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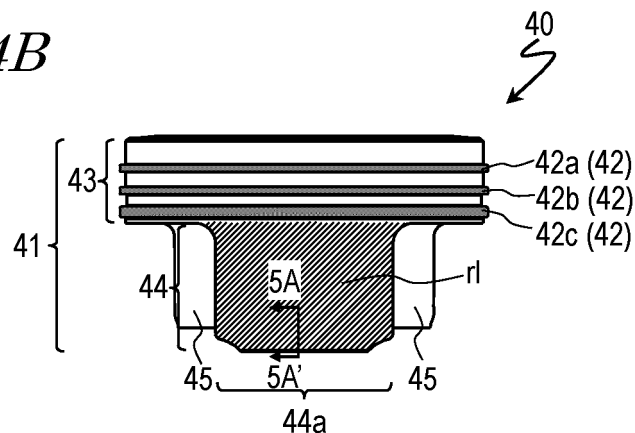
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(54) **INTERNAL COMBUSTION ENGINE AND TRANSPORT EQUIPMENT**

(57) An internal combustion engine (100) includes a piston (40) formed of an aluminum alloy, the piston including a piston head (43) and a piston skirt (44) extending from an outer circumferential portion of the piston head; and a cylinder block (10) including a cylinder wall (12) including a sliding surface (12a), along which the

piston is slidable. The cylinder block is formed of an aluminum alloy containing silicon, and includes a plurality of primary-crystal silicon grains (2) at the sliding surface. The piston skirt includes a resin layer (rl) formed on at least a part of an outer circumferential surface thereof.

FIG. 4B



Description**TECHNICAL FIELD**

[0001] The present disclosure relates to an internal combustion engine, and specifically to an internal combustion engine including a cylinder block formed of an aluminum alloy containing silicon, and also relates to a transportation vehicle including such an internal combustion engine.

BACKGROUND ART

[0002] Recently, for the purpose of reducing the weight of an engine (internal combustion engine), the material of a cylinder block is progressively shifted from cast iron to an aluminum alloy. Especially, use of a high-silicon aluminum alloy containing a high content of silicon (i.e., having a hyper eutectic composition) makes it unnecessary to use a sleeve to be fit into a cylinder bore. This may further reduce the weight of the engine and also reduce the size of the engine because of a shorter inter-cylinder distance realized.

[0003] A cylinder block formed of a high-silicon aluminum alloy contains silicon crystal grains standing out at a sliding surface, and therefore, has an improved wear resistance. In addition, since oil is held at a step portion between an aluminum alloy substrate and the silicon crystal grains, the cylinder block has an improved seizure resistance and an improved scuff resistance. It should be noted that, however, if the silicon crystal grains at the sliding surface are crushed, the wear resistance is declined. Therefore, a processing method has been proposed to realize a state where such crushed crystal grains are prevented, to a maximum possible degree, from being present at the sliding surface (e.g., Patent Document No. 1).

CITATION LIST**PATENT LITERATURE**

[0004] Patent Document No. 1: Japanese Laid-Open Patent Publication No. Hei 7-88711

SUMMARY OF INVENTION**TECHNICAL PROBLEM**

[0005] However, when the internal combustion engine is operated for the first time, the silicon crystal grains present at the sliding surface partially fall and damage a surface of a cylinder wall, which causes oil to be consumed in a deteriorated manner.

[0006] An embodiment of the present invention made in light of the above-described problem has an object of, in an internal combustion engine including a cylinder block formed of an aluminum alloy containing silicon, suppressing damage of a surface of a cylinder wall when the internal combustion engine is operated for the first time and thus suppressing oil consumption made in a deteriorated manner.

SOLUTION TO PROBLEM

[0007] This specification discloses the internal combustion engine and the transportation vehicle described in the following items.

[Item 1]

[0008] An internal combustion engine, including:

a piston formed of an aluminum alloy, the piston including a piston head and a piston skirt extending from an outer circumferential portion of the piston head; and
a cylinder block including a cylinder wall including a sliding surface, along which the piston is slidable;
wherein the cylinder block is formed of an aluminum alloy containing silicon, and includes a plurality of primary-crystal silicon grains at the sliding surface; and
wherein the piston skirt includes a resin layer formed on at least a part of an outer circumferential surface thereof.

[0009] In the internal combustion engine according to an embodiment of the present invention, the piston skirt includes

the resin layer formed on at least a part of the outer circumferential surface thereof. The resin layer is softer than an aluminum alloy substrate (matrix) of the cylinder block. Therefore, even if the primary-crystal silicon grains at the sliding surface of the cylinder wall fall, the primary-crystal silicon grains that have fallen are pushed into the resin layer, and thus damage of the surface of the cylinder wall is suppressed (namely, the cylinder wall is protected). On the piston side, piston rings protrude to an outermost position. Therefore, there is no problem even if a surface of the resin layer is damaged. Since the damage of the surface of the cylinder wall is suppressed, oil (lubricant oil) attached to the cylinder wall is scraped off appropriately by the piston rings. Therefore, oil consumption made in a deteriorated manner may be suppressed.

[0010] The resin layer of the piston skirt prevents heat transfer from the piston skirt to the cylinder wall. Therefore, after the engine is started, the piston is warmed promptly, and an appropriate size of gap is made between the piston skirt and the cylinder wall. This may quickly suppress noise generated immediately after the engine is started, and may also suppress wearing and adhesion of the piston and the cylinder wall.

[0011] After the resin layer of the piston skirt disappears as a result of the engine being operated for a certain period of time, a bare surface of the piston skirt (portion covered with the resin layer) and the cylinder wall contact each other. In the engine according to this embodiment, the primary-crystal silicon grains are present at the sliding surface of the cylinder wall, and silicon has a heat conductivity lower than that of aluminum. Therefore, the heat is not easily transferred from the piston skirt to the cylinder block. For this reason, even after the resin layer disappears, the piston is warmed promptly, which may suppress noise generated immediately after the engine is started, and may also suppress wearing and adhesion of the piston and the cylinder wall.

[Item 2]

[0012] The internal combustion engine of item 1,

wherein the piston includes a plurality of piston rings attached to the outer circumferential portion of the piston head, and
wherein each of the plurality of piston rings includes a diamond-like carbon layer on an outer circumferential surface thereof.

[0013] In the case where each of the piston rings includes the diamond-like carbon layer on the outer circumferential surface thereof, the heat of the piston is prevented from being transferred easily to the cylinder block. This makes it easier to warm the piston after the engine is started.

[Item 3]

[0014] The internal combustion engine of item 1 or 2, wherein the resin layer includes a solid lubricant agent and hard particles.

[0015] In the case where the resin layer includes hard particles, wearing of the resin layer may be delayed.

[Item 4]

[0016] The internal combustion engine of any one of items 1 through 3, wherein the resin layer has a thickness of 10 μm or greater and 50 μm or less.

[0017] From the point of view of keeping the resin layer for a long period of time, the thickness of the resin layer is preferably 10 μm or greater. From the point of view of ease of production, the thickness of the resin layer is preferably 50 μm or less.

[Item 5]

[0018] The internal combustion engine of any one of items 1 through 4, wherein the cylinder block is formed of an aluminum alloy containing silicon at a content of 15% by mass or higher and 25% by mass or lower.

[0019] From the point of view of sufficiently improving the wear resistance and the strength of the cylinder block, the aluminum alloy as the material of the cylinder block preferably contains silicon at a content of 15% by mass or higher and 25% by mass or lower. In the case where the silicon content is 15% by mass or higher, a sufficiently large amount of the primary-crystal silicon grains may be deposited, which may sufficiently improve the wear resistance of the cylinder block. In the case where the silicon content is 25% by mass or lower, the strength of the cylinder block may be kept sufficiently high.

[Item 6]

[0020] The internal combustion engine of any one of items 1 through 5, wherein the plurality of primary-crystal silicon grains have an average grain diameter of 8 μm or longer and 50 μm or shorter.

[0021] In the case where the primary-crystal silicon grains have an average grain diameter in the range of 8 μm or longer and 50 μm or shorter, the damage of the surface of the cylinder wall may be suppressed with more certainty.

[0022] In the case where the average grain diameter of the primary-crystal silicon grains is longer than 50 μm , the number of the primary-crystal silicon grains per unit area size of the sliding surface is small. Therefore, a large load is applied to each of the primary-crystal silicon grains while the engine is operated, and the primary-crystal silicon grains may possibly be crushed. The crushed pieces of the primary-crystal silicon grains act undesirably as polishing particles, which causes a risk that the surface of the cylinder wall is damaged.

[0023] In the case where the average grain diameter of the primary-crystal silicon grains is shorter than 8 μm , merely a small part of the primary-crystal silicon grains is embedded in the matrix. Therefore, the primary-crystal silicon grains easily fall while the engine is operated. The primary-crystal silicon grains that have fallen act undesirably as polishing particles, which causes a risk that the surface of the cylinder wall is damaged.

[0024] By contrast, in the case where the average grain diameter of the primary-crystal silicon grains is 8 μm or longer and 50 μm or shorter, the primary-crystal silicon grains are present in a sufficient number per unit area size of the sliding surface. Therefore, the load applied to each of the primary-crystal silicon grains while the engine is operated is relatively small, which suppresses the crushing of the primary-crystal silicon grains. Since the part of the primary-crystal silicon grains that is embedded in the matrix is sufficiently large, the fall of the primary-crystal silicon grains is suppressed. Therefore, the damage of the surface of the cylinder by the primary-crystal silicon grains that have fallen is suppressed.

[Item 7]

[0025] The internal combustion engine of any one of items 1 through 6, wherein the plurality of primary-crystal silicon grains have an area size occupying a ratio of 8% or higher of the sliding surface.

[0026] In the case where the area size of the primary-crystal silicon grains occupies a ratio of 8% or higher of the sliding surface, the surface pressure applied to the alloy substrate is decreased. Therefore, the primary-crystal silicon grains do not easily fall, which may suppress the damage of the surface of the cylinder wall with more certainty. In addition, the piston is easily warmed.

[Item 8]

[0027] The internal combustion engine of any one of items 1 through 7, wherein where the sliding surface is divided into a plurality of grids each having a size of 0.1 mm $\times$ 0.1 mm and the ratio of the number of grids where no primary-crystal silicon grain is present with respect to the total number of the grids is referred to as a "blank ratio", the blank ratio is 55.5% or lower.

[0028] The "blank ratio" is an index indicating how the primary-crystal silicon grains are dispersed. A lower blank ratio indicates that the primary-crystal silicon grains are better dispersed. In the case where the blank ratio of the sliding surface is 55.5% or lower, the surface pressure applied to the alloy substrate is sufficiently decreased. Therefore, the primary-crystal silicon grains do not easily fall, which may suppress the damage of the surface of the cylinder wall with more certainty. In addition, the piston is easily warmed.

[Item 9]

[0029] The internal combustion engine of any one of items 1 through 8, wherein the plurality of primary-crystal silicon grains have a crushing ratio of 20% or lower at the sliding surface.

[0030] In the case where the crushing ratio of the primary-crystal silicon grains at the sliding surface of the cylinder wall is 20% or lower, a large number of the primary-crystal silicon grains that are not crushed (that may be referred to as "healthy") are exposed at the sliding surface. Therefore, the surface pressure applied to the alloy substrate is sufficiently decreased. For this reason, the primary-crystal silicon grains do not easily fall, which may suppress the damage of the surface of the cylinder wall with more certainty.

[Item 10]

[0031] A transportation vehicle, including the internal combustion engine of any one of items 1 through 9.

[0032] The internal combustion engine according to an embodiment of the present invention is preferably usable in any of various types of transportation vehicles.

ADVANTAGEOUS EFFECTS OF INVENTION

[0033] According to an embodiment of the present invention, in an internal combustion engine including a cylinder block formed of an aluminum alloy containing silicon, when the internal combustion engine is operated for the first time, damage of a surface of a cylinder wall is suppressed, and thus oil consumption made in a deteriorated manner is suppressed.

BRIEF DESCRIPTION OF DRAWINGS

[0034]

FIG. 1 is a cross-sectional view schematically showing an engine (internal combustion engine) **100** according to an embodiment of the present invention.

FIG. 2 is a perspective view schematically showing a cylinder block **10** included in the engine **100**.

FIG. 3 is an enlarged plan view of a sliding surface **12a** of a cylinder wall **12**.

FIG. 4A is a side view schematically showing a piston **40** included in the engine **100**.

FIG. 4B is a side view schematically showing the piston **40**.

FIG. 5 is a cross-sectional view schematically showing a piston skirt **44** of the piston **40**.

FIG. 6 is a cross-sectional view schematically showing a piston ring **42** of the piston **40**.

FIG. 7 shows an example of image of the sliding surface **12a**.

FIG. 8 is a view provided to illustrate the definition of a blank ratio of the sliding surface **12a**.

FIG. 9 is a side view schematically showing an automatic two-wheeled vehicle including the engine **100**.

DESCRIPTION OF EMBODIMENTS

[0035] Hereinafter, an embodiment of the present invention will be described with reference to the drawings. While a water-cooled engine will be described as an example below, the engine according to an embodiment of the present invention is not limited to being of a water-cooled type and may be of an air-cooled type. While a single-cylinder engine will be described as an example below, there is no specific limitation on the number of the cylinders in the engine.

[Structure of the engine]

[0036] FIG. 1 shows an engine (internal combustion engine) **100** according to an embodiment of the present invention. FIG. 1 is a cross-sectional view schematically showing the engine **100**.

[0037] As shown in FIG. 1, the engine **100** includes a cylinder block **10**, a cylinder head **20**, and a crankcase **30**. The engine **100** further includes a piston **40**, a crankshaft **50**, and a con rod (connecting rod) **60**. The following description will be made with settings that a direction from the cylinder block **10** toward the cylinder head **20** is an "upward direction" and a direction from the cylinder block **10** toward the crankcase **30** is a "downward direction".

[0038] The cylinder block (may also be referred to as a "cylinder body") **10** includes a cylinder wall **12** and an outer wall **13**. The cylinder wall **12** is formed to define a cylinder bore **11**. The outer wall **13** surrounds the cylinder wall **12** and forms an outer enclosure of the cylinder block **10**. A water jacket **14** holding cooling water is provided between the cylinder wall **12** and the outer wall **13**.

[0039] The cylinder head **20** is provided above the cylinder block **10**. The cylinder head **20** defines a combustion chamber **70** together with the cylinder wall **12** and the piston **40**. The cylinder head **20** includes an intake port **21**, through which fuel is to be introduced into the combustion chamber **70**, and an exhaust port **22**, through which exhaust gas is to be discharged from the combustion chamber **70**. An intake valve **23** is provided in the intake port **21**, and an exhaust valve **24** is provided in the exhaust port **22**.

[0040] The crankcase **30** is provided below the cylinder block **10**. Namely, the crankcase **30** is located so as to be on the side opposite to the cylinder head **20** with the cylinder block **10** being located therebetween. The crank case **30** may be separate from, or may be integrally formed with, the cylinder block **10**.

[0041] The piston **40** is accommodated in the cylinder bore **11**. In this embodiment, no cylinder sleeve is fit into the cylinder bore **11**. Therefore, the piston **40** moves up and down in a reciprocating manner in the cylinder bore **11** while being in contact with an inner circumferential surface (cylinder bore **11**-side surface) **12a** of the cylinder wall **12**. Namely, the inner circumferential surface **12a** of the cylinder wall **12** is a sliding surface along which the piston **40** is slidable.

[0042] The crankshaft **50** is accommodated in the crankcase **30**. The crankshaft **50** includes a crankpin **51** and a crank arm **52**.

[0043] The con rod **60** includes a rod main body **61** having a rod-like shape, a small end portion **62** provided at one end of the rod main body **61**, and a large end portion **63** provided at the other end of the rod main body **61**. The con rod

60 connects the piston **40** and the crankshaft **50** to each other. Specifically, a piston pin **48** of the piston **40** is inserted into a through-hole (piston pin hole) of the small end portion **62**, and the crankpin **51** of the crankshaft **50** is inserted into a through-hole (crankpin hole) of the large end portion **63**. This structure connects the piston **40** and the crankshaft **50** to each other. A bearing **66** is provided between an inner circumferential surface of the large end portion **63** and the crankpin **51**.

[0044] FIG. 2 is a perspective view schematically showing the cylinder block **10** of the engine **100**. As described above, the cylinder block **10** includes the cylinder wall **12** including the sliding surface **12a**, and the outer wall **13**. The water jacket **14** is provided between the cylinder wall **12** and the outer wall **13**. In this embodiment, the cylinder block **10** is formed of an aluminum alloy containing silicon. More specifically, the cylinder block **10** is formed of an aluminum-silicon-based alloy having a hyper eutectic composition.

[0045] FIG. 3 is an enlarged plan view of the sliding surface **12a** of the cylinder wall **12**. The cylinder wall **12** of the cylinder block **10** includes an aluminum-containing solid-solution matrix (alloy substrate) **1** and a plurality of primary-crystal silicon grains **2** dispersed in the matrix **1**. Some of the primary-crystal silicon grains **2** are exposed to the sliding surface **12a**. Namely, the cylinder block **10** includes the primary-crystal silicon grains **2** at the sliding surface **12a**.

[0046] Although not shown, the cylinder wall **12** further includes a plurality of eutectic silicon grains dispersed in the matrix **1**. Therefore, the cylinder block **10** may further include the eutectic silicon grains at the sliding surface **12a**. When a molten aluminum-silicon-based alloy having a hyper eutectic composition is cooled, relatively large silicon crystal grains are deposited first and then relatively small silicon crystal grains are deposited. The relatively large silicon crystal grains are the "primary-crystal silicon grains", and the relatively small silicon crystal grains are the "eutectic silicon grains".

[0047] FIG. 4A and FIG. 4B are side views schematically showing the piston **40** of the engine **100**. FIG. 4A is a view of the piston **40** as seen in an axial direction of the piston pin **48** (see FIG. 1) (hereinafter, will be referred to as a "piston pin axial direction"), whereas FIG. 4B is a view of the piston **40** as seen in a direction perpendicular to the piston pin axial direction.

[0048] In this embodiment, the piston **40** (more specifically, a piston main body **41** described below) is formed of an aluminum alloy. The piston **40** may be formed by forging or casting.

[0049] As shown in FIG. 4A and FIG. 4B, the piston **40** includes the piston main body **41** and a plurality of piston rings **42**. The piston main body **41** includes a piston head **43** and a piston skirt **44**.

[0050] The piston head **43** is located at a top end of the piston **40**. Ring grooves holding the piston rings **42** are formed in an outer circumferential portion of the piston head **43**.

[0051] The piston skirt **44** extends downward from the outer circumferential portion of the piston head **43**. The piston skirt **44** includes two portions **44a** and **44b** (referred to as a "first skirt portion" and a "second skirt portion") located so as to sandwich, in a radial direction, a central axis (cylinder axis line) of the cylinder bore **11**.

[0052] The piston main body **41** includes a pair of piston pin bosses **45** having a piston pin hole **45a** into which the piston pin **48** (see FIG. 1) is insertable, and ribs **46** connecting the piston pin bosses **45** and the piston skirt **44** to each other.

[0053] The piston rings **42** are attached to an outer circumferential portion of the piston main body **41**, more specifically, to the outer circumferential portion of the piston head **43**. In this embodiment, the piston **40** includes three piston rings **42**. The number of the piston rings **42** is not limited to three. Among the three piston rings **42**, the piston rings at a top position and at a central position (a top ring and a second ring) **42a** and **42b**, for example, are compression rings that keep the combustion chamber **70** in an airtight state. The piston ring at a bottom position (third ring) **42c** is an oil ring that scrapes off extra oil attached to the cylinder wall **12**. The piston rings **42** are formed of a metal material (e.g., steel).

[0054] The piston skirt **44** includes a resin layer **rl** formed on at least a part of an outer circumferential surface thereof. In the example shown in FIG. 4A and FIG. 4B, the resin layer **rl** is formed on generally the entirety of the outer circumferential surface thereof.

[0055] FIG. 5 shows a cross-sectional structure of the piston skirt **44**. FIG. 5 is a cross-sectional view taken along line **5A-5A'** in FIG. 4B. As shown in FIG. 5, the resin layer **rl** is provided on a substrate **b1** formed of an aluminum alloy. The resin layer **rl** includes, for example, a polymer matrix and solid lubricant particles (solid lubricant agent) dispersed in the polymer matrix. As a material of the polymer matrix, thermosetting polyamideimide, for example, is preferably usable. Needless to say, the material of the polymer matrix is not limited to this. As the solid lubricant particles, any of various known types of solid lubricant particles may be used. For example, graphite particles and molybdenum disulfide particles are preferably usable. The resin layer **rl** may be formed by, for example, applying a liquid resin material to the substrate **b1** by a spray method or any of various printing methods (a screen printing method, a pad printing method or the like).

[0056] As described above, in the engine **100** according to this embodiment, the piston skirt **44** includes the resin layer **rl** formed on at least a part of the outer circumferential surface thereof. The resin layer **rl** is softer than the aluminum alloy substrate (matrix) **1** of the cylinder block **10**. Therefore, even if the primary-crystal silicon grains **2** at the sliding surface **12a** of the cylinder wall **12** fall, the primary-crystal silicon grains **2** that have fallen are pushed into the resin layer **rl**, and thus damage of the surface of the cylinder wall **12** is suppressed (namely, the cylinder wall **12** is protected). On the piston **40** side, the piston rings **42** protrude to an outermost position. Therefore, there is no problem even if a surface

of the resin layer **rl** is damaged. Since the damage of the surface of the cylinder wall **12** is suppressed, the oil (lubricant oil) attached to the cylinder wall **12** is scraped off appropriately by the piston rings **42**. Therefore, oil consumption made in a deteriorated manner is suppressed. "Wear" of the surface of the cylinder wall **12** occurs at the entirety of the sliding surface **12a** along with the sliding motion of the piston **40**, whereas the "damage" is a defect occurring locally in a much smaller range than the "wear".

[0057] The resin layer **rl** of the piston skirt **44** prevents heat transfer from the piston skirt **44** to the cylinder wall **12**. Therefore, after the engine **100** is started, the piston **40** is warmed promptly, and an appropriate size of gap is made between the piston skirt **44** and the cylinder wall **12**. This may quickly suppress noise generated immediately after the engine **100** is started, and may also suppress wearing and adhesion of the piston **40** and the cylinder wall **12**.

[0058] After the resin layer **rl** of the piston skirt **44** disappears as a result of the engine **100** being operated for a certain period of time, a bare surface of the piston skirt **44** (portion covered with the resin layer **rl**) and the cylinder wall **12** contact each other. In the engine **100** according to this embodiment, the primary-crystal silicon grains **2** are present at the sliding surface **12a** of the cylinder wall **12**, and silicon has a heat conductivity lower than that of aluminum. Therefore, the heat is not easily transferred from the piston skirt **44** to the cylinder block **10**. For this reason, even after the resin layer **rl** disappears, the piston **40** is warmed promptly, which may suppress noise generated immediately after the engine **100** is started, and may also suppress wearing and adhesion of the piston **40** and the cylinder wall **12**.

[0059] FIG. **4A** and FIG. **4B** each show an example in which the resin layer **rl** is formed on generally the entirety of the outer circumferential surface of the piston skirt **44**. The resin layer **rl** may be formed only on a part of the outer circumferential surface. It should be noted that, however, from the point of view of enhancing the above-described effect, it is preferred that the resin layer **rl** is formed on a maximum possible area of the outer circumferential surface of the piston skirt **44**. For example, with respect to the outer circumferential surface of the piston skirt **44**, the resin layer **rl** has an area size occupying a ratio of preferably 50% or higher, more preferably 70% or higher, and still more preferably 90% or higher (namely, the resin layer **rl** is formed on generally the entirety of the outer circumferential surface of the piston skirt **44**).

[0060] In the structure described above, the resin layer **rl** includes solid lubricant particles. The resin layer **rl** may include hard particles in addition to the solid lubricant agent. In the case where the resin layer **rl** includes hard particles, wearing of the resin layer **rl** may be delayed. As the hard particles, for example, metal oxide particles may be used. The amount, the particle diameter and the like of the hard particles are appropriately adjusted in accordance with the type of the hard particles used.

[0061] The resin layer **rl** has a thickness **t** (see FIG. **5**) that is not specifically limited. From the point of view of keeping the resin layer **rl** for a long period of time, the thickness **t** of the resin layer **rl** is preferably 10 μm or greater. From the point of view of ease of production, the thickness **t** of the resin layer **rl** is preferably 50 μm or less.

[0062] FIG. **6** is a cross-sectional view showing an example of structure of the piston ring **42** of the piston **40**. In the example shown in FIG. **6**, a diamond-like carbon layer (hereinafter, referred to as a "DLC layer") **42D** is formed on an outer circumferential portion (outer circumferential surface) of the piston ring **42**. The outer circumferential portion of the piston ring **42** is a portion to be in contact with the cylinder wall **12**. The piston ring **42** does not need to include the DLC layer **42D**. However, in the case where each of the piston rings **42** includes the DLC layer **42D** on the outer circumferential surface thereof, the heat of the piston **40** is prevented from being transferred easily to the cylinder block **10**. This makes it easier to warm the piston **40** after the engine **100** is started.

[0063] The DLC layer **42D** is preferably formed by a deposition method (e.g., a CVD method or a PVD method). The DLC layer **42D** may have any composition or a thickness with no specific limitation. From the point of view of enhancing the effect that the heat of the piston **40** is prevented from being transferred easily to the cylinder block **10**, the thickness of the DLC layer **42D** is preferably 2 μm or greater. From the point of view of the adhesiveness, the thickness of the DLC layer **42D** is preferably 20 μm or less.

[0064] From the point of view of sufficiently improving the wear resistance and the strength of the cylinder block **10**, the aluminum alloy as the material of the cylinder block **10** preferably contains silicon at a content of 15% by mass or higher and 25% by mass or lower. In the case where the silicon content is 15% by mass or higher, a sufficiently large amount of the primary-crystal silicon grains **2** may be deposited, which may sufficiently improve the wear resistance of the cylinder block **10**. In the case where the silicon content is 25% by mass or lower, the strength of the cylinder block **10** may be kept sufficiently high. The aluminum alloy contains aluminum at a content of, for example, 73.4% by mass or higher and 79.6% by mass or lower. The aluminum alloy may contain copper. In this case, the aluminum alloy contains copper at a content of, for example, 2.0% by mass or higher and 5.0% by mass or lower.

[0065] The primary-crystal silicon grains **2** have an average grain diameter in the range of 8 μm or longer and 50 μm or shorter. In this case, the damage of the surface of the cylinder wall **12** may be suppressed with more certainty.

[0066] In the case where the average grain diameter of the primary-crystal silicon grains **2** is longer than 50 μm , the number of the primary-crystal silicon grains **2** per unit area size of the sliding surface **12a** is small. Therefore, a large load is applied to each of the primary-crystal silicon grains **2** while the engine **100** is operated, and the primary-crystal silicon grains **2** may possibly be crushed. The crushed pieces of the primary-crystal silicon grains **2** act undesirably as

polishing particles, which causes a risk that the surface of the cylinder wall **12** is damaged. In the case where the average grain diameter of the primary-crystal silicon grains **2** is shorter than 8 μm , merely a small part of the primary-crystal silicon grains **2** is embedded in the matrix **1**. Therefore, the primary-crystal silicon grains **2** easily fall while the engine **100** is operated. The primary-crystal silicon grains **2** that have fallen act undesirably as polishing particles, which causes a risk that the surface of the cylinder wall **12** is damaged.

[0067] By contrast, in the case where the average grain diameter of the primary-crystal silicon grains **2** is 8 μm or longer and 50 μm or shorter, the primary-crystal silicon grains **2** are present in a sufficient number per unit area size of the sliding surface **12a**. Therefore, the load applied to each of the primary-crystal silicon grains **2** while the engine **100** is operated is relatively small, which suppresses the crushing of the primary-crystal silicon grains **2**. Since the part of the primary-crystal silicon grains **2** that is embedded in the matrix **1** is sufficiently large, the fall of the primary-crystal silicon grains **2** is suppressed. Therefore, the damage of the surface of the cylinder **12** by the primary-crystal silicon grains **2** that have fallen is suppressed.

[0068] The eutectic silicon grains have an average grain diameter shorter than that of the primary-crystal silicon grains **2**. The average grain diameter of the eutectic silicon grains is, for example, 7.5 μm or shorter.

[0069] The average grain diameters of the primary-crystal silicon grains **2** and the eutectic silicon grains may be measured as follows by image processing performed on an image of the sliding surface **12a**. First, a diameter (equivalent diameter) of each of the silicon crystal grains with an assumption that the silicon crystal grains are of a true circle is calculated based on an area size of each silicon crystal grain obtained by the image processing. As a result, the number (frequency) and the diameters of the silicon crystal grains are specified. Tiny crystal grains each having a diameter shorter than 1 μm are not counted as silicon crystal grains. Based on the calculated number (frequency) and the calculated diameters of the silicon crystal grains, a grain size distribution of the silicon crystal grains is obtained. The obtained grain size distribution (histogram) includes two peaks. The grain size distribution is divided into two regions with the threshold being a diameter of a portion forming a trough between the two peaks. The region corresponding to longer diameters is set as the grain size distribution of the primary-crystal silicon grains, and the region corresponding to shorter diameters is set as the grain size distribution of the eutectic silicon grains. Based on each of the grain size distributions, the average crystal diameter of the primary-crystal silicon grains and the average crystal diameter of the eutectic silicon grains may be calculated.

[0070] The primary-crystal silicon grains **2** are crushed at the sliding surface **12a** at a crushing ratio of, preferably, 20% or lower. The crushing ratio of the primary-crystal silicon grains **2** is a ratio, represented by percentage, of the area size of the crushed part of the primary-crystal silicon grains **2** with respect to the area size of the primary-crystal silicon grains **2** at the sliding surface **12a**.

[0071] In the case where the crushing ratio of the primary-crystal silicon grains **2** at the sliding surface **12a** of the cylinder wall **12** is 20% or lower, a large number of the primary-crystal silicon grains **2** that are not crushed (that may be referred to as "healthy") are exposed at the sliding surface **12a**. Therefore, the surface pressure applied to the alloy substrate **1** is sufficiently decreased. For this reason, the primary-crystal silicon grains **2** does not easily fall, which may suppress the damage of the surface of the cylinder wall **12** with more certainty.

[0072] The crushing ratio of the primary-crystal silicon grains **2** may be measured as follows, for example.

[0073] First, an image of the sliding surface **12a** is captured by use of a bore scope. FIG. 7 shows an example of the image of the sliding surface **12a**. As shown in FIG. 7, crushed parts **2a** of the primary-crystal silicon grains **2** and non-crushed parts **2b** of the primary-crystal silicon grains **2** are present at the sliding surface **12a**. Next, an area size **S1** of the crushed parts **2a** of the primary-crystal silicon grains **2** is found by binarization using image analysis software. The crushed parts **2a** have a black external appearance, and thus may be distinguished by binarization from the non-crushed parts **2b** and the alloy substrate **1**. Next, an area size **S2** of the primary-crystal silicon grains **2** (including both of the crushed parts **2a** and the non-crushed parts **2b**) is found by binarization using the image analysis software. Then, the crushing ratio of the primary-crystal silicon grains **2** is calculated based on the following expression from the found area sizes **S1** and **S2**.

Crushing ratio [%] of the primary-crystal silicon

$$\text{grains } \mathbf{2} = (\mathbf{S1}/\mathbf{S2}) \times 100$$

[0074] It is preferred that the primary-crystal silicon grains **2** have an area size occupying a ratio of 8% or higher of the sliding surface **12a**. In the case where the area size of the primary-crystal silicon grains **2** occupies a ratio of 8% or higher of the sliding surface **12a**, the surface pressure applied to the alloy substrate **1** is decreased. Therefore, the primary-crystal silicon grains **2** do not easily fall, which may suppress the damage of the surface of the cylinder wall **12** with more certainty. In addition, the piston **40** is easily warmed.

[0075] The ratio of the area size occupied by the primary-crystal silicon grains **2** with respect to the area size of the

sliding surface **12a** may be measured as follows, for example. First, an image of the sliding surface **12a** is captured by use of the bore scope. Next, the area size **S2** of the primary-crystal silicon grains **2** is found by binarization using the image analysis software. Then, the ratio of the area size occupied by the primary-crystal silicon grains **2** may be calculated based on the following expression from the found area size **S2** and an area size **S3** of the entire measurement field of view.

$$\text{Ratio [\%] of the area size occupied by the primary-crystal silicon grains with respect to the area size of the sliding surface} = (S2/S3) \times 100$$

[0076] The sliding surface **12a** may also be evaluated by a "blank ratio". FIG. **8** is a view provided to illustrate the definition of the "blank ratio". As shown in FIG. **8**, the sliding surface **12a** is divided into a plurality of grids **Sq** each having a size of 0.1 mm × 0.1 mm. These grids **Sq** naturally include grids **Sq1**, where the primary-crystal silicon grains **2** are present, and grids **Sq2**, where the primary-crystal silicon grains **2** are not present. The "blank ratio" is the ratio (percentage) of the number of the grids **Sq2** with no primary-crystal silicon grains **2** with respect to the total number of the grids **Sq**.

[0077] The "blank ratio" may be considered as an index indicating how the primary-crystal silicon grains **2** are dispersed. A lower blank ratio indicates that the primary-crystal silicon grains **2** are better dispersed. In the case where the blank ratio of the sliding surface **12a** is 55.5% or lower, the surface pressure applied to the alloy substrate **1** is sufficiently decreased. Therefore, the primary-crystal silicon grains **2** do not easily fall, which may suppress the damage of the surface of the cylinder wall **12** with more certainty. In addition, the piston **40** is easily warmed.

[Transportation vehicle]

[0078] The engine **100** according to an embodiment of the present invention is preferably usable for various types of transportation vehicles. FIG. **9** shows an example of automatic two-wheeled vehicle including the engine **100** according to an embodiment of the present invention.

[0079] In an automatic two-wheeled vehicle **300** shown in FIG. **9**, a head pipe **302** is provided at a front end of a main body frame **301**. A front fork **303** is attached to the head pipe **302** so as to be swingable in a left-right direction of the vehicle. A front wheel **304** is rotatably supported at a bottom end of the front fork **303**.

[0080] A seat rail **306** is attached so as to extend rearward from a top portion of a rear end of the main body frame **301**. A fuel tank **307** is provided on the main body frame **301**, and a main seat **308a** and a tandem seat **308b** are provided on the seat rail **306**.

[0081] A rear arm **309** extending rearward is attached to the rear end of the main body frame **301**. A rear wheel **310** is rotatably supported at a rear end of the rear arm **309**.

[0082] The engine **100** is held on a central portion of the main body frame **301**. A radiator **311** is provided to the front of the engine **100**. An exhaust pipe **312** is connected to an exhaust port of the engine **100**, and a muffler **313** is attached to a rear end of the exhaust pipe **312**.

[0083] A transmission **315** is coupled with the engine **100**. A drive sprocket **317** is attached to an output shaft **316** of the transmission **315**. The drive sprocket **317** is coupled with a rear wheel sprocket **319** of the rear wheel **310** via a chain **318**. The transmission **315** and the chain **318** act as a transmission mechanism that transmits power generated by the engine **100** to the driving wheel.

[0084] The automatic two-wheeled vehicle **300** includes the engine **100** according to an embodiment of the present invention, and therefore, may suppress oil consumption made in a deteriorated manner, and may also suppress noise generated immediately after the engine **100** is started.

[0085] In this embodiment, the automatic two-wheeled vehicle is shown as an example of the transportation vehicle. The engine according to an embodiment of the present invention is not limited to being used for an automatic two-wheeled vehicle, and is also preferably usable for any other transportation vehicle such as an automatic four-wheeled vehicle, an automatic three-wheeled vehicle, a seacraft or the like.

[0086] As described above, the internal combustion engine **100** according to an embodiment of the present invention includes the piston **40** formed of an aluminum alloy, the piston **40** including the piston head **43** and the piston skirt **44** extending from the outer circumferential portion of the piston head **43**; and the cylinder block **10** including the cylinder wall **12** including the sliding surface **12a**, along which the piston **40** is slidable. The cylinder block **10** is formed of an aluminum alloy containing silicon, and includes the plurality of primary-crystal silicon grains **2** at the sliding surface **12a**. The piston skirt **44** includes the resin layer **rl** formed on at least a part of the outer circumferential surface thereof.

[0087] In the internal combustion engine **100** according to an embodiment of the present invention, the piston skirt **44** includes the resin layer **rl** formed on at least a part of the outer circumferential surface thereof. The resin layer **rl** is softer than the aluminum alloy substrate (matrix) **1** of the cylinder block **10**. Therefore, even if the primary-crystal silicon grains **2** at the sliding surface **12a** of the cylinder wall **12** fall, the primary-crystal silicon grains **2** that have fallen are pushed into the resin layer **rl**, and thus the damage of the surface of the cylinder wall **12** is suppressed (namely, the cylinder wall **12** is protected). On the piston **40** side, the piston rings **42** protrude to the outermost position. Therefore, there is no problem even if the surface of the resin layer **rl** is damaged. Since the damage of the surface of the cylinder wall **12** is suppressed, the oil (lubricant oil) attached to the cylinder wall **12** is scraped off appropriately by the piston rings **42**. Therefore, oil consumption made in a deteriorated manner may be suppressed.

[0088] The resin layer **rl** of the piston skirt **44** prevents heat transfer from the piston skirt **44** to the cylinder wall **12**. Therefore, after the engine **100** is started, the piston **40** is warmed promptly, and an appropriate size of gap is made between the piston skirt **44** and the cylinder wall **12**. This may quickly suppress noise generated immediately after the engine **100** is started, and may also suppress wearing and adhesion of the piston **40** and the cylinder wall **12**.

[0089] After the resin layer **rl** of the piston skirt **44** disappears as a result of the engine **100** being operated for a certain period of time, a bare surface of the piston skirt **44** (portion covered with the resin layer **rl**) and the cylinder wall **12** contact each other. In the engine **100** according to this embodiment, the primary-crystal silicon grains **2** are present at the sliding surface **12a** of the cylinder wall **12**, and silicon has a heat conductivity lower than that of aluminum. Therefore, the heat is not easily transferred from the piston skirt **44** to the cylinder block **10**. For this reason, even after the resin layer **rl** disappears, the piston **40** is warmed promptly, which may suppress noise generated immediately after the engine **100** is started, and may also suppress wearing and adhesion of the piston **40** and the cylinder wall **12**.

[0090] In an embodiment, the piston **40** includes the plurality of piston rings **42** attached to the outer circumferential portion of the piston head **43**. Each of the plurality of piston rings **42** includes the diamond-like carbon layer **42D** on the outer circumferential surface thereof.

[0091] In the case where each of the piston rings **42** includes the DLC layer **42D** on the outer circumferential surface thereof, the heat of the piston **40** is prevented from being transferred easily to the cylinder block **10**. This makes it easier to warm the piston **40** after the engine **100** is started.

[0092] In an embodiment, the resin layer **rl** includes a solid lubricant agent and hard particles.

[0093] In the case where the resin layer **rl** includes hard particles, wearing of the resin layer **rl** may be delayed.

[0094] In an embodiment, the resin layer **rl** has a thickness **t** of 10 μm or greater and 50 μm or less.

[0095] From the point of view of keeping the resin layer **rl** for a long period of time, the thickness **t** of the resin layer **rl** is preferably 10 μm or greater. From the point of view of ease of production, the thickness **t** of the resin layer **rl** is preferably 50 μm or less.

[0096] In an embodiment, the cylinder block **10** is formed of an aluminum alloy containing silicon at a content of 15% by mass or higher and 25% by mass or lower.

[0097] From the point of view of sufficiently improving the wear resistance and the strength of the cylinder block **10**, the aluminum alloy as the material of the cylinder block **10** preferably contains silicon at a content of 15% by mass or higher and 25% by mass or lower. In the case where the silicon content is 15% by mass or higher, a sufficiently large amount of the primary-crystal silicon grains **2** may be deposited, which may sufficiently improve the wear resistance of the cylinder block **10**. In the case where the silicon content is 25% by mass or lower, the strength of the cylinder block **10** may be kept sufficiently high.

[0098] In an embodiment, the plurality of primary-crystal silicon grains **2** have an average grain diameter of 8 μm or longer and 50 μm or shorter.

[0099] In the case where the primary-crystal silicon grains **2** have an average grain diameter in the range of 8 μm or longer and 50 μm or shorter, the damage of the surface of the cylinder wall **12** may be suppressed with more certainty.

[0100] In the case where the average grain diameter of the primary-crystal silicon grains **2** is longer than 50 μm , the number of the primary-crystal silicon grains **2** per unit area size of the sliding surface **12a** is small. Therefore, a large load is applied to each of the primary-crystal silicon grains **2** while the engine **100** is operated, and the primary-crystal silicon grains **2** may possibly be crushed. The crushed pieces of the primary-crystal silicon grains **2** act undesirably as polishing particles, which causes a risk that the surface of the cylinder wall **12** is damaged.

[0101] In the case where the average grain diameter of the primary-crystal silicon grains **2** is shorter than 8 μm , merely a small part of the primary-crystal silicon grains **2** is embedded in the matrix **1**. Therefore, the primary-crystal silicon grains **2** easily fall while the engine **100** is operated. The primary-crystal silicon grains **2** that have fallen act undesirably as polishing particles, which causes a risk that the surface of the cylinder wall **12** is damaged.

[0102] By contrast, in the case where the average grain diameter of the primary-crystal silicon grains **2** is 8 μm or longer and 50 μm or shorter, the primary-crystal silicon grains **2** are present in a sufficient number per unit area size of the sliding surface **12a**. Therefore, the load applied to each of the primary-crystal silicon grains **2** while the engine **100** is operated is relatively small, which suppresses the crushing of the primary-crystal silicon grains **2**. Since the part of the primary-crystal silicon grains **2** that is embedded in the matrix **1** is sufficiently large, the fall of the primary-crystal

silicon grains **2** is suppressed. Therefore, the damage of the surface of the cylinder **12** by the primary-crystal silicon grains **2** that have fallen is suppressed.

[0103] In an embodiment, the plurality of primary-crystal silicon grains **2** have an area size occupying a ratio of 8% or higher of the sliding surface **12a**.

[0104] In the case where the area size of the primary-crystal silicon grains **2** occupies a ratio of 8% or higher of the sliding surface **12a**, the surface pressure applied to the alloy substrate **1** is decreased. Therefore, the primary-crystal silicon grains **2** do not easily fall, which may suppress the damage of the surface of the cylinder wall **12** with more certainty. In addition, the piston **40** is easily warmed.

[0105] In an embodiment, where the sliding surface **12a** is divided into a plurality of grids each having a size of 0.1 mm × 0.1 mm and the ratio of the number of grids where no primary-crystal silicon grain is present with respect to the total number of the grids is referred to as a "blank ratio", the blank ratio is 55.5% or lower.

[0106] The "blank ratio" is an index indicating how the primary-crystal silicon grains **2** are dispersed. A lower blank ratio indicates that the primary-crystal silicon grains **2** are better dispersed. In the case where the blank ratio of the sliding surface **12a** is 55.5% or lower, the surface pressure applied to the alloy substrate **1** is sufficiently decreased. Therefore, the primary-crystal silicon grains **2** do not easily fall, which may suppress the damage of the surface of the cylinder wall **12** with more certainty. In addition, the piston **40** is easily warmed.

[0107] In an embodiment, the plurality of primary-crystal silicon grains **2** have a crushing ratio of 20% or lower at the sliding surface **12a**.

[0108] In the case where the crushing ratio of the primary-crystal silicon grains **2** at the sliding surface **12a** of the cylinder wall **12** is 20% or lower, a large number of the primary-crystal silicon grains **2** that are not crushed (that may be referred to as "healthy") are exposed at the sliding surface **12a**. Therefore, the surface pressure applied to the alloy substrate **1** is sufficiently decreased. For this reason, the primary-crystal silicon grains **2** do not easily fall, which may suppress the damage of the surface of the cylinder wall **12** with more certainty.

[0109] A transportation vehicle according to an embodiment of the present invention includes the internal combustion engine **100** having any of the above-described structures.

[0110] The internal combustion engine **100** according to an embodiment of the present invention is preferably usable in any of various types of transportation vehicles.

INDUSTRIAL APPLICABILITY

[0111] According to an embodiment of the present invention, in an internal combustion engine including a cylinder block formed of an aluminum alloy containing silicon, when the internal combustion engine is operated for the first time, damage of a surface of a cylinder wall may be suppressed and thus oil consumption made in a deteriorated manner may be suppressed. The internal combustion engine according to an embodiment of the present invention is preferably usable in any of various types of transportation vehicles including an automatic two-wheeled vehicle.

REFERENCE SIGNS LIST

[0112] **1**: matrix (alloy substrate); **2**: primary-crystal silicon grain; **2a**: crushed part of the primary-crystal silicon grain; **2b**: non-crushed part of the primary-crystal silicon grain; **10**: cylinder block; **11**: cylinder bore; **12**: cylinder wall; **12a**: sliding surface (inner circumferential surface of the cylinder wall); **13**: outer wall; **14**: water jacket; **20**: cylinder head; **21**: intake port; **22**: exhaust port; **23**: intake valve; **24**: exhaust valve; **30**: crankcase; **40**: piston; **41**: piston main body; **42**: piston ring; **42a**: top ring; **42b**: second ring; **42c**: third ring; **42D**: diamond-like carbon layer; **43**: piston head; **44**: piston skirt; **44a**: first skirt portion; **44b**: second skirt portion; **45**: piston pin boss; **45a**: piston pin hole; **46**: rib; **48**: piston pin; **50**: crankshaft; **51**: crankpin; **52**: crank arm; **60**: con rod; **61**: rod main body; **62**: small end portion; **63**: large end portion; **70**: combustion chamber; **100**: engine (internal combustion engine); **300**: automatic two-wheeled vehicle; **Sq**: grid; **Sq1**: grid where the primary-crystal silicon grains are present; **Sq2**: grid where the primary-crystal silicon grains are not present; **b1**: substrate; **rl**: resin layer

Claims

1. An internal combustion engine, comprising:

a piston formed of an aluminum alloy, the piston including a piston head and a piston skirt extending from an outer circumferential portion of the piston head; and

a cylinder block including a cylinder wall including a sliding surface, along which the piston is slidable;

wherein the cylinder block is formed of an aluminum alloy containing silicon, and includes a plurality of primary-

crystal silicon grains at the sliding surface; and
wherein the piston skirt includes a resin layer formed on at least a part of an outer circumferential surface thereof.

2. The internal combustion engine of claim 1,

wherein the piston includes a plurality of piston rings attached to the outer circumferential portion of the piston head, and
wherein each of the plurality of piston rings includes a diamond-like carbon layer on an outer circumferential surface thereof.

3. The internal combustion engine of claim 1 or 2, wherein the resin layer includes a solid lubricant agent and hard particles.

4. The internal combustion engine of any one of claims 1 through 3, wherein the resin layer has a thickness of 10 μm or greater and 50 μm or less.

5. The internal combustion engine of any one of claims 1 through 4, wherein the cylinder block is formed of an aluminum alloy containing silicon at a content of 15% by mass or higher and 25% by mass or lower.

6. The internal combustion engine of any one of claims 1 through 5, wherein the plurality of primary-crystal silicon grains have an average grain diameter of 8 μm or longer and 50 μm or shorter.

7. The internal combustion engine of any one of claims 1 through 6, wherein the plurality of primary-crystal silicon grains have an area size occupying a ratio of 8% or higher of the sliding surface.

8. The internal combustion engine of any one of claims 1 through 7, wherein where the sliding surface is divided into a plurality of grids each having a size of 0.1 mm $\times$ 0.1 mm and the ratio of the number of grids where no primary-crystal silicon grain is present with respect to the total number of the grids is referred to as a "blank ratio", the blank ratio is 55.5% or lower.

9. The internal combustion engine of any one of claims 1 through 8, wherein the plurality of primary-crystal silicon grains have a crushing ratio of 20% or lower at the sliding surface.

10. A transportation vehicle, comprising the internal combustion engine of any one of claims 1 through 9.

FIG. 1

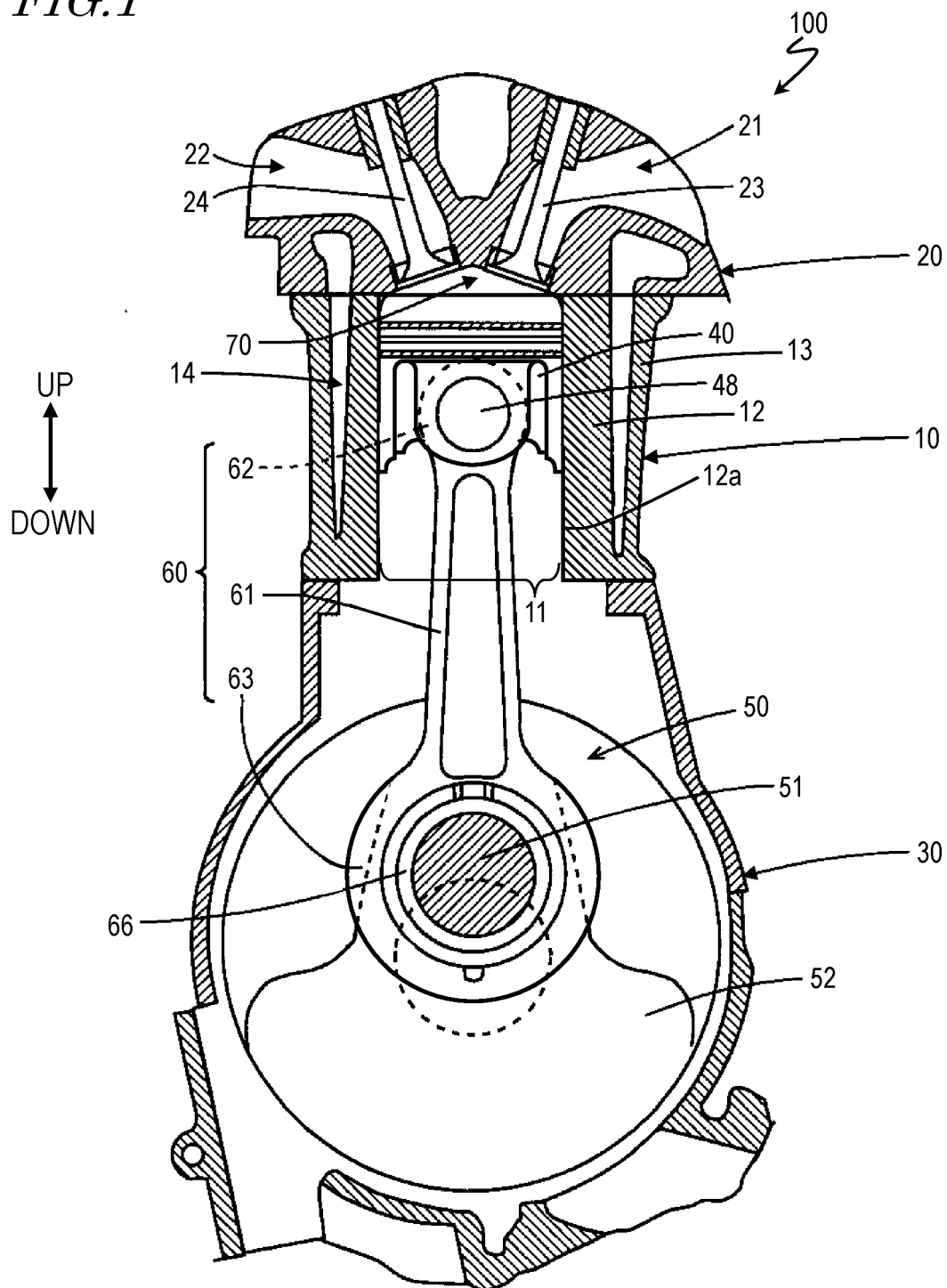


FIG.2

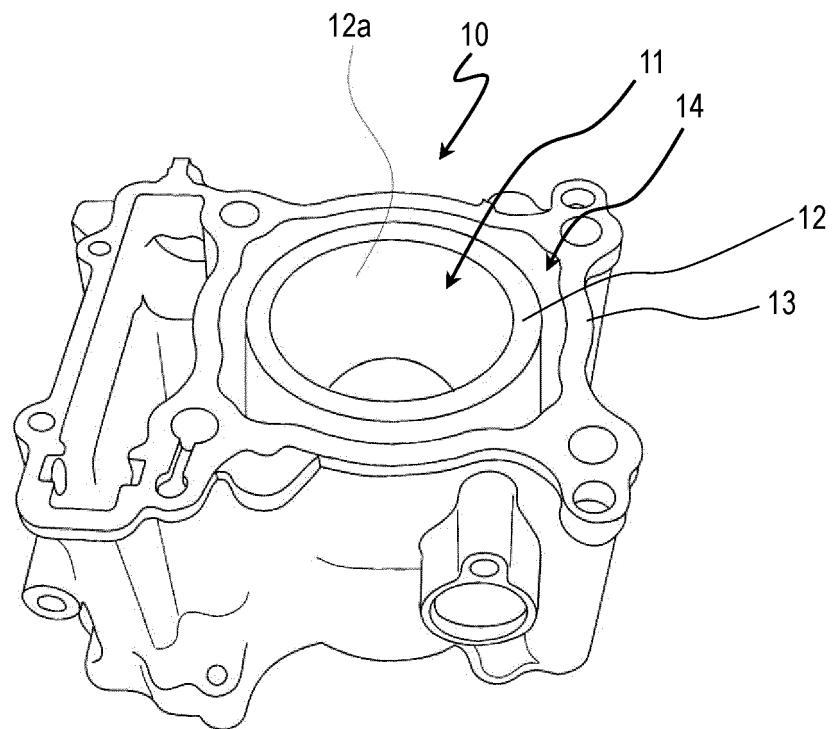


FIG.3

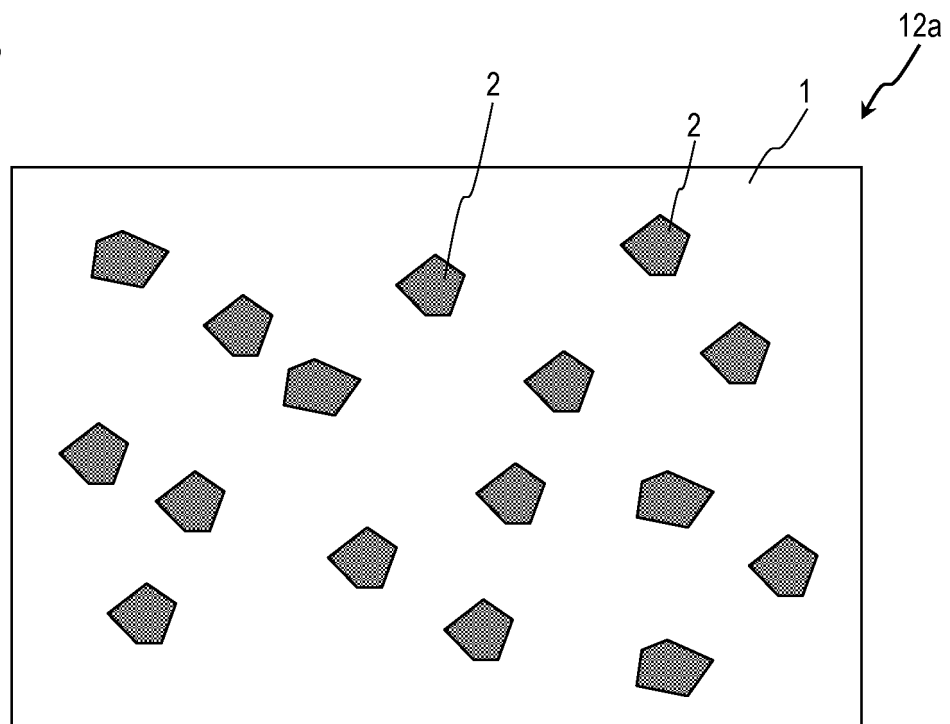


FIG. 4A

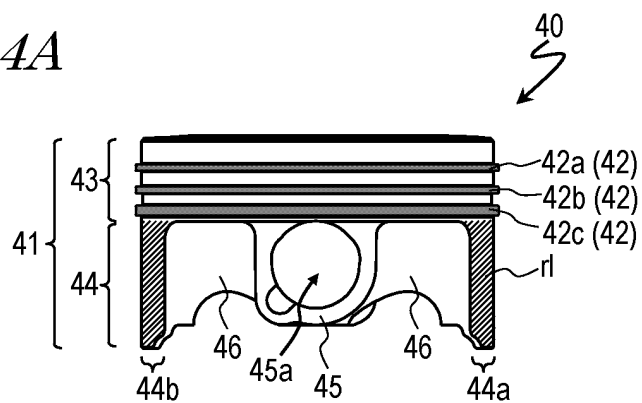


FIG. 4B

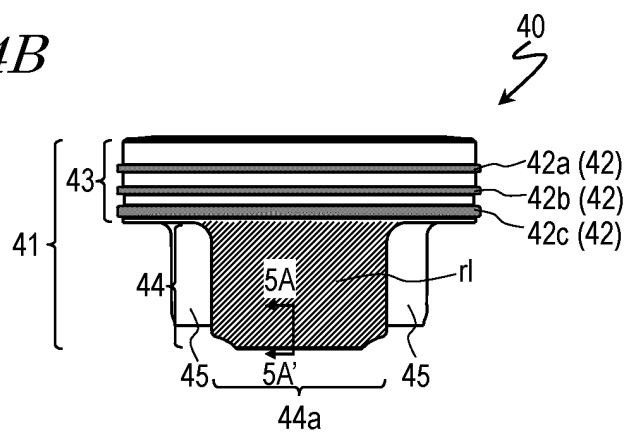


FIG. 5

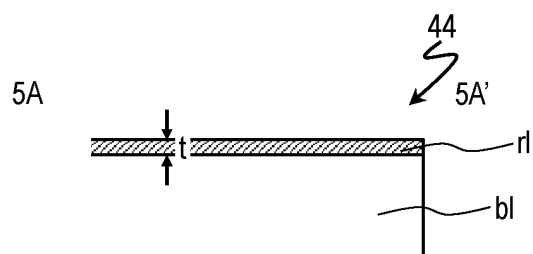


FIG. 6

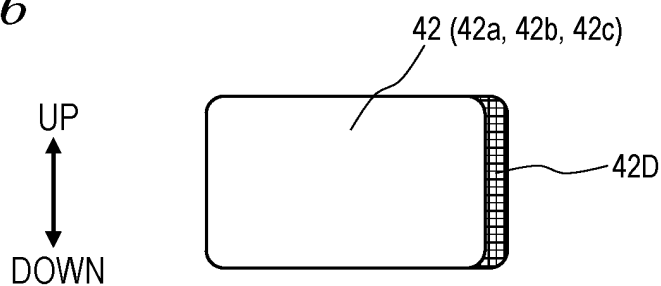


FIG. 7

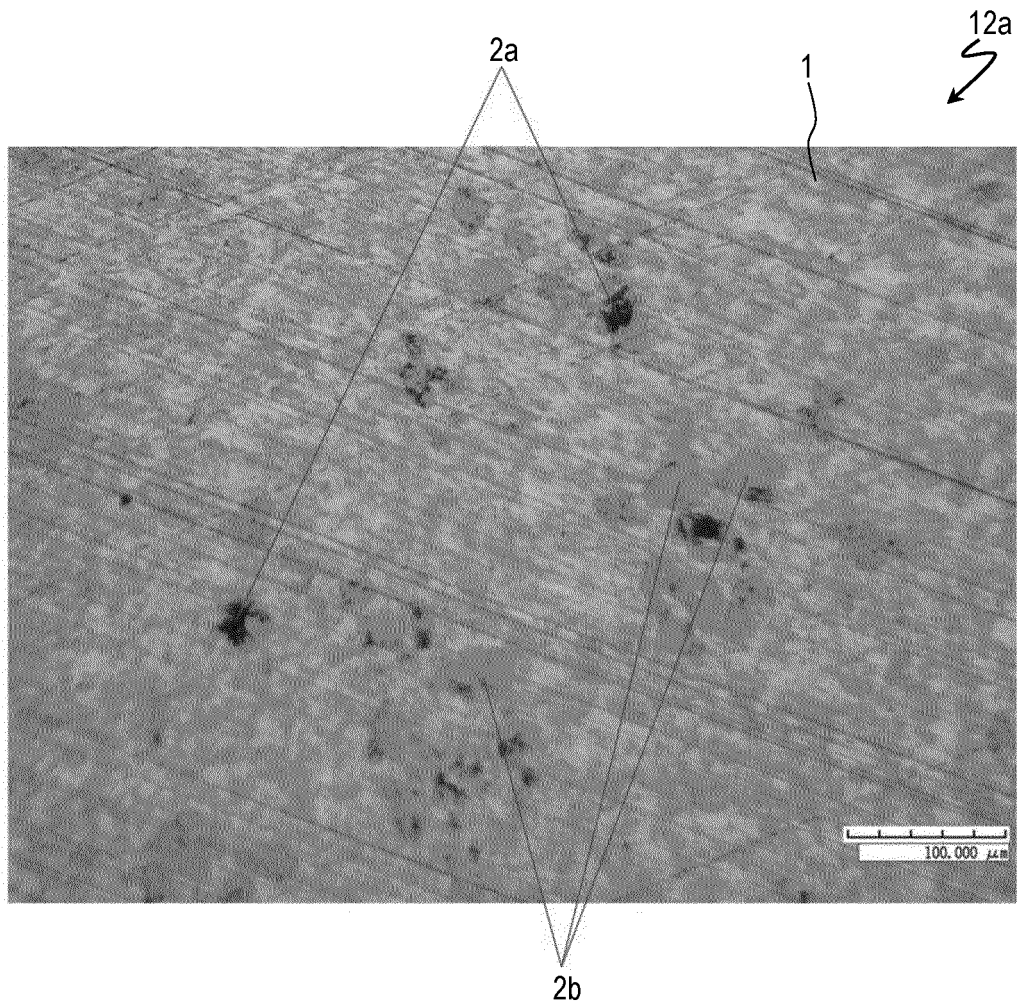
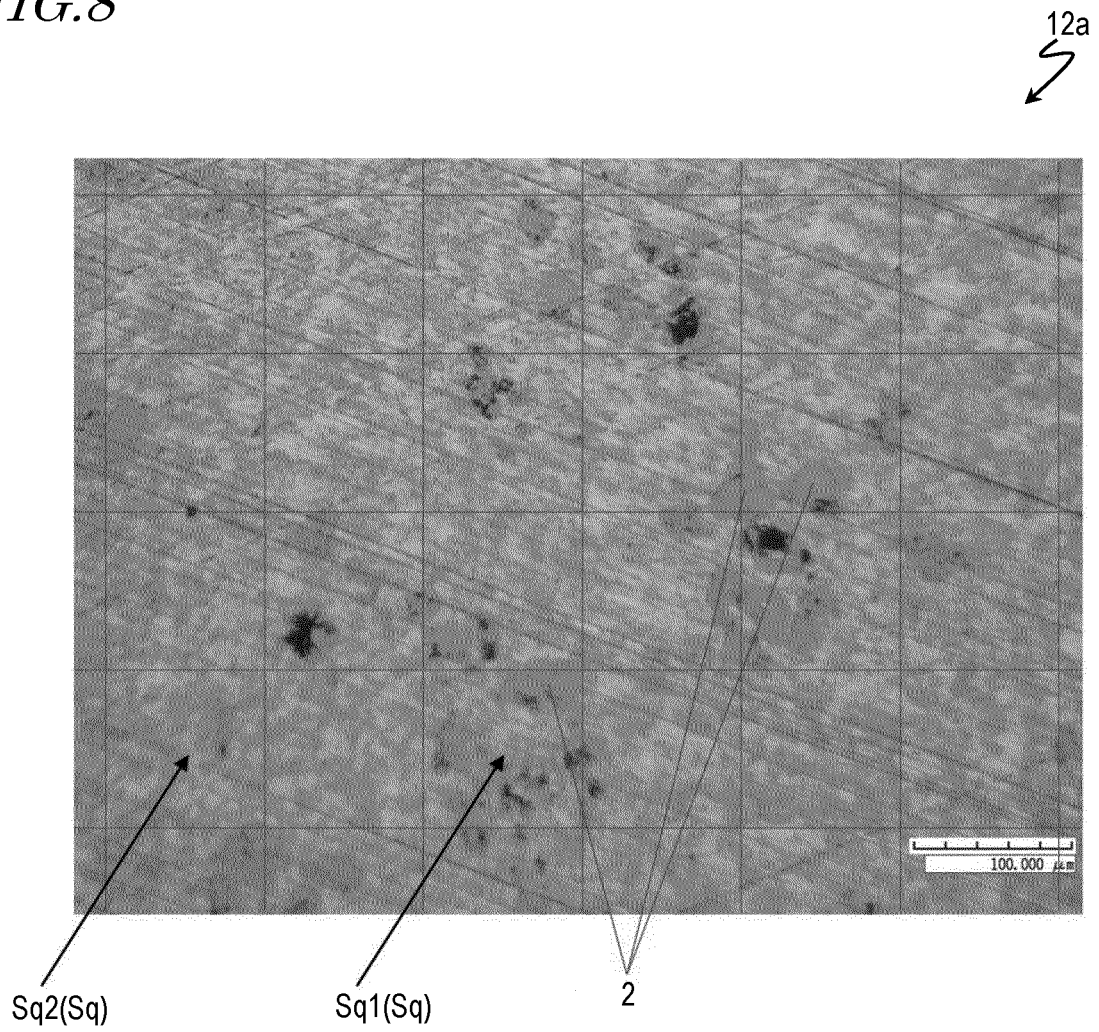


FIG. 8



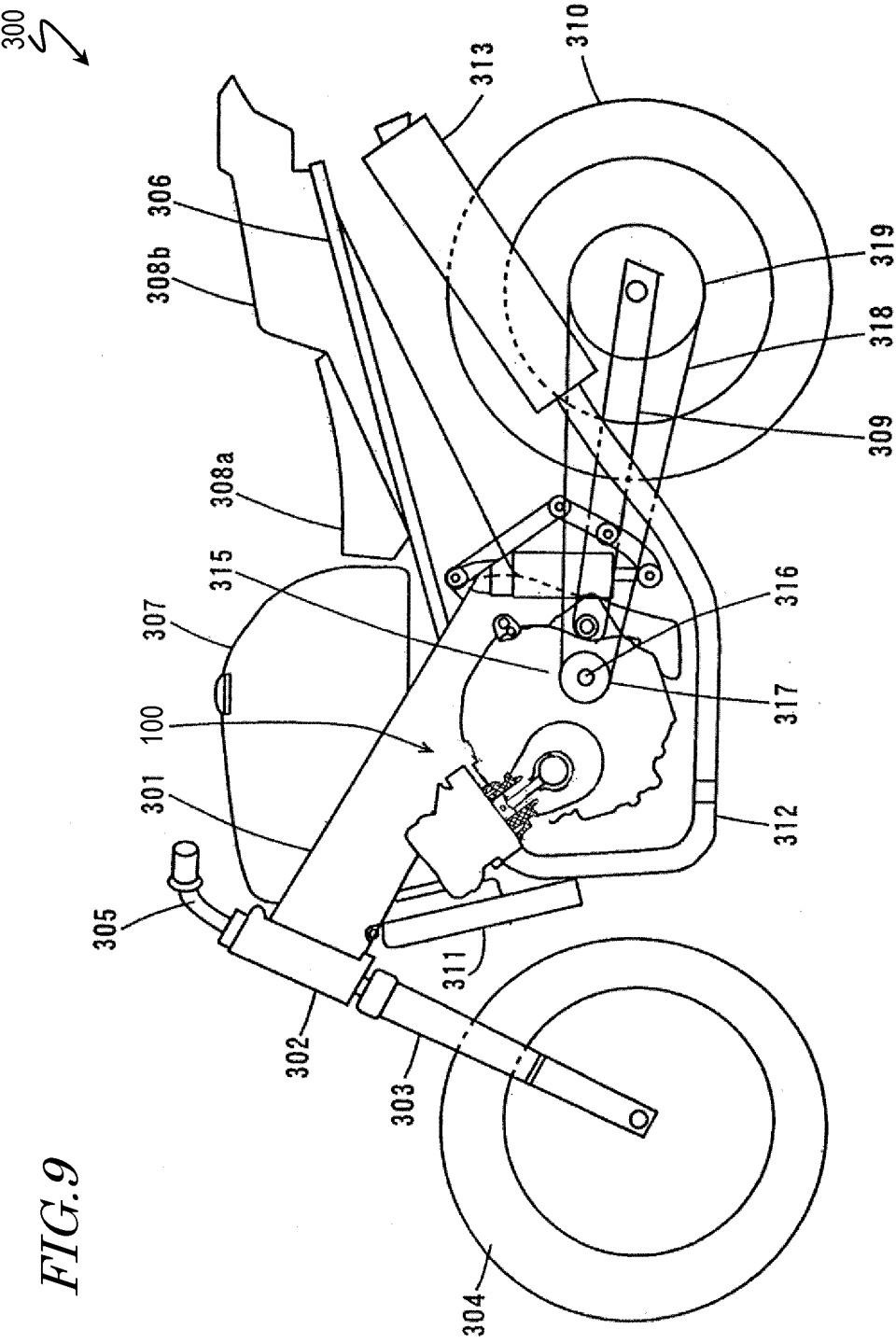


FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2021/045974

A. CLASSIFICATION OF SUBJECT MATTER F02F 1/00 (2006.01)i FI: F02F1/00 C According to International Patent Classification (IPC) or to both national classification and IPC	B. FIELDS SEARCHED																								
Minimum documentation searched (classification system followed by classification symbols) F02F1/00	Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Published examined utility model applications of Japan 1922-1996 Published unexamined utility model applications of Japan 1971-2022 Registered utility model specifications of Japan 1996-2022 Published registered utility model applications of Japan 1994-2022 Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)																								
C. DOCUMENTS CONSIDERED TO BE RELEVANT	<table border="1"> <thead> <tr> <th>Category*</th> <th>Citation of document, with indication, where appropriate, of the relevant passages</th> <th>Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td>X</td> <td>JP 1-253553 A (HONDA MOTOR CO., LTD.) 09 October 1989 (1989-10-09) page 2, upper right column, lines 3-8, page 3, upper left column, line 8 to page 3, lower left column, line 3, page 3, lower right column, line 16 to page 4, upper left column, line 17, page 4, upper right column, line 16 to page 5, lower left column, line 11, fig. 3</td> <td>1, 3-6, 10</td> </tr> <tr> <td>Y</td> <td></td> <td>2, 7-9</td> </tr> <tr> <td>X</td> <td>JP 2004-347053 A (NISSAN MOTOR CO., LTD.) 09 December 2004 (2004-12-09) paragraphs [0004], [0006], [0015], [0049]-[0050]</td> <td>1, 3-6, 10</td> </tr> <tr> <td>Y</td> <td></td> <td>2, 7-9</td> </tr> <tr> <td>Y</td> <td>JP 2003-13163 A (TOYOTA MOTOR CORP.) 15 January 2003 (2003-01-15) claim 11, paragraphs [0026]-[0027], [0047]-[0051], [0087]</td> <td>2</td> </tr> <tr> <td>Y</td> <td>JP 10-331970 A (NISSAN MOTOR CO., LTD.) 15 December 1998 (1998-12-15) abstract, claims 1-6, paragraphs [0022]-[0024], fig. 2-3</td> <td>7-9</td> </tr> <tr> <td>Y</td> <td>JP 7-88711 A (TOSHIBA TUNGALOY CO., LTD.) 04 April 1995 (1995-04-04) abstract, paragraphs [0005], [0007], [0011], [0018]</td> <td>9</td> </tr> </tbody> </table>	Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	X	JP 1-253553 A (HONDA MOTOR CO., LTD.) 09 October 1989 (1989-10-09) page 2, upper right column, lines 3-8, page 3, upper left column, line 8 to page 3, lower left column, line 3, page 3, lower right column, line 16 to page 4, upper left column, line 17, page 4, upper right column, line 16 to page 5, lower left column, line 11, fig. 3	1, 3-6, 10	Y		2, 7-9	X	JP 2004-347053 A (NISSAN MOTOR CO., LTD.) 09 December 2004 (2004-12-09) paragraphs [0004], [0006], [0015], [0049]-[0050]	1, 3-6, 10	Y		2, 7-9	Y	JP 2003-13163 A (TOYOTA MOTOR CORP.) 15 January 2003 (2003-01-15) claim 11, paragraphs [0026]-[0027], [0047]-[0051], [0087]	2	Y	JP 10-331970 A (NISSAN MOTOR CO., LTD.) 15 December 1998 (1998-12-15) abstract, claims 1-6, paragraphs [0022]-[0024], fig. 2-3	7-9	Y	JP 7-88711 A (TOSHIBA TUNGALOY CO., LTD.) 04 April 1995 (1995-04-04) abstract, paragraphs [0005], [0007], [0011], [0018]	9
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Y	JP 2003-13163 A (TOYOTA MOTOR CORP.) 15 January 2003 (2003-01-15) claim 11, paragraphs [0026]-[0027], [0047]-[0051], [0087]	2																							
Y	JP 10-331970 A (NISSAN MOTOR CO., LTD.) 15 December 1998 (1998-12-15) abstract, claims 1-6, paragraphs [0022]-[0024], fig. 2-3	7-9																							
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