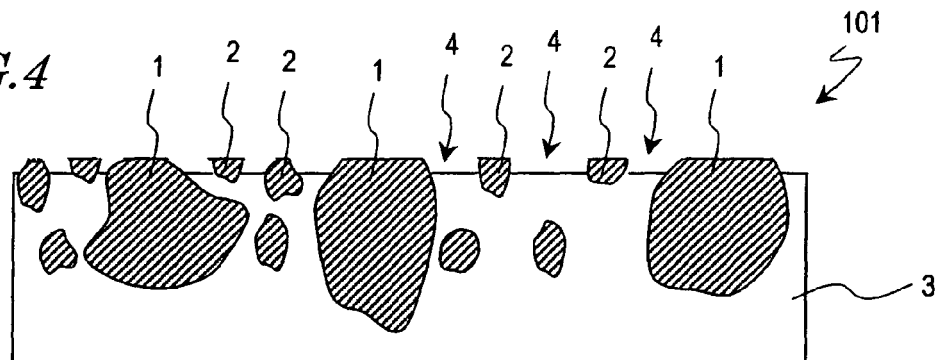


FIG. 5

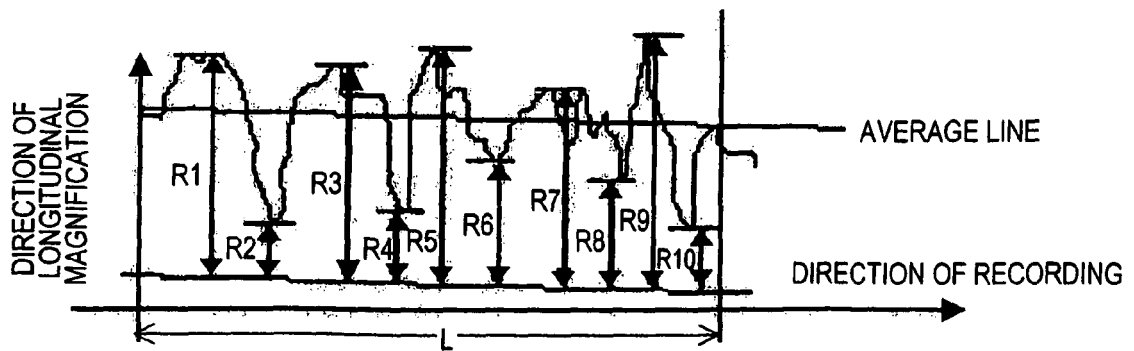


FIG. 6

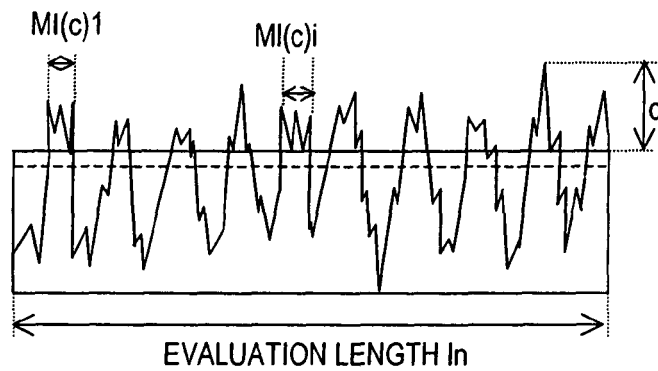


FIG. 7

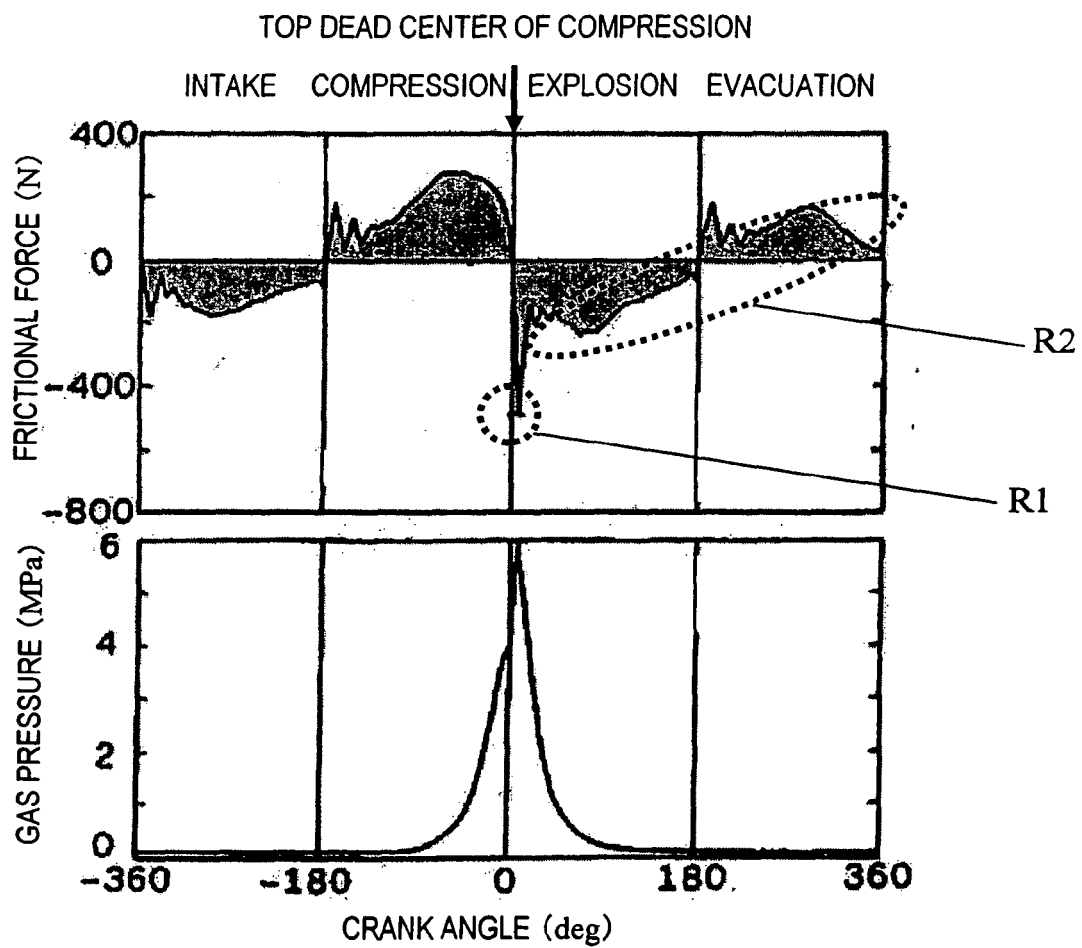


FIG. 8A

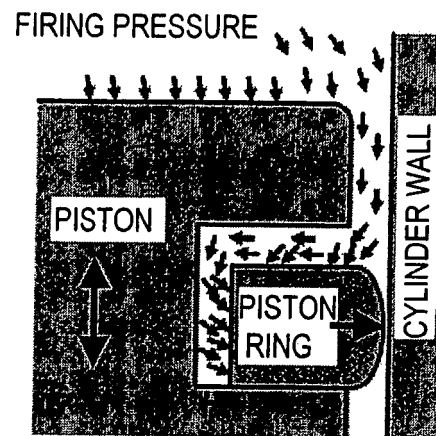


FIG. 8B

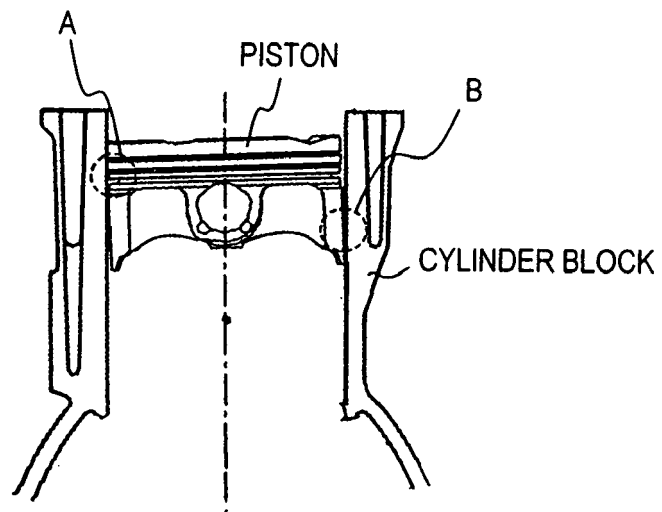


FIG. 9

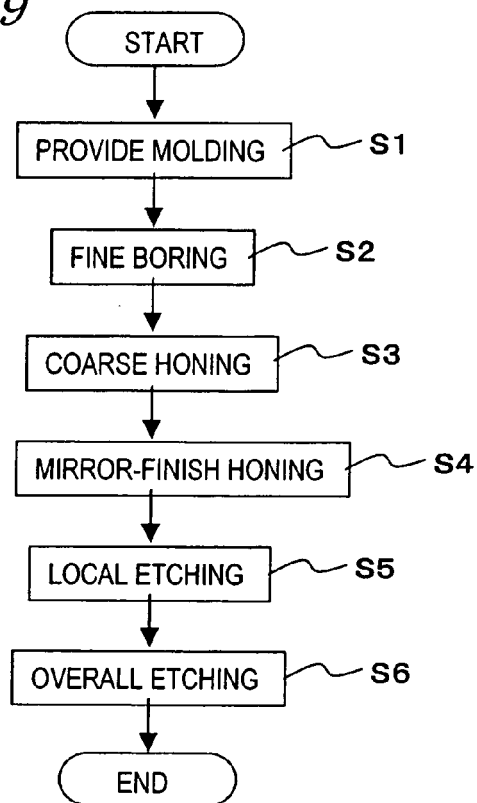


FIG. 10

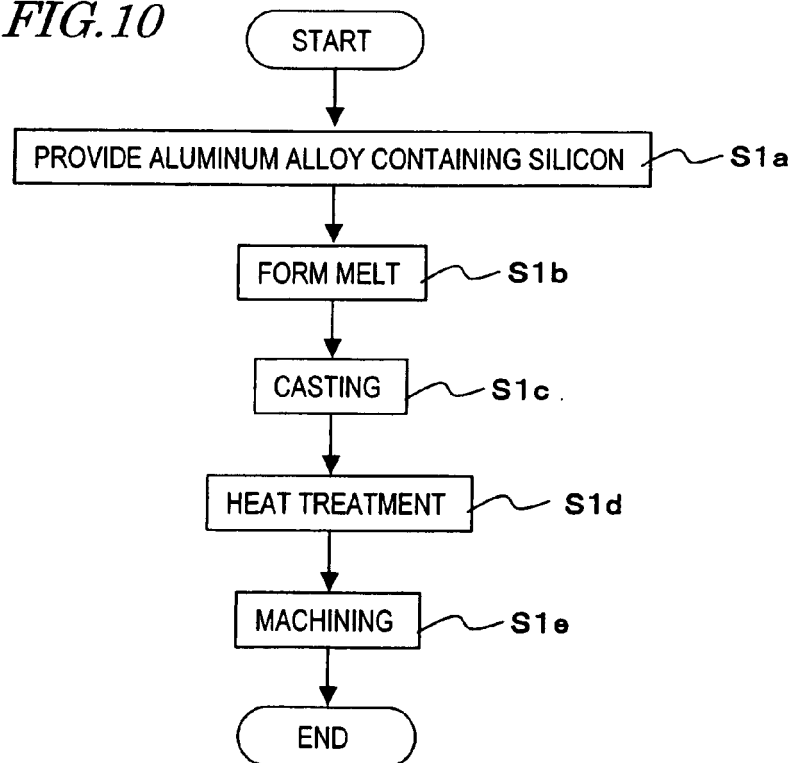


FIG. 11A

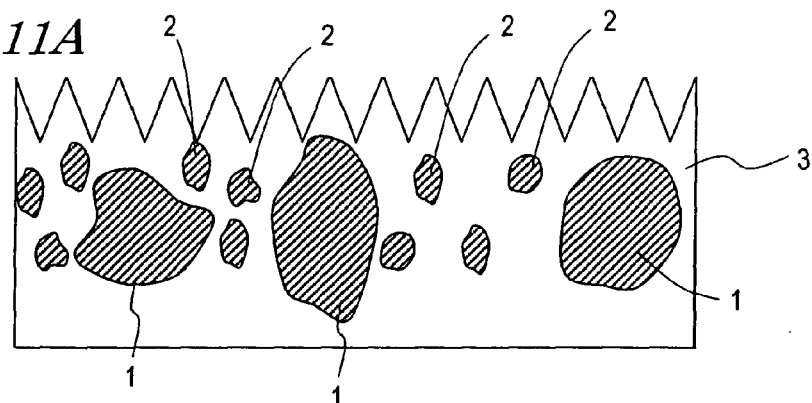


FIG. 11B

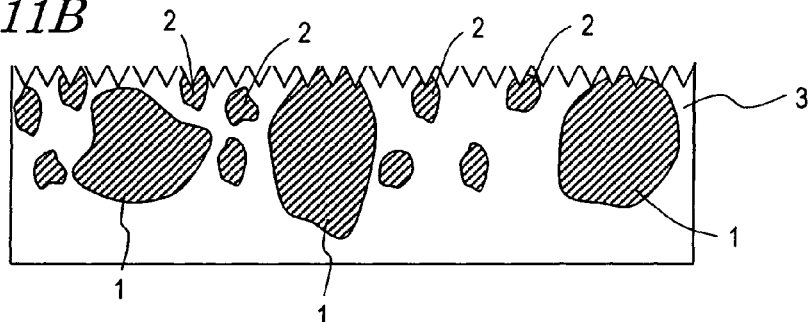


FIG. 11C

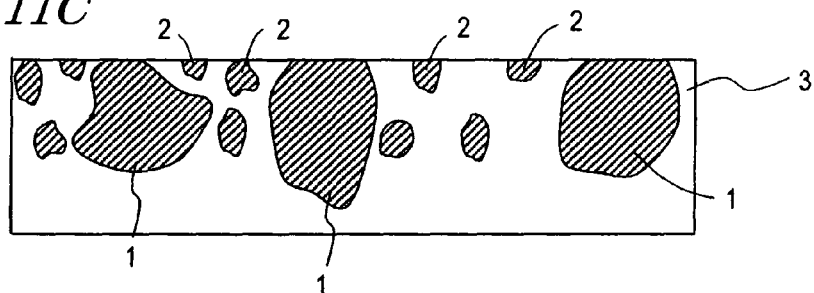


FIG. 11D

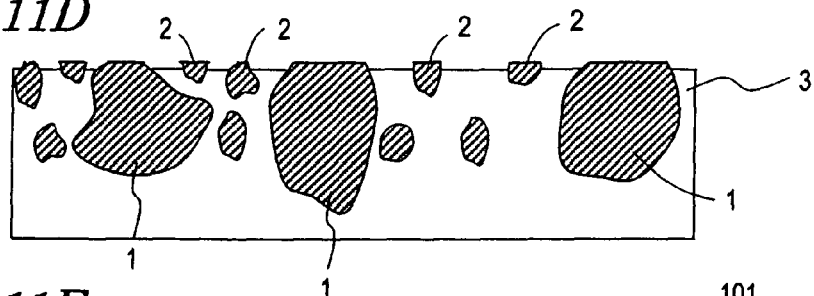


FIG. 11E

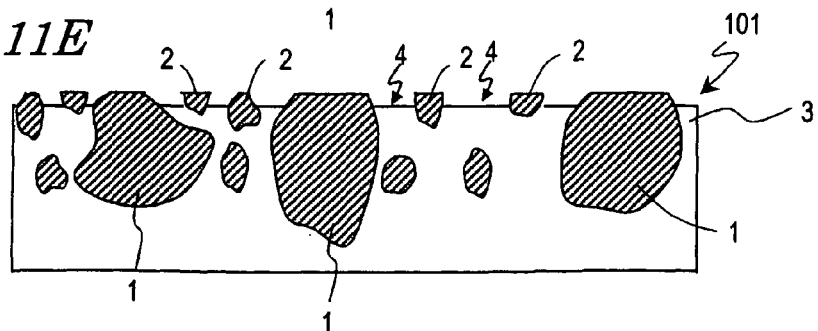


FIG. 12A

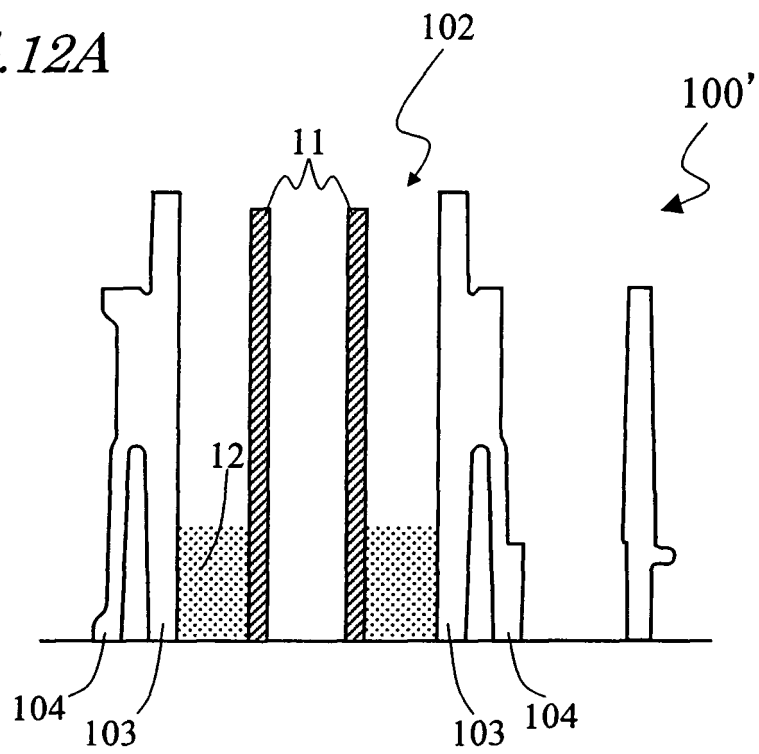


FIG. 12B

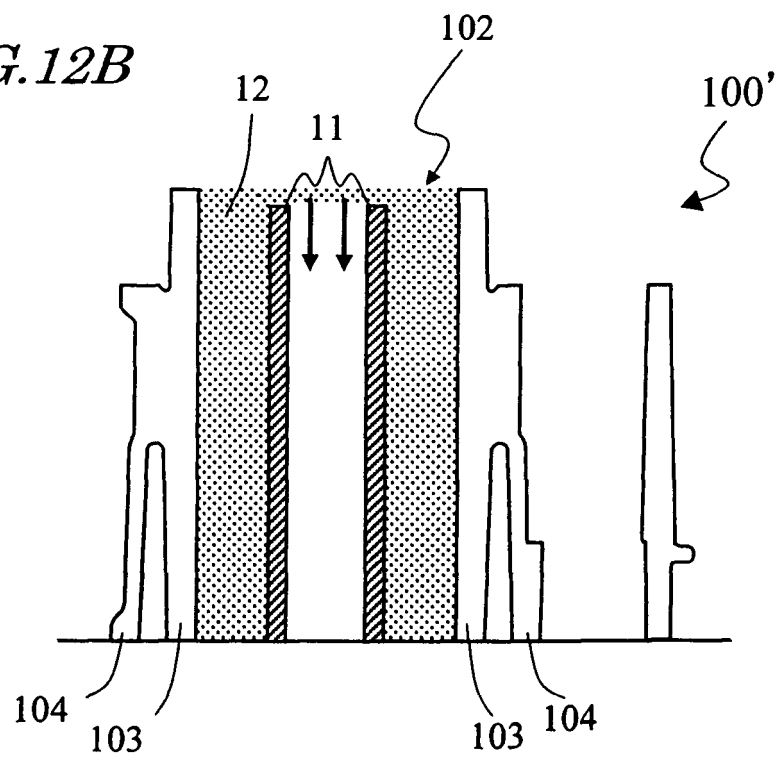


FIG.13

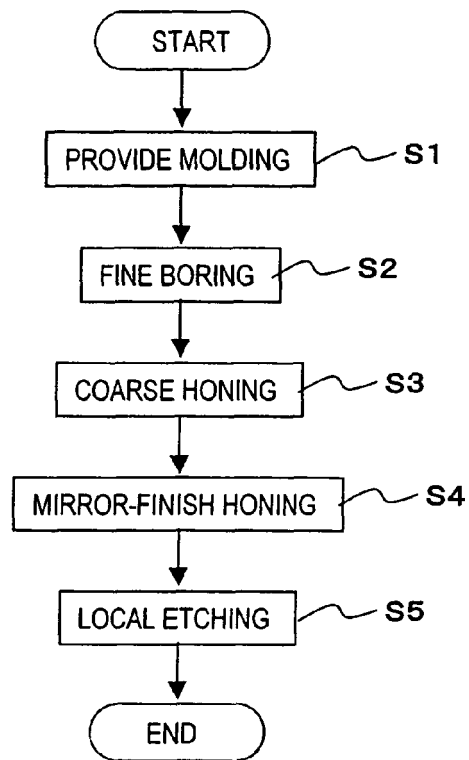


FIG.14

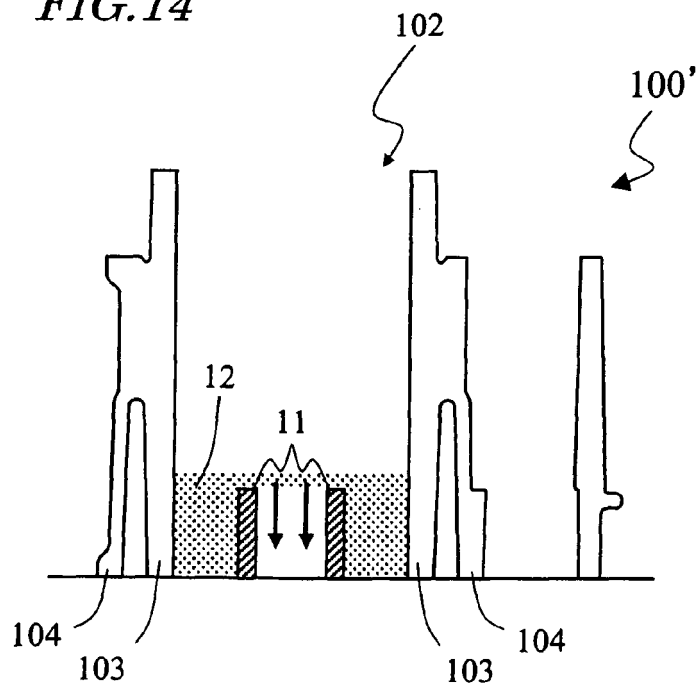
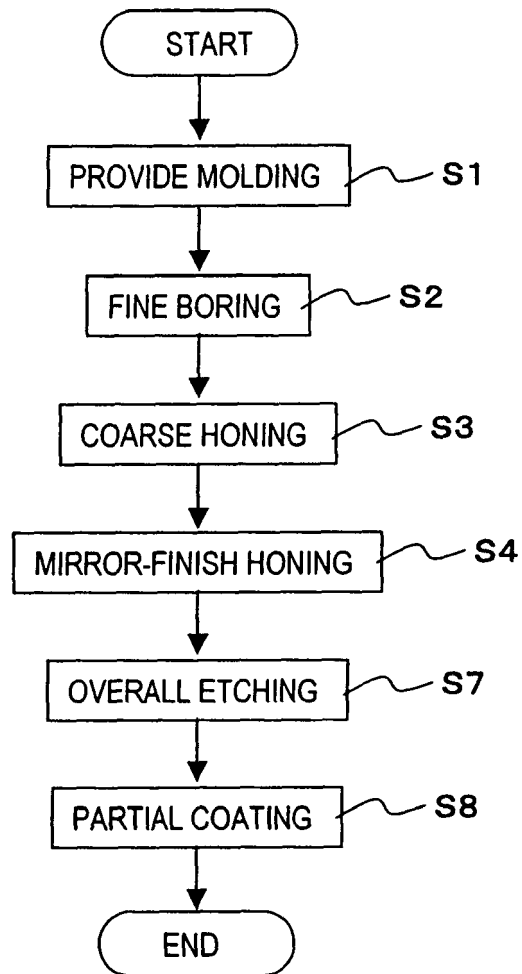


FIG.15

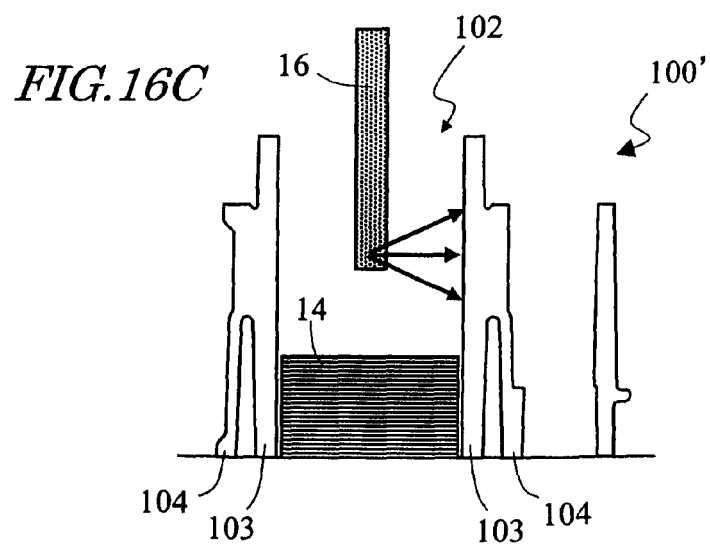
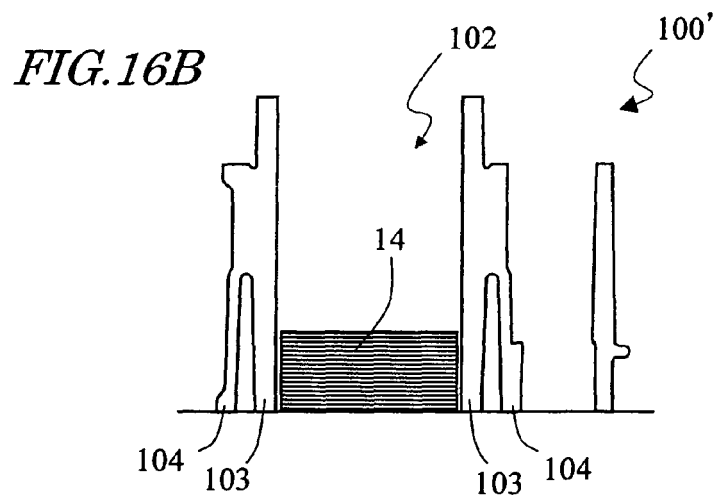
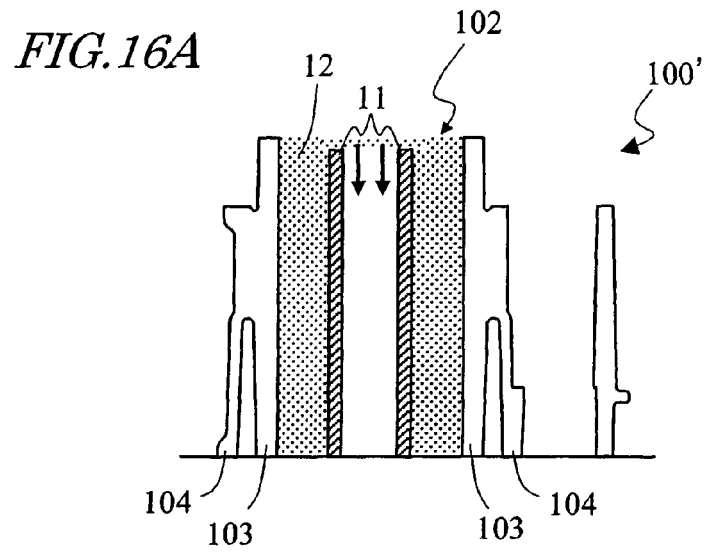


FIG.17A

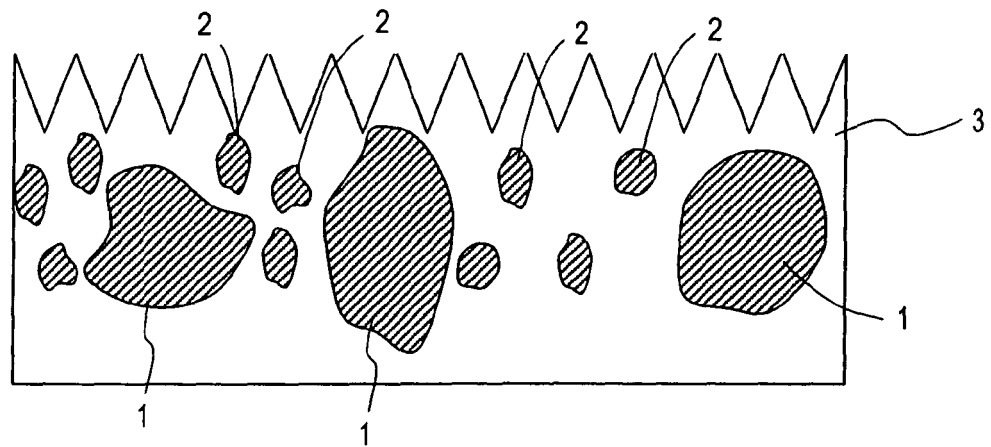


FIG.17B

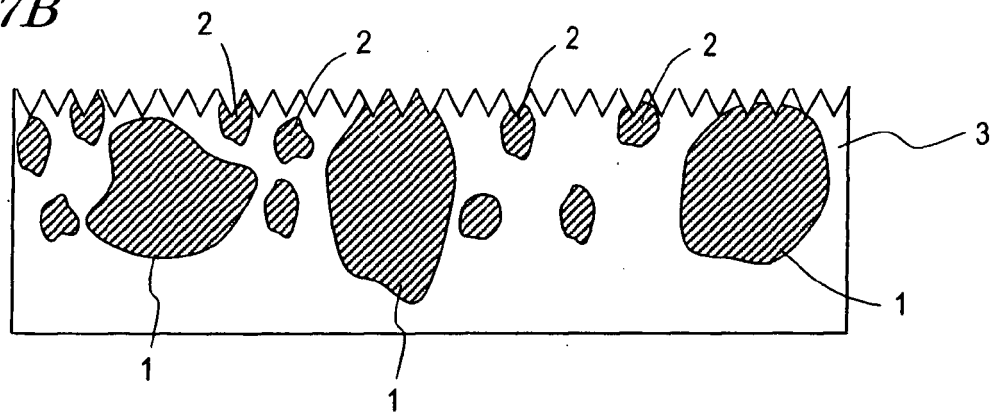


FIG.17C

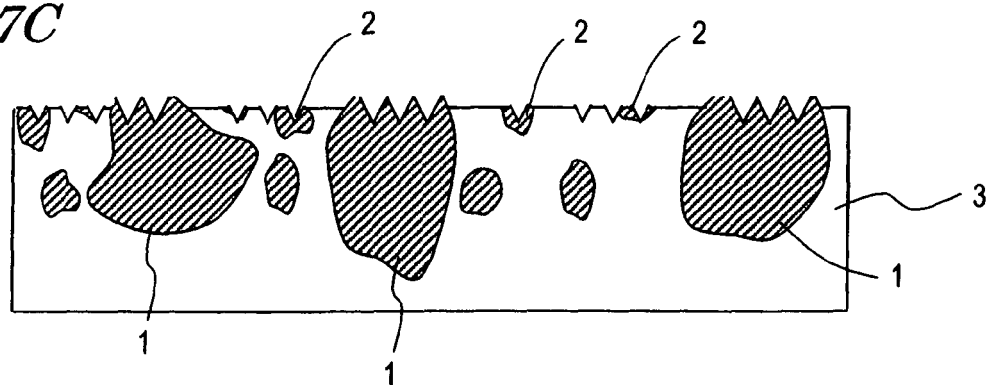


FIG.18A

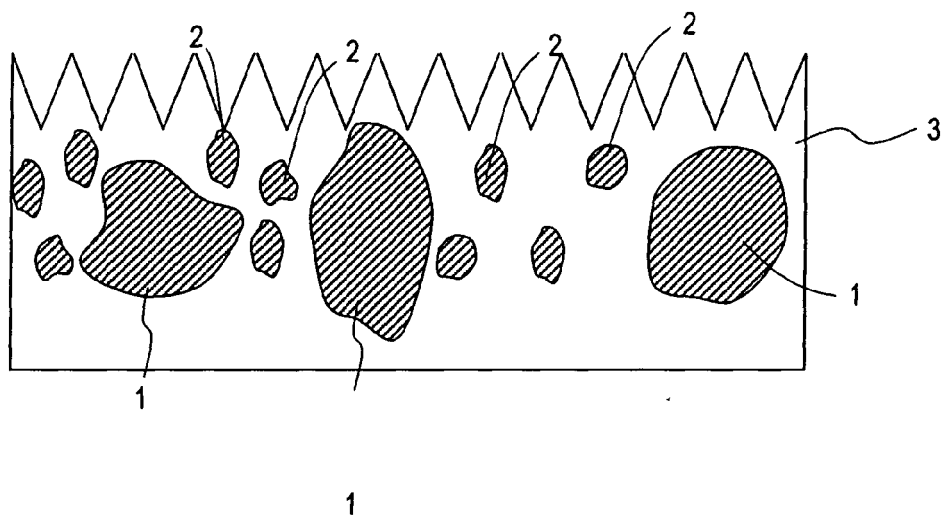


FIG.18B

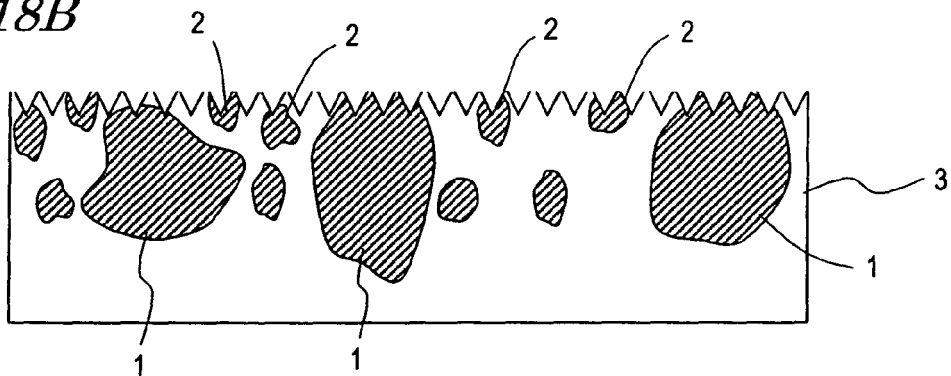


FIG.18C

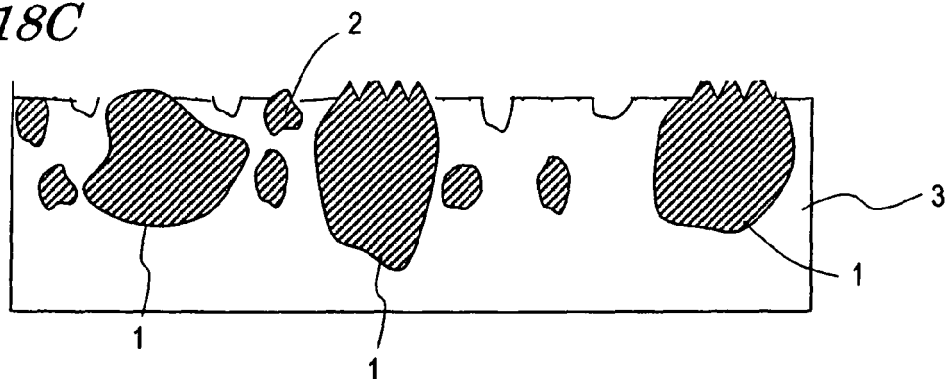


FIG.19

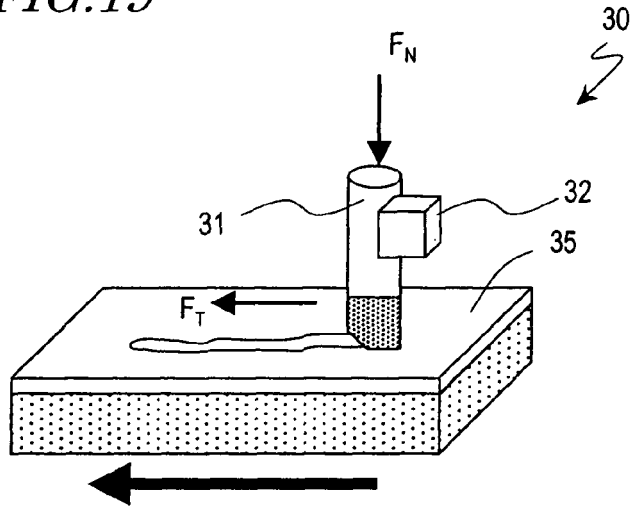


FIG.20

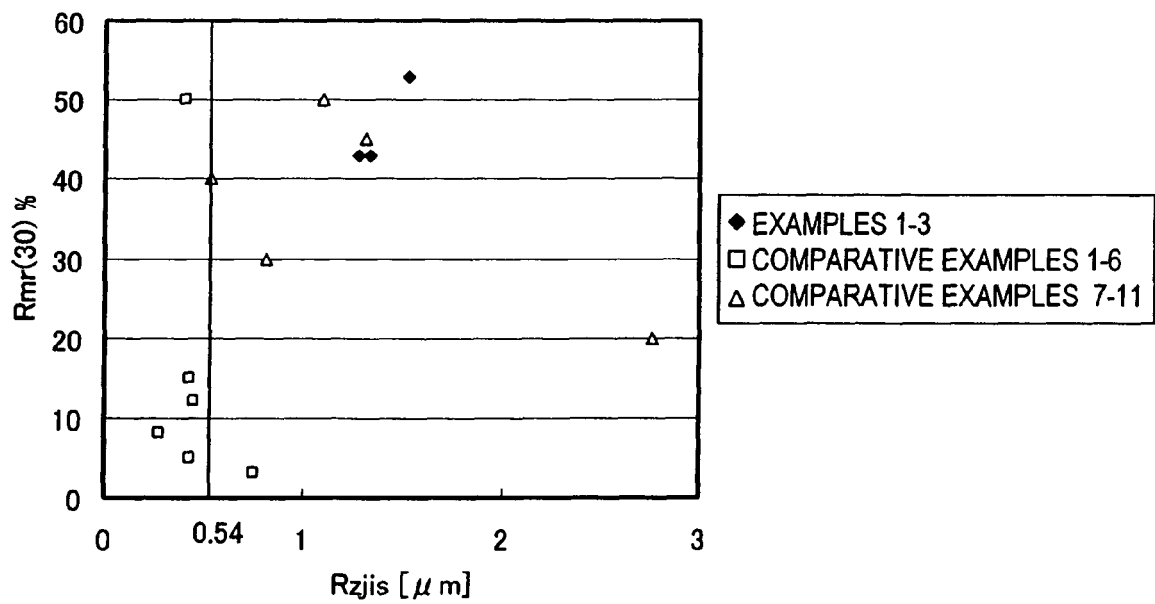


FIG.21

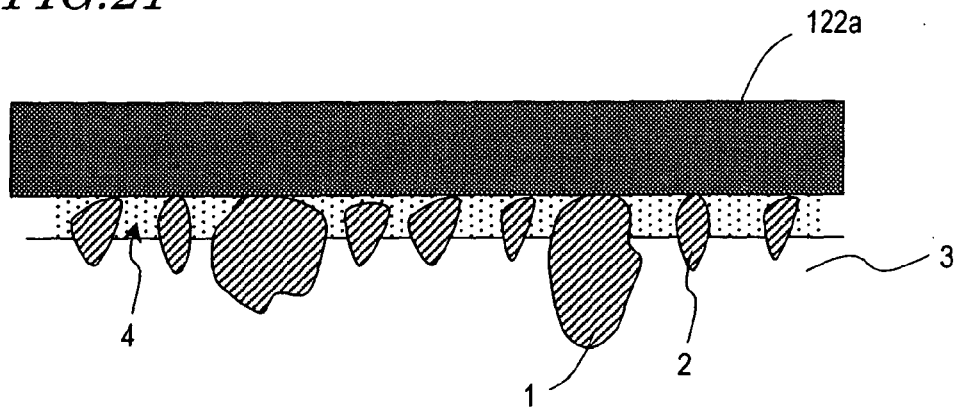


FIG.22

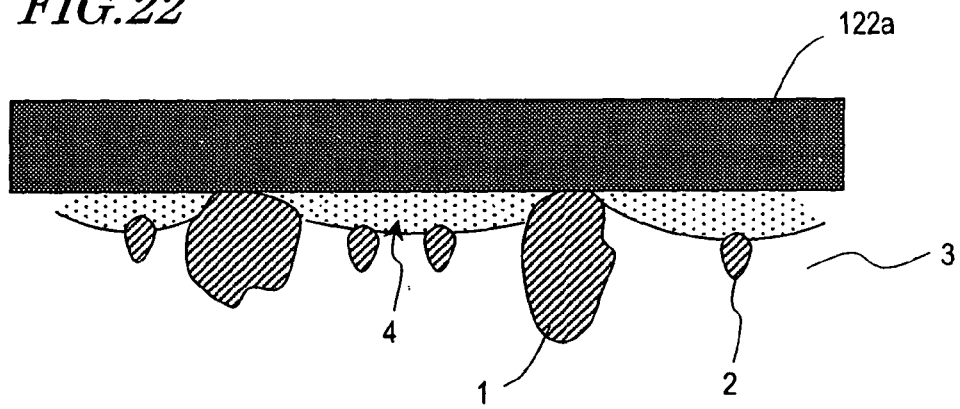


FIG.23

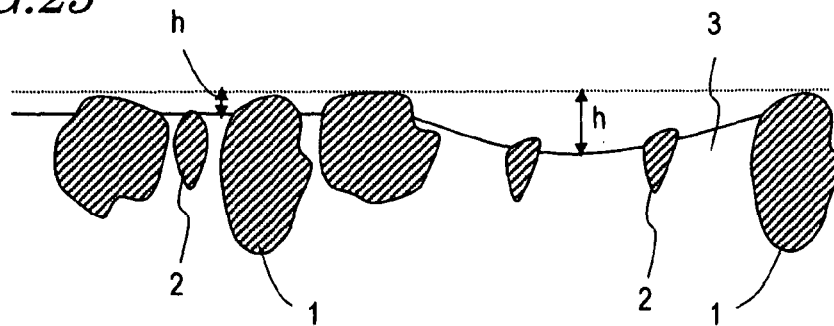


FIG.24

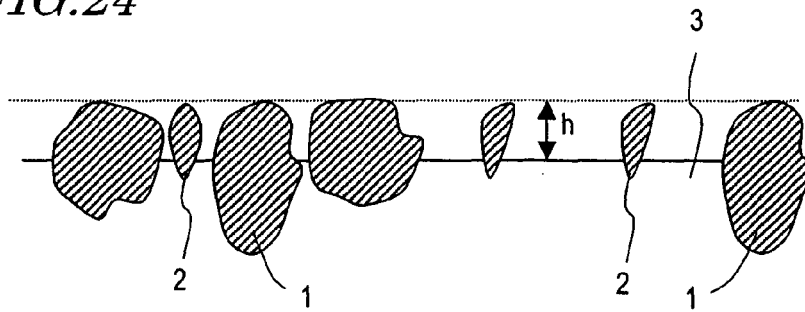


FIG.25

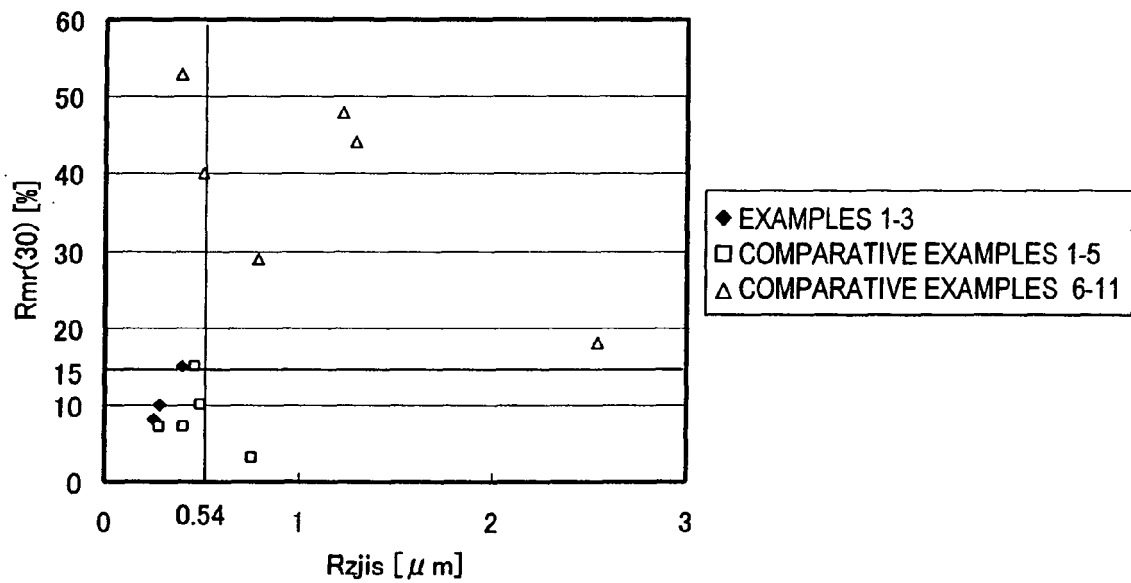


FIG.26

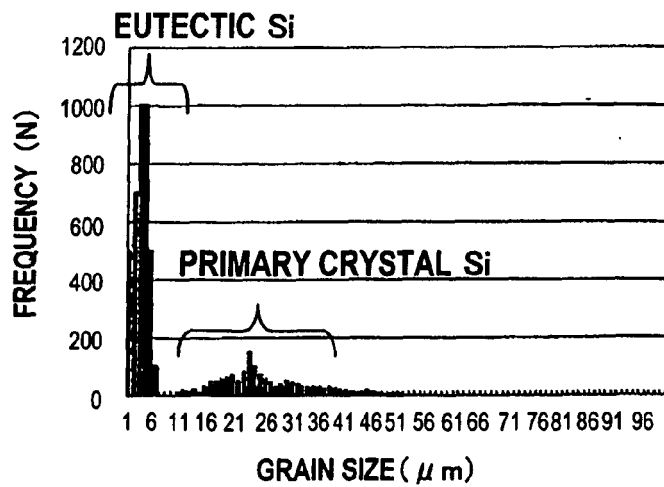
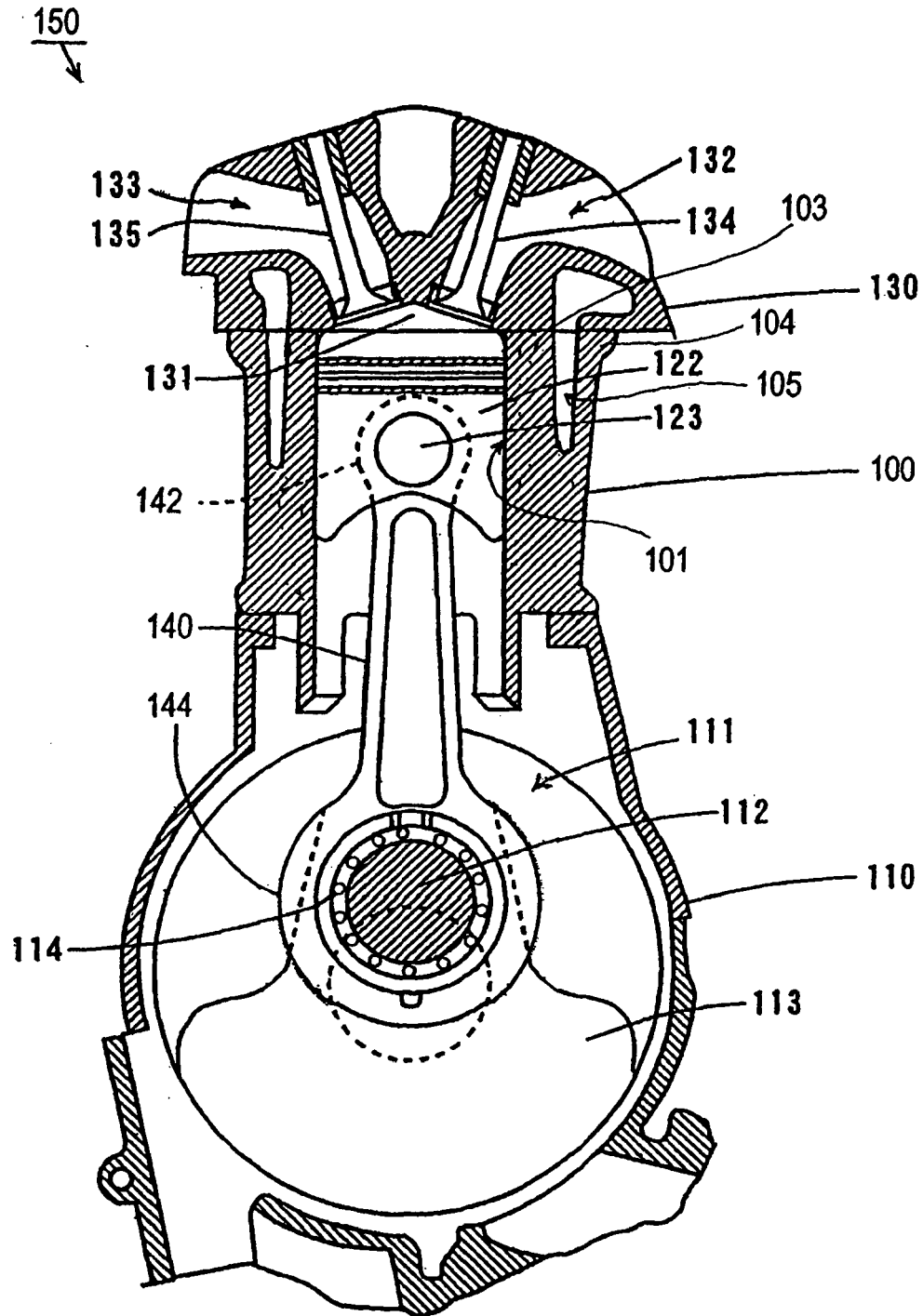


FIG. 27



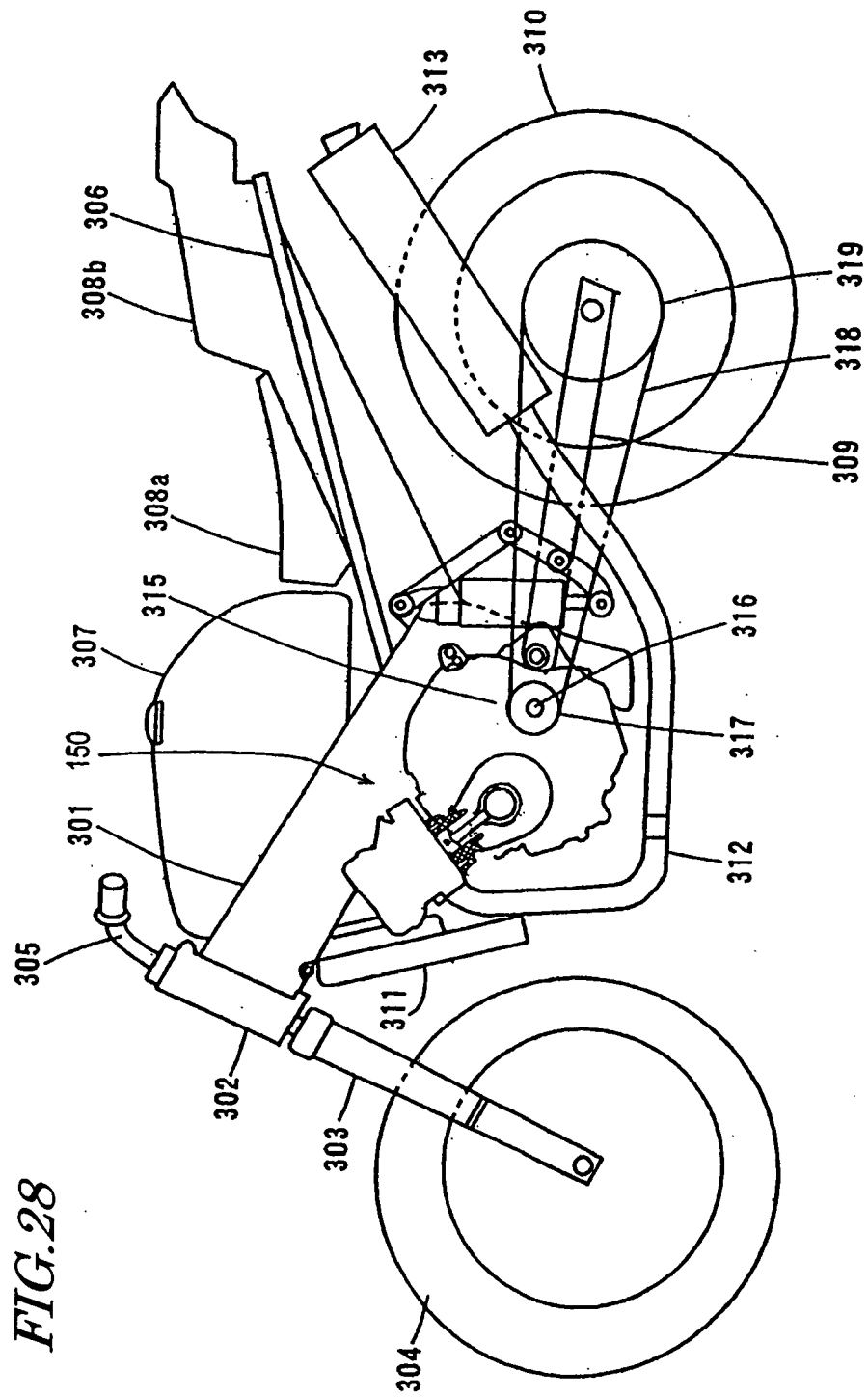


FIG. 28

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 2885407 B [0003]
- JP 2007329164 A [0008] [0009]
- WO 2004002658 A [0112] [0135]
- JP 2004268179 A [0116] [0117] [0137]
- US 6205836 B [0172]