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(54) **Apparatus and use of the apparatus for producing a cylinder block of an internal combustion engine**

Vorrichtung und deren Verwendung zum Herstellen eines Zylinderblockes einer Brennkraftmaschine

Dispositif et son usage pour la fabrication d'un bloc-cylindres d'un moteur à combustion interne

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## Description

**[0001]** The present invention relates to an apparatus for producing a cylinder block of an internal combustion engine and a method using the same. More particularly, the present invention relates to an apparatus for producing a cylinder block having a cylinder bore surface constructed from metal matrix composite (MMC).

**[0002]** As illustrated in FIG. 11, a conventional production method for MMC cylinder block includes the steps of: setting a preheated preform (or formed member) 102 having a tapered inside surface and a straight outside surface parallel to an axis of the preform onto a bore core 101 having a tapered outside surface; arranging the bore core such that it is mounted in a cavity 104 defined by a mold 103; injecting molten metal 105 from an injection cylinder 106; and pressing the injected molten metal by a plunger 107, whereby the molten metal is infiltrated (or impregnated) into the preform 102 from the outside surface of the preform 102 only so that the preform changes to an MMC. After solidified, the cylinder block cast product is taken out of the mold 103 and the bore core 101, and then the MMC cylinder bore surface is machined to a specified diameter to form a straight cylindrical cylinder bore.

**[0003]** However, the conventional production method for MMC cylinder block has the following problems:

**[0004]** First, in the conventional production method, as illustrated in FIG. 12, there is a clearance 108 between the bore core 101 and the preform 102. The clearance is caused, for example, by a difference between the taper angle of the bore core 101 and the taper angle of the preform 102 and a difference between the temperature of the bore core (for example, 100 - 200 °C) and the temperature of the preform (for example, 500 - 900 °C). In a state where the clearance 108 exists, when the molten aluminum is pressed and is infiltrated into the preform 102 as illustrated in FIG. 13A, cracks such as crack 109 often develop in the preform 102 as illustrated in FIG. 13B. More particularly, when circumferential stress in the preform that is caused by a radial compression force acting on the outside surface of the preform exceeds an allowable shear stress, a shear fracture 109 develops along a direction inclined by 45 degrees from the direction of the compression force. Buckling occurs along the fracture surface and causes a local portion of high density of reinforcement fibers. When a piston-ring slidably contacts that high density portion during actual engine operation, abrasive wear of the piston-ring increases.

**[0005]** Second, the preform 102 is usually manufactured by dipping an air permeable cylindrical former into a slurry containing reinforcement fibers and particles and aspirating the slurry water from an interior of the former thereby forming a layer of the reinforcement fibers and particles on the outside surface of the former. Then, the former and the layer of the reinforcement fibers and particles are taken out of the slurry and the layer of the reinforcement fibers and particles is dried to form a preform 102 constructed from the reinforcement fibers and particles. In the preform 102, the reinforcement fibers extend in directions perpendicular to a radial direction of the preform to form a laminar wall. As a result, the separation resistant strength of one layer from another layer of the laminar wall of the preform is relatively low. As a result, the crack 109 tends to change the propagation direction to the circumferential direction of the preform due to the shear stress thereby resulting in a circumferential crack 110 (FIG. 14). When the molten aluminum flows into the crack 110 and solidifies, and when the crack portion is exposed to the outside during machining, it causes a portion 111 that has no reinforcement fibers. Such portion 111 will cause excessive abrasive wear and seizure of the piston-ring during actual operation of the engine.

**[0006]** Third, since the preform 102 is in plane contact with the bore core 101 when it is set to the mold, the temperature of the preform 102 rapidly decreases. As a result, the molten aluminum does not tend to infiltrate smoothly into the preform and the pressure of the molten aluminum rises before the entire portion of the preform is infiltrated with the molten aluminum, whereby the non-infiltrated portion of the preform is compressed (or crushed). For smoothly removing the preform from the former, the inside surface of the preform is tapered (more than 1 degree). Therefore, as illustrated in FIG. 16, the lower the preform is in the axial direction, the larger the deformation of the preform is due to compression. When the inside surface of such a deformed preform is machined, an aluminum portion that has no reinforcement fibers tends to be exposed to the outside. The exposed portion will cause an excessive abrasive wear and seizure of a piston-ring during actual operation of the engine.

**[0007]** Further, it is referred to the international publication WO 92/15415 which discloses an apparatus for producing a cylinder block of an internal combustion engine having a cylinder bore surface constructed from a liner bulk material. The apparatus comprises a cavity defined by a mold including an insert which is provided on its outside with at least three peripherally spaced guide heels protruding outwardly for supporting a generally cylindrical liner intended to be set in the cavity. Except at the guide heels, a clearance for leading molten metal is formed between the inside surface of the liner and the outside surface of the insert allowing the molten metal to penetrate into the clearance to create equal pressure on both sides of the liner.

**[0008]** The object of the invention is to provide an apparatus for producing a cylinder block of an internal combustion engine having a cylinder bore surface of metal matrix composite (MMC) that can solve at least one of the above-described three problems: the occurrence of a shear crack, a circumferential propagation of the shear crack, and compression of a portion of the preform, as well as the problem of sticking when the cast product is removed from the apparatus.

**[0009]** The above object is achieved by an apparatus according to claim 1.

**[0010]** In addition, there is provided a method according to claim 9 related to the use of the above apparatus for producing a cylinder block of an internal combustion engine.

**[0011]** In the apparatus according to the invention, the preform is supported by the fixed and the movable part of the mold and by the bore core at the at least one protrusion protruding outwardly from the outside surface of the bore core while supplying molten metal into the cavity. In this state, the molten metal is infiltrated into the preform from both the inside surface and the outside surface of the preform whereby the preform changes to a metal matrix composite.

**[0012]** In the cylinder block, since the pressure of the molten metal is imposed on both the inside surface and the outside surface of the preform, the pressure imposed on the preform is balanced. As a result, cracks due to shear forces will not develop in the preform and circumferential propagation of such shear cracks will not occur. Further, since the molten metal infiltrates the preform from both the inside surface and the outside surface of the preform, the entire portion of the preform is easily infiltrated with the molten metal, and there will be no compression of the non-infiltrated portion of the preform. Furthermore, since the infiltration speed is high, the preheating temperature of the preform is allowed to be lower than that of the conventional process. Since the preform line-contacts the at least one protrusion of the bore core and the fixed and the movable part of the mold, the decrease in temperature of the preform is decreased.

**[0013]** Moreover, since at least one protrusion is formed separately from the bore core, and is mounted to the bore core so as to be movable in the radial direction relative to the bore core, by receding the protrusion during removing the cast product from the bore core and the mold, sticking at the tip of the protrusion can be effectively prevented.

**[0014]** The above and other objects, features, and advantages of the present invention will become more apparent and will be more readily appreciated from the following detailed description of the preferred embodiments of the present invention in conjunction with the accompanying drawings, in which:

FIG. 1A is a cross-sectional view of a mold and a preform at a first step (a step for setting the preform) of a production method for a cylinder block, applicable to the embodiment of the present invention;

FIG. 1B is a cross-sectional view of the mold and the preform at a second step (a step for pouring molten metal) of the production method for a cylinder block, applicable to the embodiment of the present invention;

FIG. 1C is a cross-sectional view of the mold and the MMC layer at a third step (a step for removing a cast product from the mold and the bore core) of the production method for a cylinder block, applicable to the embodiment of the present invention;

FIG. 1D is a cross-sectional view of the mold and the MMC layer at a fourth step (a step for machining a cylinder bore surface of the cast product) of the production method for a cylinder block, applicable to the embodiment of the present invention;

FIG. 2 is a graph of molten metal pressure versus time, applicable to the embodiment of the present invention;

FIG. 3 is a cross-sectional view of a first example of an apparatus having features which are applicable to the embodiment of the present invention;

FIG. 4 is a plan view of the apparatus of FIG. 3 viewed in direction P;

FIG. 5 is a cross-sectional view of a second example of an apparatus having features which are applicable to the embodiment of the present invention;

FIG. 6 is an oblique view of a bore core of a third example of an apparatus having features which are applicable to the embodiment of the present invention;

FIG. 7 is a cross-sectional view of a fourth example of an apparatus having features which are applicable to the embodiment of the present invention;

FIG. 8 is a cross-sectional view of a portion of a fifth example of an apparatus having features which are applicable to the embodiment of the present invention;

FIG. 9 is a cross-sectional view of a bore core having protrusions which is part of the apparatus according to the embodiment of the present invention;

FIG. 10 is a partial, cross-sectional view of the bore core and the protrusion of FIG. 9;

FIG. 11 is a cross-sectional view of an apparatus for conducting a conventional production method for a cylinder block;

FIG. 12 is a cross-sectional view of a bore core and a preform for conducting the conventional method;

FIG. 13A is a cross-sectional view of a portion of the preform on which a compression force is imposed;

FIG. 13B is a cross-sectional view of the portion of the preform where a crack due to a shear force is caused;

FIG. 14 is a cross-sectional view of a portion of a preform where a circumferential crack is caused;

FIG. 15 is an oblique view of a portion of the preform where a circumferential crack is caused and is exposed to outside when machined; and

FIG. 16 is a cross-sectional view of a portion of a cast cylinder block illustrating a compression of the preform.

**[0015]** FIGS. 1A - 1D and FIG. 2 illustrate a production method for a cylinder block of an internal combustion engine applicable to the embodiment of the present invention; FIGS. 3 - 4 illustrate a first example, FIG. 5 a second example, FIG. 6 a third example, FIG. 7 a fourth example, and FIG. 8 a fifth example which are not covered by the scope of the invention but have features which are applicable to the embodiment of the invention. FIGS. 9 and 10 illustrate the embodiment of the present invention. Portions common or similar to all of the the examples and the embodiment of the present invention are denoted with the same reference numerals.

**[0016]** First, portions common or similar to all of the examples and the embodiment of the present invention will be explained with reference to FIGS. 1A - 1D and FIG. 2.

**[0017]** A production method for a cylinder block of an internal combustion engine includes a first step and a second step.

**[0018]** At the first step, as illustrated in FIG. 1A, a generally cylindrical, preheated, preform 2 having an inside surface 2a and an outside surface 2b is set in a cavity 4 defined by a mold 3 which includes a bore core 1 having an outside surface 1a so that a clearance 8 where molten metal is lead is formed between the inside surface 2a of the preform 2 and the outside surface 1a of the bore core 1. In order that molten metal can smoothly flow in the clearance 8, it is preferable that the clearance 8 has a thickness equal to or greater than 0.5 mm. The clearance 8 is formed throughout an entire circumference of the inside surface of the preform 2, except portions where protrusions contact the bore core 1 in a case where the preform is supported by the bore core.

**[0019]** At the second step, as illustrated in FIG. 1B, molten metal 5 (molten aluminum) is supplied into the cavity 4 so that the molten metal 5 is infiltrated into the preform 2 from both the inside surface 2a and the outside surface 2b of the preform 2 whereby the preform 2 changes to a metal matrix composite (MMC).

**[0020]** As illustrated in FIGS. 1C and 1D, the production method for a cylinder block may include a third step and a fourth step.

**[0021]** At the third step, as illustrated in FIG. 1C, a cylinder block cast product 9 is taken out of the mold 3 and the bore core 1 after the molten metal has solidified.

**[0022]** At the fourth step, as illustrated in FIG. 1D, a cylinder bore surface of metal matrix composite of each cylinder bore of the cylinder block cast product 9 is machined to a specified diameter.

**[0023]** In FIGS. 1A - 1D, the molten metal is injected into the cavity 4 by an injection cylinder 6 having a plunger tip 7. Though the bore core 1 and the preform 2 are arranged laterally in the molding apparatus, the bore core 1 and the preform 2 may be arranged vertically. The molten metal is, for example, molten aluminum, though the molten metal is not limited to molten aluminum.

**[0024]** The preheating temperature of the preform 2 may be lower than that of the conventional one. More particularly, while the preheating temperature of the conventional method was about 700 °C when the preform was taken out of the preheating furnace or was set to the mold, the preheating temperature of the preform 2 according to the present invention is equal to or higher than 300 °C and lower than 700 °C. Though the temperature of the bore core 1 is lower than the temperature of the preform and is, for example, 100 - 200 °C, since a decrease in the temperature of the preform 2 is delayed due to the clearance 8 between the preform 2 and the bore core 1, the temperature of the preform 2 can be relatively low.

**[0025]** FIG. 2 illustrates a relationship between a change in the pressure of the molten metal and beginning and completion of the infiltration of the molten metal into the preform during the second step. During a certain period of time A when the molten metal is being supplied into the cavity, the pressure of the molten metal in the cavity almost does not increase. At the time B when the molten metal has just filled the cavity, the pressure of the molten metal in the cavity begins to increase suddenly. At the time C when the pressurizing has been completed, the pressure of the molten metal in the cavity is about 750 - 850 kg/cm$^2$ (73.5 - 83.3 MPa). At an early stage of the pressure increasing period of time from the point B, infiltration of the molten metal into the preform 2 will be completed. In the case where the pressure of the molten metal is imposed on the preform from a radially outside surface of the preform, like in the conventional method, a crack due to a shear force will occur at about 3 kg/cm$^2$ (0.294 MPa). In contrast, in the present invention, since the pressures acting on the outside surface and the inside surface balance or almost balance with each other, a crack due to a shear force does not happen throughout the pressure increasing period from point B to point C in FIG. 2.

**[0026]** Effects of the above-described portion common or similar to all of the examples and the embodiment of the present invention will be explained.

**[0027]** Since the clearance 8 between the preform 2 and the bore core 1 is formed throughout the entire circumference of the preform 2, the pressure of the molten metal is imposed on both the inside surface 2a and the outside surface 2b of the preform 2. Since the pressures acting on the inside and outside surfaces of the preform 2 balance with each other, no crack due to a shear force is caused to occur unlike the conventional case where a shear crack 109 shown in FIG. 13B is caused along a plane inclined by 45 degrees from the circumferential direction of the preform.

**[0028]** Further, a circumferential crack 110 shown in FIG. 14 that initiates at an end of the propagating shear crack will not be caused to occur because the shear crack itself does not occur and because the preform 2 is pressed from both the inside and outside surfaces of the preform and therefore no separating force acting between the layers of the reinforcement fibers will result.

**[0029]** Furthermore, unlike the conventional case, a radially inner portion of the preform is unlikely to be crushed. The reason is as follows:

**[0030]** Generally, if the preform has enough strength to endure a pressure equal to or greater than the pressure at the time when infiltration of the molten metal into the preform has just been completed, crushing of the preform will not occur. However, in the case of the conventional method, since the pressure at the time when infiltration of the molten metal into the preform has just been completed is high, it is difficult to prevent crushing of the preform. More particularly, when the molten metal is infiltrating the preform, the temperature of the tip portion of the molten metal will be decreased so that the viscosity of the tip portion of the molten metal will be increased. A portion close to the bore core, of the preheated preform is cooled by the bore core and the decrease in temperature of the molten metal at that portion of the preform close to the bore core is large. The molten metal will solidify at that portion of the preform so that a large pressure of the molten metal will act on the radially inner portion of the preform.

**[0031]** In contrast, with the above method, due to the clearance 8 provided between the bore core 1 and the inside surface of the preform 2, the following effects are caused:

(1) Because the preform 2 does not contact the bore core 1 or a contact surface of the preform 2 with the bore core 1 is minimized, the temperature of the preheated preform 2 is unlikely to decrease easily;
(2) Because the molten metal infiltrates into the preform 2 from both of the inside and outside surfaces of the preform 2, the distance by which the molten metal has to infiltrate into the preform before crushing of the preform begins is allowed to be a half of that of the conventional case.
(3) Because the molten metal infiltrates into the preform from not only the outside surface but also the inside surface of the preform, the surface area through which the molten metal infiltrates into the preform is increased. As a result, the molten metal can easily infiltrate into the preform and a distance by which the molten metal infiltrates into the preform can be large.

**[0032]** Because of these reasons, compression of the preform is unlikely to occur.

**[0033]** Portions unique to each example and the embodiment of the present invention will now be explained.

**[0034]** With the first example, as illustrated in FIGS. 3 and 4, at the first step, the preform 2 is supported by and squeezed between a fixed mold 3a and a movable mold 3b of the mold 3. The preform 2 does not contact the bore core 1, and the clearance 8 is formed throughout the entire circumference of the preform 2. The fixed mold 3a includes a cylinder block journal forming portion 3c having opposite surfaces. In order to introduce the molten metal 5 (see FIGS. 1A and 1B) into the clearance 8, an opening 3d for introducing a portion of the molten metal 5 to the clearance 8 inside of the preform 2 is formed between an upper end of each of the opposite surfaces of the cylinder block journal forming portion 3c and a lower end of the inside surface of the preform 2. The bore core 1 is supported by the movable mold 3b and is moved together with the movable mold 3b.

**[0035]** An effect of the first example is as follows:

**[0036]** With the conventional method where a preform 2 is supported by a bore core 1, there are various problems. More particularly, if a foreign substance is attached to the bore core 1, the preform 2 may not be able to be set onto the bore core 1. If the molten metal cannot enter the clearance formed between the bore core 1 and the preform 2, the preform 2 may be destroyed. If the clearance is too small, the preform may be destroyed during setting. In contrast, in the present example, because the preform 2 is supported by the movable mold 3b and the fixed mold 3a, the above-described problems are solved.

**[0037]** With the second example, as illustrated in FIG. 5, the bore core 1 has at least one protrusion 11 which protrudes radially outwardly from the outside surface 1a of the bore core 1 and which is integral with the bore core 1. At the first step, the preform 2 is supported by the bore core 1 at the protrusion 11. The preform 2 and the protrusion 11 line-contact or point-contact with each other. The clearance 8 is interrupted at the protrusion 11. The shape of the protrusion 11 is selected not to prevent the molten metal from filling the clearance 8.

**[0038]** With an effect of the second example, since the preform 2 is supported by the bore core 1 via the protrusion 11, it is easy to control the thickness of the clearance 8. As a result, the thickness of the clearance 8 can be controlled to about 0.5 mm which is a minimum thickness to ensure smooth filling of the molten metal, whereby the amount of machining of the cylinder bore after casting is minimized.

**[0039]** With the third example, as illustrated in FIG. 6, the bore core 1 has a plurality of protrusions which protrude from the outside surface 1a (FIG. 3) of the bore core and which are integral with the bore core 1. The protrusions extend in an axial (longitudinal) direction of the bore core 1. At the first step, the preform 2 is supported by the bore core 1 via the protrusions 11. Preferably, the number of the protrusions is equal to or more than three. The preform and the protrusions 11 line-contact with each other.

**[0040]** With an effect of the third example, since the protrusions extend in the axial direction of the bore core 1, the protrusions do not prevent the molten metal from flowing in the clearance 8 in the axial direction of the bore core 1. However, each clearance portion between the protrusions has to communicate with the opening (3d in FIG. 4) for introducing the molten metal to the clearance.

**[0041]** With the fourth example, as illustrated in FIG. 7, the bore core 1 has at least one protrusion 11 protruding radially outwardly from the outside surface 1a of the bore core. The protrusion 11 extends in an axial (longitudinal) direction of the bore core 1.

**[0042]** A portion of the bore core facing a cylinder block portion between adjacent cylinder bores (a portion of the bore core facing a cylinder block portion located on a line connecting centers of adjacent cylinder bores) is necessarily provided with the at least one protrusion 11.

**[0043]** The at least one protrusion 11 is omitted from the outboard portion of each of outboard two bore cores of multi-bore cores arranged in a longitudinal direction of a cylinder block. At the first step, the preform 2 is supported by the bore core 1 at the at least one protrusion 11. The preform 2 and the at least one protrusion 11 line-contact with each other. There is a clearance 8 except at the at least one protrusion.

**[0044]** With an effect of the fourth example, when the molten metal passes through a portion of the cavity between adjacent cylinder bores, the molten metal is throttled and imposes a greater pressure on the preform 2 at the throttle portion than other portions. However, since the preform 2 is necessarily supported by the protrusion 11, fracture of the preform 2 is prevented.

**[0045]** In the case where the bore core 1 is provided with the protrusion 11, aluminum adheres to the tip of the protrusion 11 and, as a result, it becomes difficult to set a preform member 2 to the protrusion at the next molding cycle. Since adhesion of aluminum resulting in seizure of the mold product with the protrusions occurs due to shrinkage at solidification of the cast material, it tends to occur at the longitudinal opposite ends of the cylinder block. However, in the present example, since the protrusions 11 at the outboard portions at the outboard bore cores are omitted, adhesion and solidification of aluminum to the protrusions is unlikely to occur.

**[0046]** With the fifth example, as illustrated in FIG. 8, the bore core 1 has a plurality of protrusions 11 protruding radially outwardly from the outside surface 1a of the protrusion 1. The protrusions extend in the axial (longitudinal) direction of the bore core 1. One 11' of the protrusions 11 is also provided at an outboard portion of each of outboard two bore cores of multi-bore cores arranged in a longitudinal direction of a cylinder block. The outboard protrusion 11' has a height that is lower than heights of two protrusions adjacent to the outboard protrusion 11' and that protrudes outboard from a line connecting tips of the two protrusions adjacent to the outboard protrusion 11'. At the first step, the preform 2 is supported by the bore core 1 at the protrusions 11. There is a clearance 8 except at the protrusions 11.

**[0047]** With an effect of the fifth example, the two outboard protrusions 11' are not used for supporting the preform 2. The protrusions 11 adjacent to the outboard protrusion 11' are used for supporting the preform 2. The outboard protrusion 11' is a dummy protrusion to which molten aluminum is caused to adhere thereby preventing much aluminum from adhering to the protrusions adjacent to the outboard protrusion 11' and preventing an excessive shrinkage force from acting on the protrusions 11 adjacent to the outboard protrusion 11'. Even if aluminum adheres to the outboard protrusion 11', since the outboard protrusion 11' is low in height, it is easy to remove the cast product from the protrusion 11' and no problem will arise during setting a preform to the core bore at the next cycle.

**[0048]** With the embodiment of the present invention, as illustrated in FIGS. 9 and 10, the protrusion (protruding member) 11 is formed separately from the bore core 1 and is mounted to the bore core 1 so as to be movable in a radial direction of the bore core 1. A tapered member 12 is provided between the protrusion 11 and a groove formed in the bore core 1 so as to be slidable relative to the bore core 1 and the protrusion 11. By moving the tapered member 12 in the axial direction of the bore core 1, the protrusion 11 is moved in the radial direction of the bore core 1 so that the protruding height of the protrusion 11 from the outside surface 1a of the bore core 1 is adjusted.

**[0049]** With an effect of the embodiment of the present invention, during setting the preform 2 to the bore core 1 and during supplying the molten metal to the cavity, the protrusion 11 is adjusted to take a most protruding position. While removing the cast product from the mold and bore core 1, the protrusion 11 is adjusted to take a most receding position, whereby the removing resistance is small and the cast product can be smoothly removed.

**[0050]** According to the present invention, the following technical advantages are obtained:

**[0051]** First, since the clearance 8 is formed between the preform 2 and the core bore 1, the pressures at the inside surface and the outside surface of the preform 2 balance with each other. As a result, a crack due to a shear force is unlikely to be caused in the preform 2, and a circumferential crack initiating a tip of the shear crack will not happen. Further, the molten metal can infiltrate into the preform from the inside and outside surfaces of the preform 2, compression of a portion of the preform in the thickness direction of the preform is unlikely to occur. Furthermore, due to the clearance 8, the temperature decrease of the preform 2 is suppressed and, as a result, the preheating temperature of the preform 2 is allowed to be low compared with the conventional method.

**[0052]** Second, in the case where the preform is supported by the upper mold and the lower mold, the preform 2 does not contact the bore core 1. As a result, the preform 2 does not need to be tapered, and the preform 2 is allowed to be formed as thin as possible.

**[0053]** Third, in the case where the preform 2 is supported by the bore core 1 at the protrusion 11, the thickness of the clearance 8 can be controlled substantially exactly to a specified thickness.

**[0054]** Fourth, in the case where the protrusion 11 extends axially in the bore core 1, the protrusion 11 does not prevent the molten metal from flowing into the clearance 8.

**[0055]** Fifth, in the case where the protrusion 11 is necessarily provided at a portion of the bore core 1 facing a portion of the cylinder block between adjacent cylinder bores, when a relatively large pressure of the molten metal flowing the portion between the cylinder bores acts on the preform 2, the preform can endure the pressure.

**[0056]** Sixth, in the case where the protrusion 11 is not provided at the outboard portion of the outboard bore core 1, even if the cylinder block material (cast product) causes a shrinkage in the longitudinal direction of the cylinder block, sticking at the tip of the outboard protrusion does not occur.

**[0057]** Seventh, in the case where the outboard protrusion is formed to have a low height, sticking at the tips of the protrusions adjacent to the outboard protrusion is prevented, and sticking at the tip of the outboard protrusion itself is prevented.

**[0058]** Last, since the protrusion is formed separately from the bore core 1 and is mounted to the bore core 1 so as to be movable in the radial direction relative to the bore core 1, by receding the protrusion during removing the cast product from the bore core 1 and the mold, sticking at the tip of the protrusion can be effectively prevented.

## Claims

1. An apparatus for producing a cylinder block of an internal combustion engine having a cylinder bore surface of metal matrix composite, comprising:

    a cavity (4) defined by a mold (3) comprising a fixed and a movable part (3a, 3b), including a bore core (1) having an outside surface (1a), said bore core (1) having at least one protrusion (11) protruding outwardly from said outside surface (1a) of the bore core (1) in a radial direction of the bore core (1) for supporting a generally cylindrical preform (2) intended to be set in the cavity (4) and having an inside surface (2a) and an outside surface (2b) such that except at the at least one protrusion (11) a clearance (8) for leading molten metal (5) is formed between the inside surface (2a) of the preform (2) and the outside surface (1a) of the bore core (1), wherein

    said at least one protrusion (11) is formed separately from the bore core (1) and is supported movably in a radial direction of the bore core (1) so that a protrusion height of the least one protrusion (11) from the outside surface (1a) of the bore core (1) is changeable.

2. An apparatus according to claim 1, wherein said clearance (8) has a thickness equal to or greater than 0.5 mm.

3. An apparatus according to claim 1, wherein said fixed part (3a) of the mold (3) includes a cylinder block journal forming portion (3c) having opposite surfaces, and wherein an opening (3d) for introducing a portion of said molten metal (5) to said clearance (8) inside of said preform (2) is formed between an upper end of each of said opposite surfaces of said cylinder block journal forming portion (3c) and a lower end of said inside surface (2a) of said preform (2).

4. An apparatus according to claim 1, wherein said at least one protrusion (11) is a plurality of protrusions that are spaced from each other in a circumferential direction of said bore core (1), each protrusion extending in an axial direction of said bore core (1).

5. An apparatus according to claim 4, wherein the total number of said plurality of protrusions (11) per cylinder bore is equal to or more than three.

6. An apparatus according to claim 1, wherein a portion of said bore core (1) facing a cylinder block portion between adjacent bores is necessarily provided with said at least one protrusion (11).

7. An apparatus according to claim 1, wherein said at least one protrusion (11) is omitted from an outboard portion of each of outboard two bore cores of a plurality of said bore cores (1) arranged in a longitudinal direction of the cylinder block.

8. An apparatus according to claim 1, wherein said at least one protrusion (11) is at least three protrusions among which one protrusion (11') is disposed at an outboard portion of each of two outboard bore cores of a plurality of said bore cores (1) arranged in a longitudinal direction of the cylinder block, and wherein said outboard protrusion (11') has a height that is lower than the heights of two protrusions (11) adjacent to said outboard protrusion (11') and that protrudes outboard from a line connecting tips of said two protrusions (11) adjacent to said outboard protrusion (11').

9. A method for producing a cylinder block of an internal combustion engine using an apparatus according to claim 1 and comprising the steps of:

    adjusting the protrusion height of said at least one protrusion (11) to take a most protruding position;

    setting a generally cylindrical preform (2) having an inside surface (2a) and an outside surface (2b) in said cavity (4) defined by said mold (3) including said bore core (1) such that the

preform (2) is supported by the at least one protrusion (11);
supplying molten metal (5) into the cavity (4) so that the molten metal (5) infiltrates the preform (2) from both the inside surface (2a) and the outside surface (2b) of the preform (2) whereby said preform (2) changes to a metal matrix composite and a cylinder block cast product (9) is obtained;
adjusting the protrusion height of the at least one protrusion (11) to take a most receding position;
taking the cylinder block cast product (9) out from the mold (3) and the bore core (1) after the molten metal (5) has solidified; and
machining a cylinder bore surface of metal matrix composite of each cylinder bore of the cylinder block cast product (9) to a specified diameter.

**10.** A method according to claim 10, wherein, during said setting, said preform (2) is preheated to a temperature equal to or higher than 300°C and lower than 700°C.

## Patentansprüche

**1.** Gerät zum Herstellen eines Zylinderblocks einer Verbrennungskraftmaschine, der eine Zylinderbohrungsoberfläche aus einem Metallmatrixverbundwerkstoff hat, mit:

einem Hohlraum (4), der durch eine Form (3) mit einem fixierten und einem beweglichen Teil (3a, 3b) definiert ist, die einen Bohrungskern (1) mit einer Außenfläche (1a) umfassen,

wobei der Bohrungskern (1) mindestens einen Vorsprung (11) hat, der nach außen von der Außenfläche (1a) des Bohrungskerns (1) in eine radiale Richtung des Bohrungskerns (1) zum Lagern einer im allgemeinen zylindrischen in den Hohlraum (4) einsetzbaren Vorform (2) vorspringt, und der eine Innenfläche (2a) und eine Außenfläche (2b) hat, so dass mit Ausnahme des mindestens einen Vorsprungs (11) ein Freiraum (8) zum Leiten des geschmolzenen Metalls (5) zwischen der Innenfläche (2a) der Vorform (2) und der Außenfläche (1a) des Bohrungskerns (1) ausgebildet ist,

wobei der mindestens eine Vorsprung (11) getrennt von dem Bohrungskern (1) ausgebildet ist und in eine radiale Richtung des Bohrungskerns (1) so beweglich gelagert.ist, dass eine Vorsprungshöhe des mindestens einen Vorsprungs (11) von der Außenfläche (1a) des Bohrungskerns (1) veränderbar ist.

**2.** Gerät nach Patentanspruch 1, wobei der Freiraum (8) eine Dicke gleich oder größer als 0,5 mm hat.

**3.** Gerät nach Patentanspruch 1, wobei der fixierte Teil (3a) der Form (3) einen Zylinderblocklager bildenden Abschnitt (3c) mit entgegengesetzten Oberflächen umfasst und wobei eine Öffnung (3d) zum Einführen eines Teils des geschmolzenen Metalls (5) in den Freiraum (8) innenseitig der Vorform (2) zwischen einem oberen Ende von jedem der entgegengesetzten Oberflächen des Zylinderblocklager bildenden Abschnitts (3c) und einem unteren Ende der Innenfläche (2) der Vorform (2) ausgebildet ist.

**4.** Gerät nach Patentanspruch 1, wobei der mindestens eine Vorsprung (11) eine Mehrzahl von voneinander in eine Umfangsrichtung des Bohrungskerns (1) beabstandete Vorsprünge aufweist, wobei jeder Vorsprung sich in eine axiale Richtung des Bohrungskerns (1) erstreckt.

**5.** Gerät nach Patentanspruch 4, wobei die Gesamtzahl der Mehrzahl von Vorsprüngen (11) pro Zylinderbohrung gleich oder größer als drei ist.

**6.** Gerät nach Patentanspruch 1, wobei ein Abschnitt des Bohrungskerns (1), der einem Zylinderblockabschnitt zwischen benachbarten Bohrungen gegenüberliegt, notwendiger Weise mit dem mindestens einen Vorsprung (11) vorgesehen ist.

**7.** Gerät nach Patentanspruch 1, wobei der mindestens eine Vorsprung (11) von einem äußeren Abschnitt eines jeden der äußeren zwei Bohrungskerne einer Mehrzahl von in einer Längsrichtung des Zylinderblocks angeordneten Bohrungskernen (1) weggelassen sind.

**8.** Gerät nach Patentanspruch 1, wobei der mindestens eine Vorsprung (11) mindestens einer von drei Vorsprüngen ist, unter denen ein Vorsprung (11') an einem äußeren Abschnitt eines jeden von zwei äußeren Bohrungskernen einer Mehrzahl der Bohrungskerne (1) angeordnet ist, die in eine Längsrichtung des Zylinderblocks angeordnet sind, und wobei der äußere Vorsprung (11') eine Höhe hat, die niedriger ist als die Höhen von zwei Vorsprüngen (11), die zu dem äußeren Vorsprung (11') benachbart sind, und der außerhalb einer Linie vorspringt, die Spitzen der zwei Vorsprünge (11), die zu dem äußeren Vorsprung (11') benachbart sind, verbindet.

**9.** Verfahren zum Herstellen eines Zylinderblocks einer Verbrennungskraftmaschine unter Verwendung eines Geräts nach Patentanspruch 1 mit den Schritten:

Einstellen der Vorsprungshöhe des mindestens einen Vorsprungs (11), um eine am meisten vorspringende Position einzunehmen;
Setzen einer im Allgemeinen zylindrischen Vorform (2) mit einer Innenfläche (2a) und einer Außenfläche (2b) in den Hohlraum (4), der durch die den Bohrungskern (1) enthaltende Form (3) definiert ist, so dass die Vorform (2) durch den mindestens einen Vorsprung (11) gelagert ist;
Zuführen von geschmolzenem Metall (5) in den Hohlraum (4), so dass das geschmolzene Metall (5) die Vorform (2) von beiden, der Innenfläche (2a) und der Außenfläche (2b) der Vorform (2), infiltriert, wodurch die Vorform (2) sich in einen Metallmatrixverbundwerkstoff verändert und ein Zylinderblockgussprodukt (9) erhalten wird;
Einstellen der Vorsprungshöhe des mindestens einen Vorsprungs (11) um eine am meisten gesenkte Stellung einzunehmen;
Nehmen des Zylinderblockgussprodukts (9) von der Form (3) und dem Bohrungskern (1), nachdem das geschmolzene Metall (5) sich verfestigt hat; und
Bearbeiten einer Zylinderbohrungsoberfläche aus Metallmatrixverbundwerkstoff einer jeden Zylinderbohrung des Zylinderblockgussprodukts (9) auf einen bestimmten Durchmesser.

**10.** Verfahren nach Patentanspruch 10, wobei die Vorform (2) während des Einsetzens auf eine Temperatur gleich oder höher als 300°C und niedriger als 700°C vorgewärmt wird.

## Revendications

**1.** Dispositif destiné à la fabrication d'un bloc-cylindres d'un moteur à combustion interne comportant une surface d'alésages de cylindres d'un composite de matrice de métal, comprenant :

une cavité (4) définie par un moule (3) comprenant une partie fixe et une partie mobile (3a, 3b), comprenant un noyau d'alésage (1) présentant une surface extérieure (1a),
ledit noyau d'alésage (1) comportant au moins une saillie (11) dépassant vers l'extérieur depuis ladite surface extérieure (1a) du noyau d'alésage (1) dans une direction radiale du noyau d'alésage (1) en vue de supporter une préforme sensiblement cylindrique (2) prévue pour être installée dans la cavité (4) et présentant une surface intérieure (2a) et une surface extérieure (2b) de sorte qu'à l'exception de la au moins une saillie (11), un dégagement (8) destiné à conduire du métal fondu (5) est formé entre la surface intérieure (2a) de la préforme (2) et la surface extérieure (1a) du noyau d'alésage (1), dans lequel
ladite au moins une saillie (11) est formée séparément du noyau d'alésage (1) et est supportée de façon mobile dans une direction radiale du noyau d'alésage (1) de sorte qu'une hauteur de saillie de la au moins une saillie (11) depuis la surface extérieure (1a) du noyau d'alésage (1) est modifiable.

**2.** Dispositif selon la revendication 1, dans lequel ledit dégagement (8) présente une épaisseur supérieure ou égale à 0,5 mm.

**3.** Dispositif selon la revendication 1, dans lequel ladite partie fixe (3a) du moule (3) comprend une partie formant une portée du bloc-cylindres (3c) présentant des surfaces opposées, et dans lequel une ouverture (3d) destinée à introduire une partie dudit métal fondu (5) vers ledit dégagement (8) à l'intérieur de ladite préforme (2) est formée entre une extrémité supérieure de chacune desdites surfaces opposées de ladite partie formant une portée du bloc-cylindres (3c) et une extrémité inférieure de ladite surface intérieure (2a) de ladite préforme (2).

**4.** Dispositif selon la revendication 1, dans lequel ladite au moins une saillie (11) est constituée d'une pluralité de saillies qui sont espacées les unes des autres dans une direction circonférentielle dudit noyau d'alésage (1), chaque saillie s'étendant dans une direction axiale dudit noyau d'alésage (1).

**5.** Dispositif selon la revendication 4, dans lequel le nombre total de ladite pluralité de saillies (11) par alésage de cylindre est supérieur ou égal à trois.

**6.** Dispositif selon la revendication 1, dans lequel une partie dudit noyau d'alésage (1) faisant face à une partie de bloc-cylindres entre des alésages adjacents est nécessairement munie de ladite au moins une saillie (11).

**7.** Dispositif selon la revendication 1, dans lequel ladite au moins une saillie (11) est omise d'une partie extérieure de chacun des deux noyaux d'alésage extérieurs parmi une pluralité desdits noyaux d'alésage (1) disposés dans une direction longitudinale du bloc-cylindres.

**8.** Dispositif selon la revendication 1, dans lequel ladite au moins une saillie (11) est constituée d'au moins trois saillies parmi lesquelles une saillie (11') est disposée au niveau d'une partie extérieure de chacun des deux noyaux d'alésage extérieurs parmi une pluralité desdits noyaux d'alésage (1) disposés dans une direction longitudinale du bloc-cylindres, et dans lequel ladite saillie extérieure (11') présente une hauteur qui est inférieure aux hauteurs des deux saillies (11) adjacentes à ladite saillie extérieure (11') et qui dépasse à l'extérieur d'une ligne reliant les pointes desdites deux saillies (11) adjacentes à ladite saillie extérieure (11').

**9.** Procédé destiné à la fabrication d'un bloc-cylindres d'un moteur à combustion interne utilisant un dispositif selon la revendication 1 et comprenant les étapes consistant à :

ajuster la hauteur de saillie de ladite au moins une saillie (11) afin d'adopter une position davantage saillante,
installer une préforme sensiblement cylindrique (2) présentant une surface intérieure (2a) et une surface extérieure (2b) dans ladite cavité (4) définie par ledit moule (3) comprenant ledit noyau d'alésage (1) de sorte que la préforme (2) soit supportée par la au moins une saillie (11),
introduire du métal fondu (5) dans la cavité (4) de sorte que le métal fondu (5) s'infiltre dans la préforme (2) depuis à la fois la surface intérieure (2a) et la surface extérieure (2b) de la préforme (2), grâce à quoi ladite préforme (2) se transforme en un composite de matrice de métal, et un produit moulé de bloc-cylindres (9) est obtenu,
ajuster la hauteur de saillie de la au moins une saillie (11) pour qu'elle adopte une position plus retirée,
retirer le produit moulé de bloc-cylindres (9) du moule (3) et du noyau d'alésage (1) après que le métal fondu (5) se soit solidifié, et
usiner une surface d'alésage de cylindre du composite de matrice de métal de chaque alésage de cylindre du produit moulé de bloc-cylindres (9) à un diamètre spécifié.

**10.** Procédé selon la revendication 9, dans lequel, durant ladite installation, ladite préforme (2) est préchauffée à une température supérieure ou égale à 300 °C et inférieure à 700 °C.

FIG. 1A

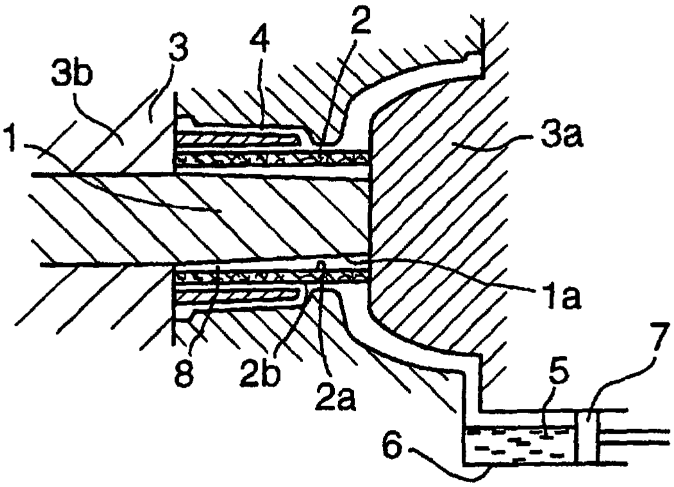



FIG. 1B

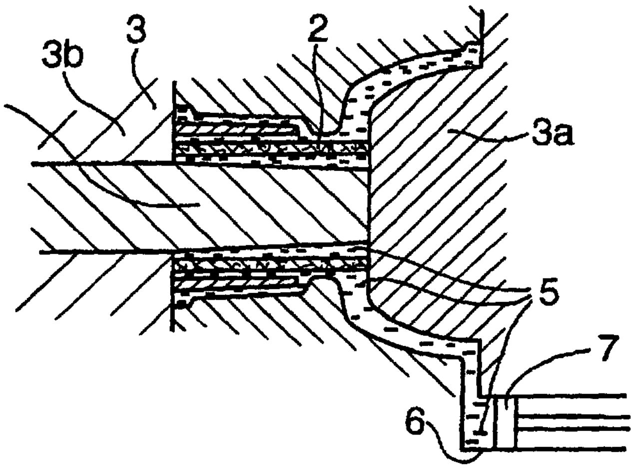



FIG. 1C

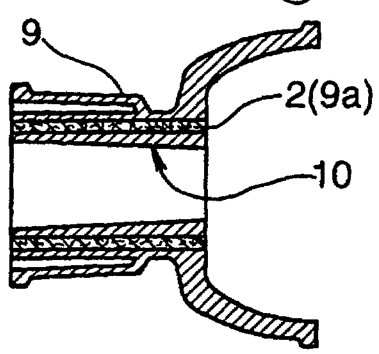



FIG. 1D

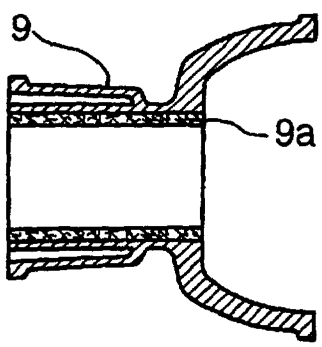


FIG. 2

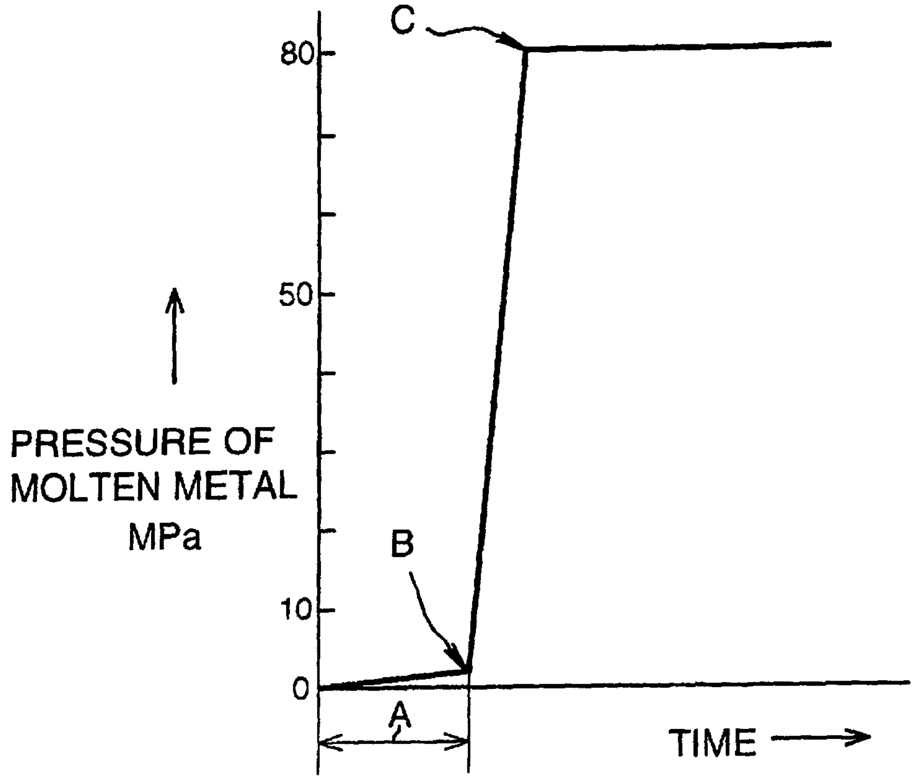

C
80
50
10
0
PRESSURE OF
MOLTEN METAL
MPa
B
A
TIME

FIG. 3

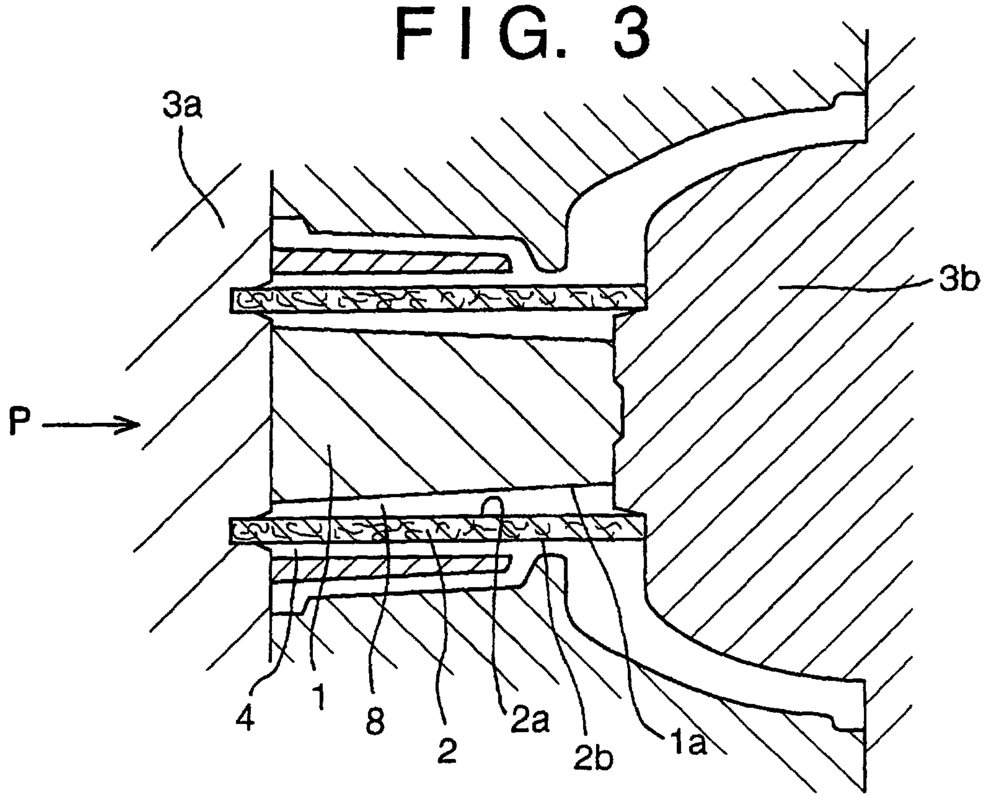

3a
3b
P
4
1
8
2
2a
2b
1a

FIG. 4

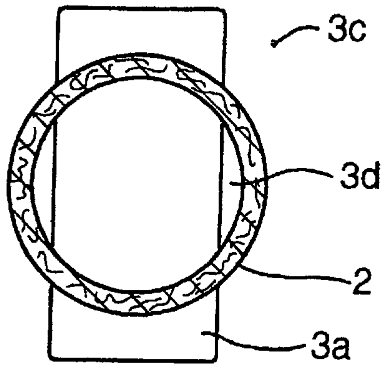



FIG. 5

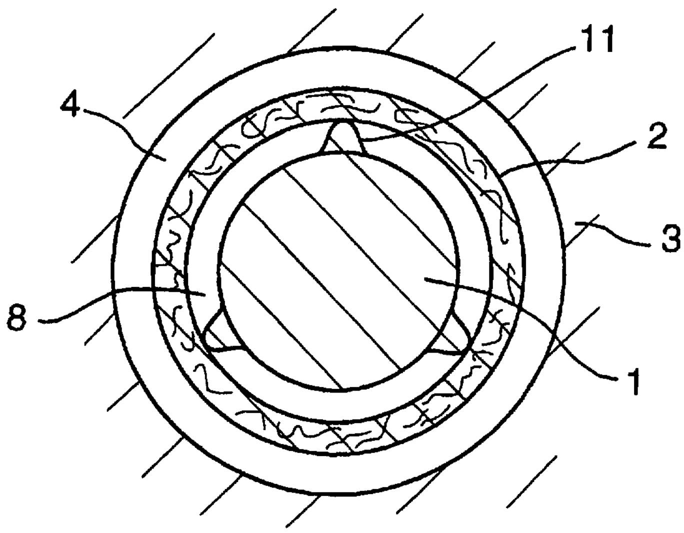



FIG. 6

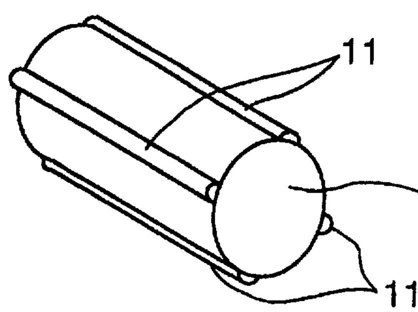


FIG. 7

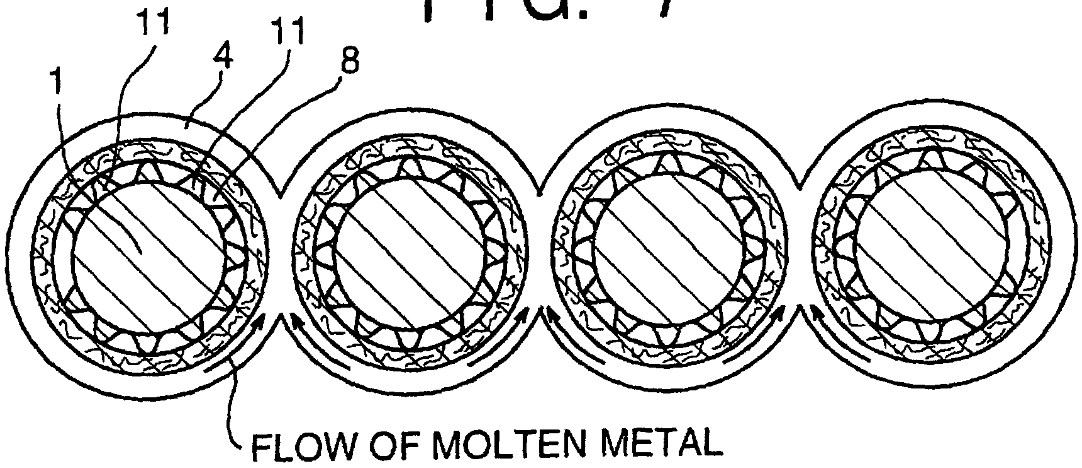



FIG. 8

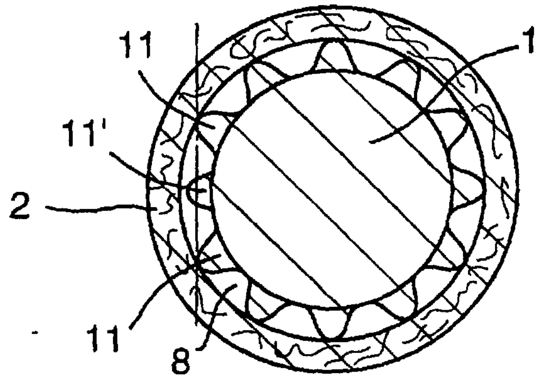



FIG. 9

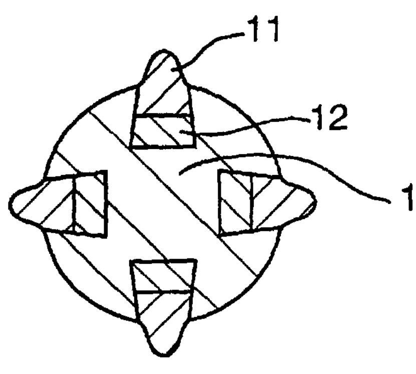


FIG. 10

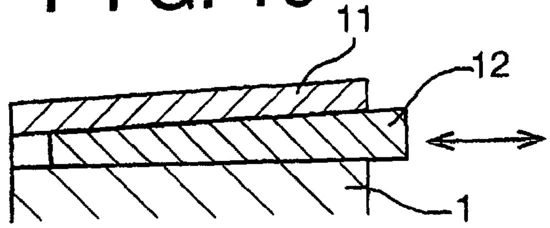



FIG. 11 (PRIOR ART)

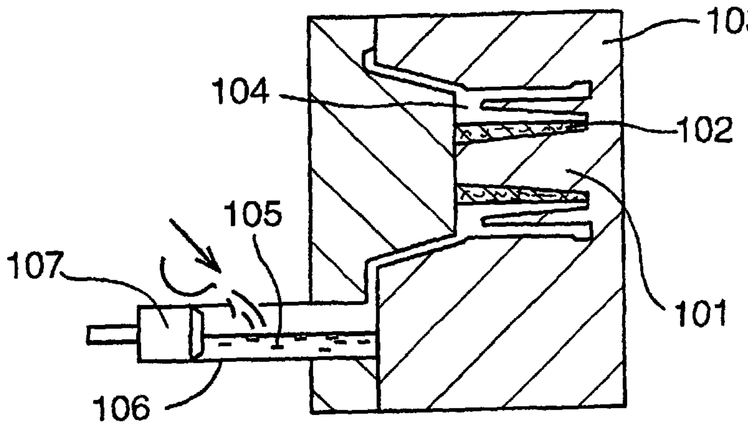



FIG. 12 (PRIOR ART)

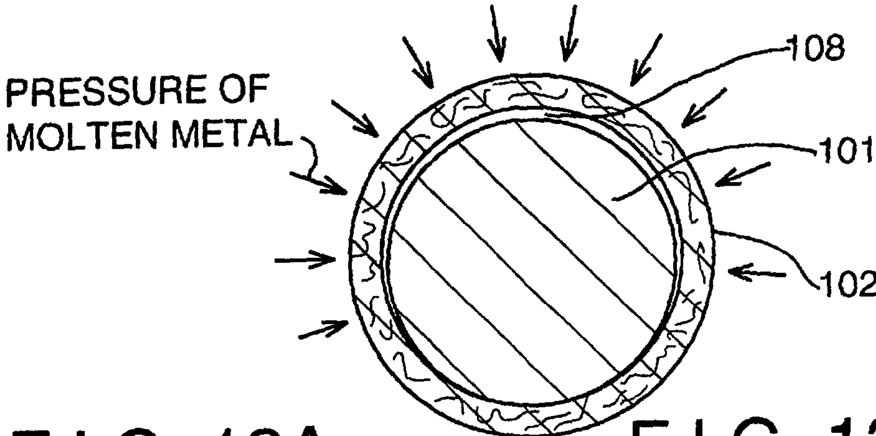



FIG. 13A (PRIOR ART)

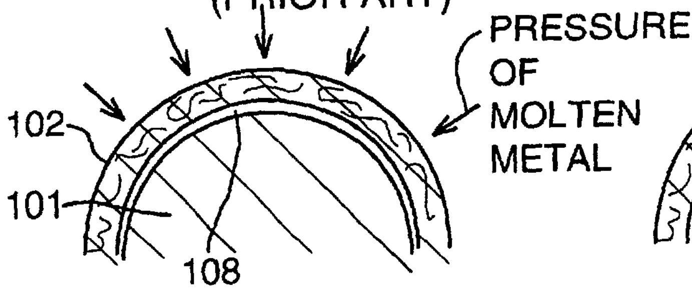
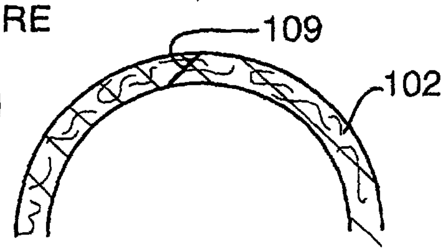
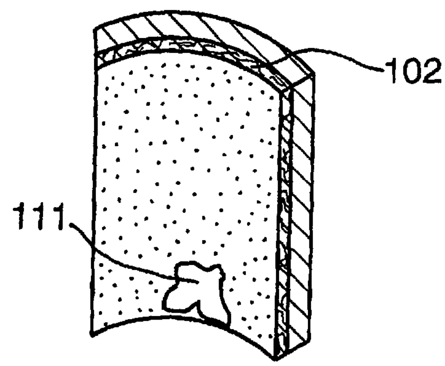



FIG. 13B (PRIOR ART)



F I G. 14 (PRIOR ART)


F I G. 15 (PRIOR ART)




F I G. 16 (PRIOR ART)