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(71) Applicant: **Hitachi Metals, Ltd.**
Tokyo 1088224 (JP)

(72) Inventor: **FUKUMOTO Kentaro**
Miyako-gun
Fukuoka 800-0393 (JP)

(74) Representative: **Diehl & Partner GbR**
Patentanwälte
Erika-Mann-Strasse 9
80636 München (DE)

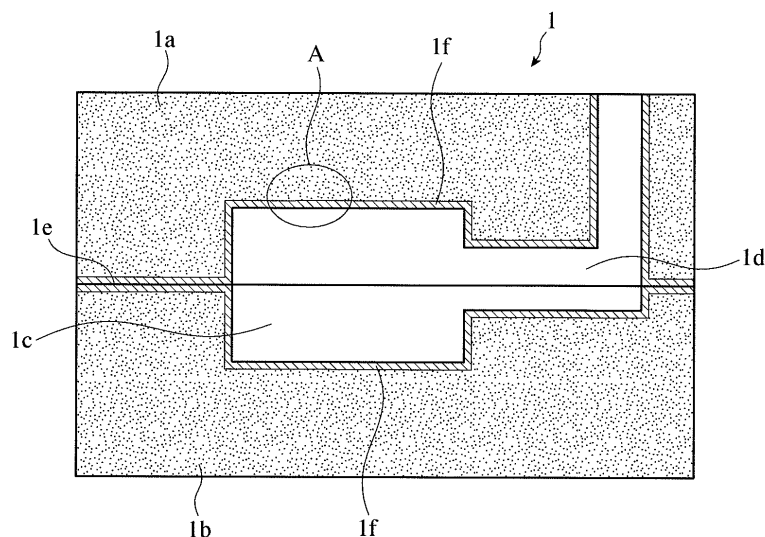
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(54) **GREEN SAND FOR CASTING OF STEEL CASTINGS, METHOD FOR PRODUCING SAME, AND METHOD FOR PRODUCING METAL CASTINGS USING SAID GREEN SAND**

(57) A green sand mold for producing a cast steel article, which is formed by casting sand comprising sand, a binder, and 3 parts or less by mass of a carbonaceous component per 100 parts by mass of sand, and provided with a coating layer of a thermosetting resin formed at

least on a recess including a cavity for forming the cast steel article, the coating layer having average hardness (measured by a self-hardening hardness meter) of 50-95 and a thickness of 0.5-2.5 mm.

Fig. 1



Description

FIELD OF THE INVENTION

[0001] The present invention relates to a green sand mold suitable for producing a cast stainless steel article known as a particularly hard-to-cut material, and its production method, and a method for producing a cast steel article using such a green sand mold.

BACKGROUND OF THE INVENTION

[0002] Casting sand constituting green sand molds for producing cast steel articles generally comprises aggregates (sand), a binder such as bentonite, etc., carbonaceous components (coal, starch, etc.) as secondary additives, and water. The ratios of aggregates, a binder, etc. in the casting sand are properly determined to provide the green sand molds with desired properties [air permeability, strength, the stability of cavity surfaces, and compactability (CB), etc.]. Carbonaceous components such as coal powder, coke powder, graphite powder, pitch powder, etc. added to the casting sand prevent the sticking of aggregates (sand) to castings (sand seizure), thereby stabilizing the as-cast surface quality of cast steel articles. Technologies concerning coal are disclosed in JP 63-177939 A and JP 2009-291801 A.

[0003] JP 63-177939 A discloses a method for producing a casting green sand mold by blending 1-2 parts of an additive for a casting sand mold, which comprises 10-90% by weight of a mineral oil and 90-10% by weight of a carbonaceous material; 100 parts of aggregate, 10 parts of bentonite (binder), 1 part of starch, and 3 parts of water; and forming the resultant casting sand into the green sand mold. JP 2009-291801 A discloses casting sand for a green sand mold, which comprises a carbonaceous additive comprising as a main component an edible vegetable oil containing glycerin, bentonite (binder), and if necessary, additives such as starch, etc., and a predetermined amount of water.

[0004] However, when cast steel articles having hypo-eutectoid compositions containing about 0.05-0.60% by mass of carbon are produced by green sand molds formed by casting sand containing the additives disclosed in JP 63-177939 A and JP 2009-291801 A, which include mineral oils, carbonaceous materials or vegetable oils, the cast steel articles may have as-cast surfaces carburized by carbonaceous components contained in the green sand molds. With the carburized as-cast surface layers, cast steel articles are not easily machined. This problem is particularly serious in cast stainless steel articles needing high heat resistance and corrosion resistance, which are used, for example, as exhaust members for internal combustion engines.

OBJECT OF THE INVENTION

[0005] Accordingly, an object of the present invention is to provide a green sand mold for producing a cast steel article with suppressed sand seizure and carburization on an as-cast surface layer while keeping as good as-cast surface quality as conventional one, and its production method, and a method for producing a cast steel article using such a green sand mold.

DISCLOSURE OF THE INVENTION

[0006] As a result of intensive research to satisfy two contradicting objects of suppressing the carburization of an as-cast surface layer while keeping as good as-cast surface quality (sand seizure) as conventional one, it has been found that (1) by reducing the ratio of a carbonaceous component in casting sand constituting a green sand mold to such a level as not generating carburization, and (2) by setting the thickness of a coating layer of a thermosetting resin formed on a recess of a green sand mold, to such a level that (a) a cavity surface is covered with a gas generated by the decomposition of the thermosetting resin until a melt introduced into the cavity starts to be solidified, thereby preventing sand seizure, and that (b) the decomposition gas disappears immediately after the solidification of the melt, the as-cast surface quality can be kept while suppressing the carburization of an as-cast surface layer. The present invention has been completed based on such finding.

[0007] Thus, the green sand mold of the present invention for producing a cast steel article is formed by casting sand comprising sand, a binder, and 3 parts or less by mass of a carbonaceous component per 100 parts by mass of the sand; at least a recess including a cavity for forming the cast steel article being provided with a coating layer of a thermosetting resin; and the coating layer having average hardness (measured by a self-hardening hardness meter) of 50-95 and a thickness of 0.5-2.5 mm.

[0008] The amount of the thermosetting resin forming the coating layer is preferably 100-500 g/m² on a solid basis.

[0009] The amount of carbon remaining in a unit volume of the coating layer is preferably 20-200 mg/cm³ after heated to 800°C at a speed of 10°C/minute in the air.

[0010] The method of the present invention for producing the above green sand mold comprises forming casting sand comprising sand, a binder, and 3 parts or less by mass of a carbonaceous component per 100 parts by mass of sand, into at least a pair of green sand mold parts (for example, upper and lower mold parts), which comprises a recess including a cavity for forming the cast steel article;

coating at least the recess with a coating solution comprising a thermosetting resin and an organic solvent; and thermally curing the thermosetting resin coated on the recess, to form a coating layer having average hardness (measured by a self-hardening hardness meter) of 50-95.

[0011] The thermosetting resin may be thermally cured before and/or after combining the green sand mold parts. In the first embodiment, at least a pair of green sand mold parts are combined after thermally curing the thermosetting resin. In the second embodiment, the hardening of a coating layer obtained by drying the coating solution is carried out by a first hardening step of heating to average hardness (measured by a self-hardening hardness meter) of 30-45, and a second hardening step of further heating the primarily hardened coating layer to average hardness (measured by a self-hardening mold hardness tester) of 50-95.

[0012] The coating solution preferably has a viscosity of 15-100 mPa·s.

[0013] The method of the present invention for producing a cast steel article uses the above green sand mold.

EFFECTS OF THE INVENTION

[0014] Because the green sand mold of the present invention formed by casting sand containing 3 parts or less by mass of a carbonaceous component per 100 parts by mass of sand comprises a recess, on which a coating layer of a thermosetting resin having average hardness (measured by a self-hardening hardness meter) of 50-95 and a thickness of 0.5-2.5 mm is formed, a cast steel article having less carburized as-cast surface layer can be produced while keeping as good as-cast surface quality as conventional one.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015]

Fig. 1 is a cross-sectional view showing the structure of the green sand mold of the present invention.

Fig. 2 is an enlarged partial cross-sectional view showing a portion A in Fig. 1.

Fig. 3(a) is a cross-sectional view showing a mold-forming step in the first example of the production processes of the green sand mold shown in Fig. 1.

Fig. 3(b) is a cross-sectional view showing a coating-solution-applying step in the first example of the production processes of the green sand mold shown in Fig. 1.

Fig. 3(c) is a cross-sectional view showing a thermosetting-resin-curing step in the first example of the production processes of the green sand mold shown in Fig. 1.

Fig. 3(d) is a cross-sectional view showing a molds-combining step in the first example of the production processes of the green sand mold shown in Fig. 1.

Fig. 4(a) is a cross-sectional view showing a mold-forming step in the second example of the production processes of the green sand mold shown in Fig. 1.

Fig. 4(b) is a cross-sectional view showing a coating-solution-applying step in the second example of the production processes of the green sand mold shown in Fig. 1.

Fig. 4(c) is a cross-sectional view showing a first thermosetting-resin-curing step in the second example of the production processes of the green sand mold shown in Fig. 1.

Fig. 4(d) is a cross-sectional view showing a molds-combining step in the second example of the production processes of the green sand mold shown in Fig. 1.

Fig. 4(e) is a cross-sectional view showing a second thermosetting-resin-curing step in the second example of the production processes of the green sand mold shown in Fig. 1.

Fig. 5(a) is an enlarged schematic view showing casting sand (before coated with a thermosetting resin) constituting the green sand mold.

Fig. 5(b) is an enlarged schematic view showing thermosetting-resin-coated casting sand constituting the green sand mold.

Fig. 6 is a cross-sectional view showing the production method of a cast steel article using the green sand mold shown in Fig. 1.

Fig. 7 is an enlarged partial cross-sectional view showing a portion B in Fig. 6.

Fig. 8(a) is a SEM photograph (100 times) showing casting sand constituting the green sand mold of Example 1.

Fig. 8(b) is a SEM photograph (100 times) showing phenol-resin-coated casting sand constituting the green sand mold of Example 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0016] The embodiments of the present invention will be explained in detail below referring to the attached drawings, without intention of restricting the present invention thereto. Explanations of each embodiment will be applicable to other embodiments unless otherwise mentioned.

[0017] Fig. 1 shows the structure of the green sand mold of the present invention, Fig. 2 enlargedly shows a portion A in Fig. 1, Figs. 3 and 4 show the production steps of the green sand mold shown in Fig. 1, and Fig. 6 shows a production step of a cast steel article using the green sand mold of Fig. 1. The term "cast steel article" used herein means a casting having a hypo-eutectoid composition comprising 0.05-0.6% by mass of C and other elements (Ni, Cr, Si, W, Mo, Nb, etc.), the balance being Fe and inevitable impurities, though not restrictive.

[1] Structure of green sand mold

[0018] As shown in Fig. 1, a green sand mold 1 formed by casting sand containing substantially no carbonaceous component is constituted by an upper mold part 1a and a lower mold part 1b combined along a parting surface 1e. The green sand mold 1 obtained by combining the upper mold part 1a and the lower mold part 1b comprises a cavity (article-forming cavity) 1c for forming an article, and a runner 1d. The article-forming cavity 1c and the runner 1d are formed by recesses in the upper mold part 1a and the lower mold part 1b. Of course, the green sand mold 1 may be encircled by a flask. In addition to the article-forming cavity 1c and the runner 1d, the green sand mold 1 may comprise a riser, a gate, a sprue, etc.

(A) Casting sand

[0019] The casting sand comprises sand, a binder, and a carbonaceous component.

(1) Sand

[0020] As aggregate constituting the casting sand, sand per se may be usual one, which may be, for example, mountain sand, semi-synthesized sand or synthesized sand. The mountain sand may be natural sand containing at least 2% of clay, for example, Noma sand in Aichi Prefecture, Kawachi sand in Osaka, Shima sand in Mie Prefecture, Matsue sand in Shimane Prefecture, Ohta sand in Fukushima Prefecture, etc. as well as Enshu sand, Genkai sand, etc. The semi-synthesized sand may be mountain sand properly blended with silica sand, a binder and additives. The synthesized sand may be silica sand, etc. blended with a binder and additives without using mountain sand at all. Sand for the synthesized sand may be natural silica sand such as Gairome silica sand, beach sand and river sand, artificial silica sand, zirconium silicate, olivine sand, chromite sand, etc.

(2) Binder

[0021] The binder may be bentonite, clay, montmorillonite, kaolin, etc. The amount of the binder is generally 5-12 parts by mass per 100 parts by mass of sand, though properly adjustable depending on the characteristics of the green sand mold.

(3) Carbonaceous component

[0022] The carbonaceous component may be a carbonaceous material such as coal, graphite, cokes, pitch cokes, asphalt, etc.; a starch-type additive such as dextrin, starch, etc.; a liquid oil such as mineral oil, vegetable oil, etc. The carbonaceous component does not include a carbon compound contained in sand or a binder. The carbonaceous components may be used alone or combined.

[0023] To prevent the carburization of a cast steel article, the carbonaceous component is 3 parts or less by mass per 100 parts by mass of sand in the present invention. When casting is conducted using a green sand mold in which the carbonaceous component is more than 3 parts by mass of the casting sand, a cast surface layer is carburized. The amount of the carbonaceous component is more preferably 1 part by mass, most preferably 0.7 parts or less by mass.

(B) Coating layer

[0024] As shown in Figs. 1 and 2, at least a surface layer of the article-forming cavity 1c is provided with a coating layer 1f made of a thermosetting resin having average hardness of 50-95 (measured by a self-hardening hardness meter). To achieve the object of the present invention of suppressing the carburization of a cast surface layer while keeping a conventional level of as-cast surface quality, the coating layer 1f need only be formed on the article-forming cavity 1c, though carburization can be suppressed more effectively when a coating layer 1f is also formed on a runner 1d through which a melt passes. Accordingly, the coating layer 1f is formed on at least a recess including the cavity 1c and the runner 1d in the present invention. Further, when a coating layer 1f is also formed on parting surfaces 1e, the parting surfaces 1e can have increased strength, suppressing the breakage of the mold, etc. when the melt is supplied.

[0025] The thermosetting resin is not particularly restricted, as long as it is a high-strength, high-hardness thermosetting resin, which is not broken when combining the mold parts, and easily gasified by decomposition by contact with a steel melt. It includes, for example, phenol resins, epoxy resins, melamine resins, urea resins, unsaturated polyester resins, alkyd resins, polyurethanes, thermally curable polyimides, etc. The thermoset resin coating layer 1f has average hardness in a range of 50-95. The hardness of the coating layer 1f is measured by a self-hardening mold hardness tester (NK-009 available from Nakayama Co., Ltd.). The coating layer 1f cannot suppress sand seizure when having too low average hardness. On the other hand, it cannot hold enough air permeability, likely suffering gas defects, when having too high average hardness.

[0026] The thermosetting resin forming the coating layer 1f is gasified and partially carbonized by contact with a high-temperature melt, leaving a carbonaceous component in a surface layer of the article-forming cavity 1c. To prevent the carburization of an as-cast surface layer effectively, the amount of residual carbon per a unit volume of the coating layer 1f is preferably 200 mg/cm³ or less, when heated from room temperature to 800°C at a speed of 10°C/minute in the air. When the amount of residual carbon is too small, sand seizure likely occurs because too little gas is generated. Accordingly, the amount of residual carbon is preferably 20 mg/cm³ or more. When the amount of residual carbon is too much, the carburization of an as-cast surface layer cannot be prevented sufficiently. Accordingly, the upper limit of the amount of residual carbon is preferably 200 mg/cm³. The amount of residual carbon is more preferably 20-100 mg/cm³. The amount of residual carbon is determined by the thermogravimetric analysis (TGA) of a thermosetting resin.

[0027] As shown in Fig. 2, the green sand mold 1 formed by sand particles 1j and a binder (not shown), etc. has a lot of voids (pores) 1i between sand particles 1j for enough gas permeability. Because the coating solution containing a thermosetting resin in an organic solvent intrudes into pores 1i in the surface layer of the article-forming cavity 1c, the thermosetting resin remains on sand particles 1j in the surface layer, after the coating solution is dried. As a result, a region comprising sand particles 1j covered with the thermosetting resin is formed in the surface layer of the article-forming cavity 1c. This region is called "coating layer 1f." In the coating layer 1f, sand particles 1j are covered with the thermosetting resin, leaving voids (pores) 1i. The thickness T of the coating layer 1f is expressed by an average value, because the thermosetting resin does not have uniform depth as shown in Fig. 2. The thickness T of the coating layer 1f is measured at plural points (for example, 3 points) in a cross section of the article-forming cavity 1c provided with the coating layer 1f, and averaged.

[0028] When the coating layer 1f has too large thickness T, the undecomposed thermosetting resin is carbonized, leaving a carbonaceous component by which the as-cast surface layer is likely carburized. To prevent the carburization of an as-cast surface layer effectively, the thickness T of the coating layer 1f is preferably 2.5 mm or less, more preferably 2.0 mm or less, most preferably 1.5 mm or less. When the coating layer 1f has too small thickness T, the coating layer 1f easily peels during a casting operation, so that a melt intruding into portions exposed by peeling of the coating layer 1f comes into direct contact with sand in the green sand mold, resulting in sand seizure. Accordingly, the thickness T of the coating layer 1f is preferably 0.5 mm or more.

[0029] What are important in the coating layer 1f are not only its thickness T but also the amount of the coated thermosetting resin. The amount of the coated thermosetting resin is expressed by the dry weight (g/m²) of a thermosetting resin per a unit area. The amount of the coated thermosetting resin is preferably 100-500 g/m². When the amount of the coated thermosetting resin is less than 100 g/m², sand seizure cannot be prevented. On the other hand, when the amount of the coated thermosetting resin is more than 500 g/m², the green sand mold has too low air permeability. As a result, gas defects likely occur, and the undecomposed thermosetting resin is carbonized, leaving a carbonaceous component by which the as-cast surface layer is likely carburized. To prevent the carburization of an as-cast surface layer effectively while keeping good as-cast surface quality, the amount of the curable resin in the coating layer 1f is more preferably 220-380 g/m². The amount of the coated thermosetting resin can be determined by dividing the weight increment ΔD (g) of the green sand mold after drying the coating solution by the coating area (m²) of the thermosetting resin.

[0030] The coating layer 1f preferably has air permeability of 70-150. When the coating layer 1f has too low air permeability, the generated gas is trapped by a melt, likely resulting in a cast steel article having defects such as pinholes, etc. When the coating layer 1f has too high air permeability, the coating layer 1f peels, resulting in a cast steel article

having poor appearance and sand detachability. The air permeability can be measured by a rapid method described in Attachment 3 of JIS Z 2601.

[2] Production method of green sand mold

(A) First example

(1) Mold-forming step

[0031] As shown in Fig. 3(a), casting sand obtained by blending predetermined amounts of sand, a binder, a carbonaceous component and water is formed into an upper mold part 1a and a lower mold part 1b having recesses 1g-1, 1g-2 for an article-forming cavity 1c and a runner 1d. To provide a green sand mold with enough strength with easy forming, the amounts of a binder and water added to the casting sand are generally 5-12 parts by mass of a binder and 1-5 parts by mass of water per 100 parts by mass of sand, though properly adjustable depending on the characteristics of a green sand mold.

[0032] The upper mold part 1a and the lower mold part 1b are formed, for example, by charging the casting sand into each flask in which a casting model for an article-forming cavity, a runner, etc. is placed, compressing the casting sand by a jolt squeeze method, etc., and finally removing the casting model.

(2) Coating step

[0033] In the upper mold part 1a and the lower mold part 1b, as shown in Fig. 3(b), surfaces of the recesses 1g-1, 1g-2 for a cavity 1c and a runner 1d, and parting surfaces 1e are coated with a coating solution 1k comprising a thermosetting resin and an organic solvent to form coating layers 1f. Though not only the recesses 1g-1, 1g-2 but also the parting surfaces 1e are coated with a coating solution 1k in the depicted example, coating need only be conducted at least on the recesses 1g-1, 1g-2. To stabilize the amount of coating to provide the coating layer 1f with uniform thickness, the coating solution 1k is preferably sprayed by a horizontally moving nozzle 10 as shown in Fig. 3(b).

[0034] In order that a proper amount of a coating solution 1k intrudes into voids 1i between sand particles 1j from the surfaces of the recesses 1g-1, 1g-2, the coating solution 1k preferably has viscosity (measured by a Brookfield viscometer according to JIS K6910) of 15-100 mPa·s. As a result, a coating layer 1f having a thickness T of 0.5-2.5 mm is formed in surface layers of the recesses 1g-1, 1g-2. With too large viscosity, the coating solution 1k does not easily intrude into the surface layers of the recesses 1g-1, 1g-2, resulting in a coating layer 1f formed only near the surfaces of the recesses 1g-1, 1g-2. Accordingly, the coating layer 1f easily peels, resulting in a cast steel article having poor appearance and sand detachability. With too small viscosity, the coating solution 1k intrudes excessively, resulting in too thick a coating layer 1f. Though variable depending on the concentration of a thermosetting resin, the amount of a coating solution 1k applied is preferably set such that the amount of a thermosetting resin coated on the recesses 1g-1, 1g-2 is 100-500 g/m² on a solid basis as described above.

(3) Coating-layer-forming step

[0035] As shown in Fig. 3(c), the coating solution applied to the recesses 1g-1, 1g-2 of the upper mold part 1a and the lower mold part 1b is heated to cure the thermosetting resin. Heating may be conducted during or after evaporating the organic solvent. Thus formed is a coating layer 1f having average hardness (measured by a self-hardening hardness meter) in a range of 50-95. Though not particularly restrictive, the coating solution 1k can be heated, for example, by hot air supplied from a horizontally moving blower 11 as shown in Fig. 3(c), or by heaters arranged on a horizontal plane.

(4) Molds-combining step

[0036] As shown in Fig. 3(d), the upper mold part 1a and the lower mold part 1b each having a coating layer 1f on each recess 1g-1, 1g-2 are combined, to form an integral green sand mold 1 shown in Fig. 1.

(B) Second example

[0037] The second example of the production methods of a green sand mold 1 is explained referring to Fig. 4. In Fig. 4, the same reference numerals are assigned to the same portions as in Fig. 3, with their detailed explanations omitted. The second example of the production methods of a green sand mold 1 is the same as the first example, except for having the first and second hardening steps shown in Figs. 4(c) and 4(e).

[0038] In the second example, the recesses 1g-1, 1g-2 of the upper mold part 1a and the lower mold part 1b formed

in the mold-forming step shown in Fig. 4(a) are coated with a coating solution 1k in the coating step shown in Fig. 4(b), and hot air is supplied from a blower 11 to heat the coating solution 1k, thereby forming a semi-hardened layer 1L, in the first hardening step shown in Fig. 4(c). After the upper mold part 1a and the lower mold part 1b each provided with a semi-hardened layer 1L are combined in the molds-combining step shown in Fig. 4(d), hot air supplied from a blower 12 is introduced into a cavity 1c through a runner 1d, to thermally harden the semi-hardened layer 1L to form a coating layer 1f, in the second hardening step shown in Fig. 4(e).

[0039] Before the second hardening step for forming a coating layer 1f, the semi-hardened layer 1L is formed by pre-hardening in the first hardening step, to prevent the cracking, etc. of the coating layer 1f by rapid hardening, thereby avoiding the cast steel article from having poor appearance. From this aspect, the average hardness of the semi-hardened layer 1L measured by a self-hardening hardness meter is preferably 30-45. In the second example, too, the average hardness (measured by a self-hardening hardness meter) of the coating layer 1f is preferably in a range of 50-95.

[0040] By the method of the present invention, a thin thermosetting resin layer is formed on binder-bonded sand particles 1j [Fig. 5(a)]. As a result, a coating layer 1f having voids 1i [Fig. 5(b)] is formed at least on the recesses 1g-1, 1g-2 of the green sand mold 1.

[3] Production method of cast steel article

[0041] As shown in Fig. 6, a melt is introduced into the article-forming cavity 1c of the green sand mold 1 constituted by the upper mold part 1a and the lower mold part 1b each having a coating layer 1f through the runner 1d, thereby producing a cast steel article with reduced carburization in an as-cast surface layer, while keeping as good surface quality as conventional one with respect to sand seizure. The reasons therefor are not necessarily clear, but may be presumed as follows: (a) When the coating layer 1f of the article-forming cavity 1c comes into contact with a high-temperature melt M as shown in Fig. 7, the thermosetting resin in the coating layer 1f is substantially completely gasified, thereby suppressing sand seizure by a gas (shown by arrows) generated by the decomposition of the thermosetting resin; and (b) because as relatively thin a coating layer 1f as 0.5-2.5 mm disappears immediately after coming into contact with the melt M, and because the amount of a carbonaceous component in the casting sand constituting the green sand mold 1 is as small as 3 parts or less by mass, the solidifying melt M is in contact with carbon only in a short period of time, resulting in the suppressed carburization of the as-cast surface layer. Cast steel articles suffering less carburization have excellent machinability. A thermosetting resin, which is gasified slightly later in a deep region of the coating layer 1f than in a shallow region, contributes to prevent direct contact of the melt M with the casting sand of the article-forming cavity 1c until the melt M is solidified.

[0042] The present invention will be explained in more detail with Examples below, without intention of restricting the present invention thereto.

Example 1

(1) Sand-preparing step

[0043] 100 parts by mass of silica sand was mixed with 8.1 parts by mass of bentonite, 3.0 parts by mass of water, and 3 parts by mass of carbon powder, to prepare casting sand.

(2) Mold-forming step

[0044] Casting sand was charged into flasks in each of which a casting design model was set, and compressed by a jolt-squeeze method to form upper and lower mold parts. Measurement at five points by a self-hardening mold hardness tester (NK-009 available from Nakayama Co., Ltd.) revealed that the average hardness of each recess of the upper and lower mold parts was 20. Fig. 8(a) is a SEM photograph (100 times) showing a recess surface of the formed green sand mold. As is clear from Fig. 8(a), there were a lot of voids between binder-covered sand particles.

(3) Coating step

[0045] As shown in Table 2, a coating solution (viscosity: 20 mPa·s) comprising 40% by mass of a phenol resin and 60% by mass of ethanol was applied to the recesses and parting surfaces of the upper and lower mold parts. The amount of the coating solution applied was 300 g/m² on a solid basis.

(4) Coating layer-forming step

[0046] The coating solution applied to the recesses and parting surfaces of the upper and lower mold parts was

thermally cured by an incandescent lamp, to form a coating layer. Fig. 8(b) is a SEM photograph (100 times) showing a recess surface of the green sand mold provided with the coating layer. As is clear from Fig. 8(b), there are sufficient voids remaining between sand particles covered with the coating layer, making it possible to sufficiently discharge a gas generated by the decomposition of the thermosetting resin.

(a) Measurement of thickness T

[0047] Five blocks of 3 cm x 3 cm x 3 cm were cut out of recess surfaces of the upper and lower mold parts provided with the coating layer by a spoon, and the casting sand was removed from each block by a brush without destroying the coating layer. The thickness of each sample consisting only of a hardened coating layer was measured by a vernier caliper. The thickness T of the hardened coating layer, which was determined by averaging the measured thickness values of all blocks, was 1.1 mm.

(b) Measurement of amount of residual carbon

[0048] After thickness measurement of the coating layer, each sample, whose coating layer had a volume of $3 \times 3 \times T \text{ cm}^3$, with a surface area of $3 \times 3 \text{ cm}^2$ and a thickness T, was subjected to thermogravimetric analysis (TGA) by heating from room temperature to 800°C at a speed of 10°C/minute in the air, to determine the amount of residual carbon per a unit volume. As a result, the amount of carbon remaining in the coating layer was 100 mg/cm³.

(c) Measurement of hardness

[0049] The hardness of the coating layer was measured by a self-hardening mold hardness tester (NK-009 available from Nakayama Co., Ltd.) at five points, and averaged. As a result, the hardness of the coating layer on the recess was 67.

(5) Mold-combining step

[0050] The upper and lower mold parts provided with coating layers on recesses and parting surfaces were combined by a usual method to obtain a green sand mold.

[0051] A melt having a composition comprising 0.45% by mass of C, 1.30% by mass of Si, 1.02% by mass of Mn, 10.1% by mass of Ni, 19.9% by mass of Cr, 10.0% by mass of Nb, 0.15% by mass of S, and 0.18% by mass of N, the balance being Fe and inevitable impurities, was poured at 1620-1630°C into a cavity of the above green sand mold. After the solidification of the melt, the green sand mold was broken to take a cast steel article, from which casting sand attached to its as-cast surface was removed by shot-blasting for 15 minutes using steel balls of 2.4 mm in average diameter. Likewise, totally 100 cast steel articles were produced.

(a) Measurement of sand seizure ratio

[0052] Sand seizure on the shot-blasted as-cast surface was observed with the naked eye, and the number of cast steel articles suffering sand seizure was divided by the total number (100) of cast steel articles to determine the sand seizure ratio (%). As a result, the sand seizure ratio was 1%.

(b) Measurement of surface defect ratio

[0053] The surface defects of the cast steel article, such as pinholes generated by insufficient gas evacuation, burr generated by the cracking and breakage of the coating layer on the recess, etc., were observed with the naked eye. The number of cast steel articles suffering surface defects was divided by the total number (100) of cast steel articles, to determine the surface defect ratio (%). As a result, the surface defect ratio was 2%.

(c) Evaluation of machinability

[0054] To evaluate the machinability of an as-cast surface of a cast steel article, a surface layer (depth range: 1.0 mm including the as-cast surface) of the cast steel article was cut by milling with a cemented carbide insert PVD-coated with TiAlN, under the following conditions:

Cutting speed: 150m/minute,
Cutting depth: 1.0 mm,
Feed per blade: 0.2 mm/blade,

Feed speed: 381 mm/minute,
 Rotation speed: 76 rpm, and
 Cutting liquid: No (dry).

5 **[0055]** A cutting time until the wear of a cemented carbide insert flank became 0.2 mm or more was judged as a tool life, as a parameter of machinability. With the tool life (machinability) in Comparative Example 1 being 100, the machinability in Example 1 was 126.

Example 2

10 **[0056]** 100 cast steel articles were produced in the same manner as in Example 1, except for changing (a) the ratio of a phenol in the coating solution to 30% by mass, (b) the viscosity and amount of the coating solution to 17 mPa·s and 100 g/m², respectively, and (c) the coating-layer-forming conditions, to form a coating layer having hardness of 50 and a thickness T of 2.3 mm, the amount of residual carbon being 22 mg/cm³, on the recess. The same measurements of
 15 machinability, a sand seizure ratio and a surface defect ratio as in Example 1 revealed that the machinability was 133, the sand seizure ratio was 3%, and the surface defect ratio was 3%.

Example 3

20 **[0057]** 100 cast steel articles were produced in the same manner as in Example 1, except for forming a coating layer having hardness of 50 and a thickness T of 1.7 mm, the amount of residual carbon being 50 mg/cm³, on the recess by (a) a phenol ratio of 20% by mass in the coating solution, (b) a coating solution viscosity of 13 mPa·s, and (c) the two-step hardening of the coating layer. The two-step hardening comprised a first hardening step of forming a semi-hardened layer having hardness of 36, the combining of the mold parts, and a second hardening step of further heating to completely
 25 harden the semi-hardened layer. The same measurements of machinability, a sand seizure ratio and a surface defect ratio as in Example 1 revealed that the machinability was 130, the sand seizure ratio was 2%, and the surface defect ratio was 4%.

Examples 4-6

30 **[0058]** 100 cast steel articles were produced in the same manner as in Example 1, except for changing the ratio of a phenol in the coating solution and the amount of the coating solution applied as shown in Table 2. The machinability, sand seizure ratio and surface defect ratio of the cast steel article of each Example were measured in the same manner as in Example 1. In Example 4, the machinability was 113, the sand seizure ratio was 1%, and the surface defect ratio
 35 was 4%. In Example 5, the machinability was 109, the sand seizure ratio was 1%, and the surface defect ratio was 3%. In Example 6, the machinability was 118, the sand seizure ratio was 2%, and the surface defect ratio was 2%.

Comparative Example 1

40 **[0059]** 100 cast steel articles were produced in the same manner as in Example 1, except for changing the ratio of carbon powder in the casting sand to 4.0 parts by mass. The same measurements of machinability, a sand seizure ratio and a surface defect ratio as in Example 1 revealed that the machinability was 100, the sand seizure ratio was 3%, and the surface defect ratio was 11%.

Comparative Example 2

45 **[0060]** 100 cast steel articles were produced in the same manner as in Comparative Example 1, except for changing the ratio of a phenol in the coating solution and the amount of the coating solution applied as shown in Table 2. The same measurements of machinability, a sand seizure ratio and a surface defect ratio as in Example 1 revealed that the
 50 machinability was 92, the sand seizure ratio was 1%, and the surface defect ratio was 35%.

Comparative Example 3

55 **[0061]** 100 cast steel articles were produced in the same manner as in Example 1, except for changing the ratio of a phenol in the coating solution and the amount of the coating solution applied as shown in Table 2. The same measurement of machinability, a sand seizure ratio and a surface defect ratio as in Example 1 revealed that the machinability was 72, the sand seizure ratio was 23%, and the surface defect ratio was 10%. The deterioration of machinability appears to be due to the sand seizure of an as-cast surface.

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[0062] With respect to Examples 1-6 and Comparative Examples 1-3, the production conditions of green sand molds are shown in Table 1, and the composition, viscosity and amount of a coating solution applied to each green sand mold, as well as the hardness, thickness and residual carbon content of each coating layer are shown in Table 2. Also, the evaluations of machinability, sand seizure ratio and surface defect ratio of their cast steel articles, and their overall evaluations are shown by three grades in Table 3.

Machinability (expressed by a relative value to 100 in Comparative Example 1)

[0063]

Excellent: 120 or more.

Good: more than 100 and less than 120.

Poor: 100 or less.

Sand seizure ratio

[0064]

Excellent: 2% or less.

Good: more than 2% and less than 10%.

Poor: 10% or more.

Surface defect ratio

[0065]

Excellent: 2% or less.

Good: more than 2% and less than 10%.

Poor: 10% or more.

Overall evaluation

[0066]

Excellent: All evaluations of machinability, sand seizure ratio and surface defect ratio were excellent.

Good: Any one of evaluations of machinability, sand seizure ratio and surface defect ratio was good.

Poor: Any one of evaluations of machinability, sand seizure ratio and surface defect ratio was poor.

Table 1

No.	Production conditions of Green Sand Mold				
	Casting Sand				Hardness ⁽¹⁾ of Formed Recesses
	Bentonite	Water	Carbonaceous Component		
			Type	Ratio	
Example 1	8.1	3	Carbon Powder	3	20
Example 2	8.1	3	Carbon Powder	3	20
Example 3	8.1	3	Carbon Powder	3	20
Example 4	8.1	3	Carbon Powder	3	20
Example 5	8.1	3	Carbon Powder	3	20
Example 6	8.1	3	Carbon Powder	3	20
Com. Ex. 1	8.1	3	Carbon Powder	4	20
Com. Ex. 2	8.1	3	Carbon Powder	4	20

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(continued)

No.	Production conditions of Green Sand Mold				
	Casting Sand				Hardness ⁽¹⁾ of Formed Recesses
	Bentonite	Water	Carbonaceous Component		
			Type	Ratio	
Com. Ex. 3	8.1	3	Carbon Powder	3	20
Note: (1) Average hardness of recesses (with no coating) of the formed upper and lower mold parts.					

Table 2-1

No.	Thermosetting Resin		Coating Solution		Number of Hardening Steps
	Type	% by mass	Viscosity (mPa·s)	Applied Amount (g/m ²)	
Example 1	Ph ⁽¹⁾	40	20	300	1
Example 2	Ph ⁽¹⁾	30	17	100	1
Example 3	Ph ⁽¹⁾	20	13	300	2 ⁽²⁾
Example 4	Ph ⁽¹⁾	70	100	340	1
Example 5	Ph ⁽¹⁾	50	45	500	1
Example 6	Ph ⁽¹⁾	22	15	500	1
Com. Ex. 1	Ph ⁽¹⁾	40	20	300	1
Com. Ex. 2	Ph ⁽¹⁾	80	140	550	1
Com. Ex. 3	Ph ⁽¹⁾	5	10	200	1
Note: (1) Phenol. (2) The thermosetting resin was thermally cured by the first and second hardening steps, and the surface hardness of the recess after the first hardening step was 36.					

Table 2-2

No.	Coating Layer		
	Surface Hardness ⁽¹⁾	Thickness T (mm)	Residual Carbon (mg/cm ³)
Example 1	67	1.1	100
Example 2	50	2.3	22
Example 3	50	1.7	50
Example 4	80	0.5	198
Example 5	95	0.9	208
Example 6	69	2.3	92
Com. Ex. 1	67	1.1	100
Com. Ex. 2	98	0.4	360
Com. Ex. 3	36	2.8	8
Note: (1) Surface hardness of recesses.			

Table 3

No.	Properties of Products			
	Machinability	Sand Seizure Ratio	Surface Defect Ratio	Overall Evaluation
Example 1	Excellent	Excellent	Excellent	Excellent
Example 2	Excellent	Good	Good	Good
Example 3	Excellent	Excellent	Good	Good
Example 4	Good	Excellent	Good	Good
Example 5	Good	Excellent	Good	Good
Example 6	Good	Excellent	Excellent	Good
Com. Ex. 1	Poor	Good	Poor	Poor
Com. Ex. 2	Poor	Excellent	Poor	Poor
Com. Ex. 3	Poor	Poor	Poor	Poor

[0067] In Examples 1-6, with the ratio of a carbonaceous component in the green sand mold, and the surface hardness of the coating layer adjusted as described above, cast steel articles with good or excellent machinability, and good or excellent sand seizure ratios and surface defect ratios as shown in Table 3 were obtained. On the other hand, in Comparative Examples 1-3, in which the ratio of a carbonaceous component in the green sand mold and the surface hardness of the coating layer were outside the ranges of the present invention, the resultant cast steel articles were poor in one or more of machinability, a sand seizure ratio and a surface defect ratio.

DESCRIPTION OF REFERENCE NUMERALS

[0068]

- 1: Green sand mold
- 1a: Upper mold part
- 1b: Lower mold part
- 1c: Article-forming cavity
- 1d: Runner
- 1e: Parting surface
- 1f: Coating layer
- 1g-1, 1g-2: Recess
- 1i: Void
- 1j: Sand particle
- 1k: Coating solution
- 1L: Semi-hardened layer
- M: Melt

Claims

1. A green sand mold for producing a cast steel article, which is formed by casting sand comprising sand, a binder, and 3 parts or less by mass of a carbonaceous component per 100 parts by mass of sand;
at least a recess including a cavity for forming said cast steel article being provided with a coating layer of a thermosetting resin; and
said coating layer having average hardness (measured by a self-hardening hardness meter) of 50-95 and a thickness of 0.5-2.5 mm.
2. The green sand mold according to claim 1, wherein the amount of the thermosetting resin forming said coating layer is 100-500 g/m² on a solid basis.
3. The green sand mold according to claim 1 or 2, wherein the amount of carbon remaining in a unit volume of said

coating layer is 20-200 mg/cm³ after heated to 800°C at a speed of 10°C/minute in the air.

4. A method for producing the green sand mold recited in any one of claims 1-3, comprising forming casting sand comprising sand, a binder, and 3 parts or less by mass of a carbonaceous component per 100 parts by mass of sand, into at least a pair of green sand mold parts comprising a recess including a cavity for forming said cast steel article; coating at least said recess with a coating solution comprising a thermosetting resin and an organic solvent; and thermally curing said thermosetting resin coated on said recess to form a coating layer having average hardness (measured by a self-hardening hardness meter) of 50-95.
5. The method for producing a green sand mold according to claim 4, wherein said thermosetting resin is thermally cured before and/or after combining said mold parts.
6. The method for producing a green sand mold according to claim 5, wherein at least a pair of green sand mold parts are combined after thermally curing said thermosetting resin.
7. The method for producing a green sand mold according to claim 5, wherein the hardening of a coating layer obtained by drying the applied coating solution is carried out by a first hardening step of heating to obtain average hardness (measured by a self-hardening hardness meter) of 30-45, and a second hardening step of further heating the primarily hardened coating layer to average hardness (measured by a self-hardening hardness meter) of 50-95.
8. The method for producing a green sand mold according to any one of claims 5-7, wherein said coating solution has a viscosity of 15-100 mPa·s.
9. A method for producing a cast steel article using the green sand mold recited in any one of claims 1-3.

Fig. 1

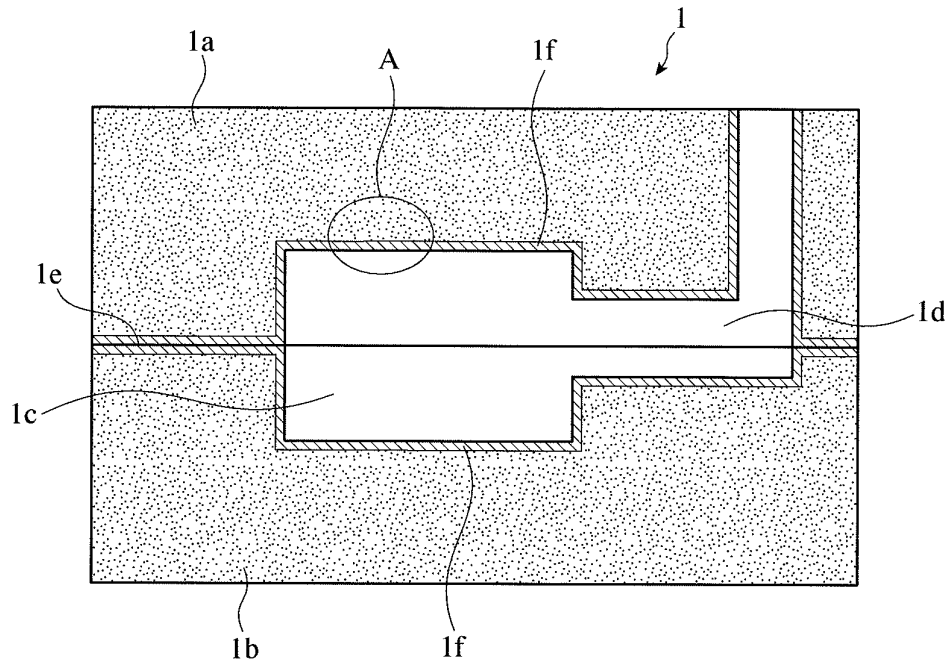


Fig. 2

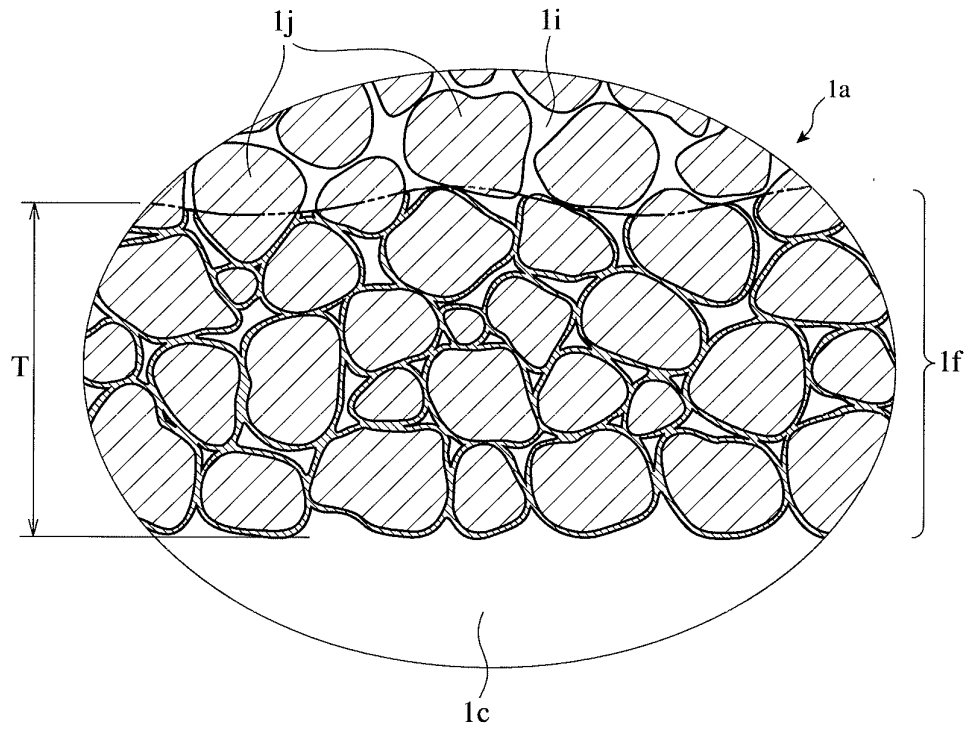


Fig. 3(a)

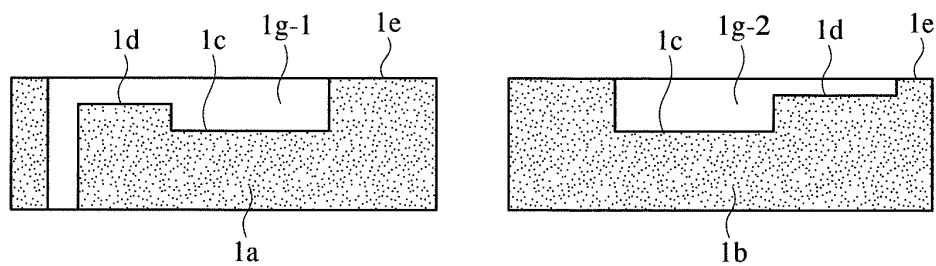


Fig. 3(b)

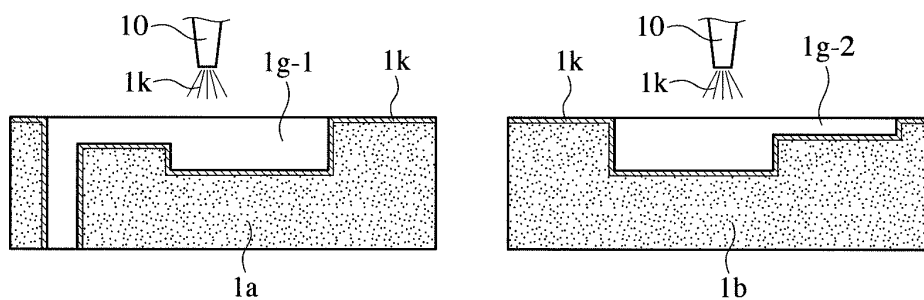


Fig. 3(c)

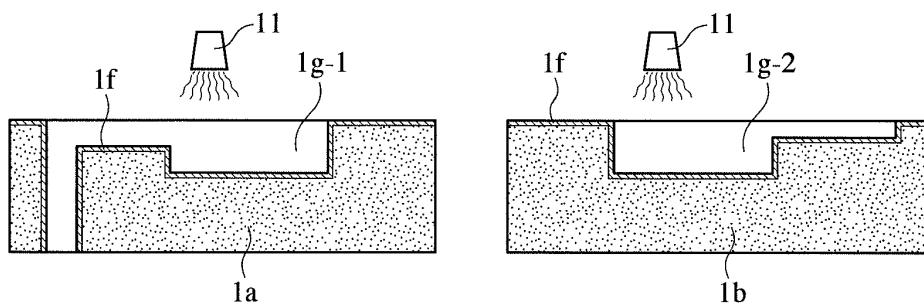


Fig. 3(d)

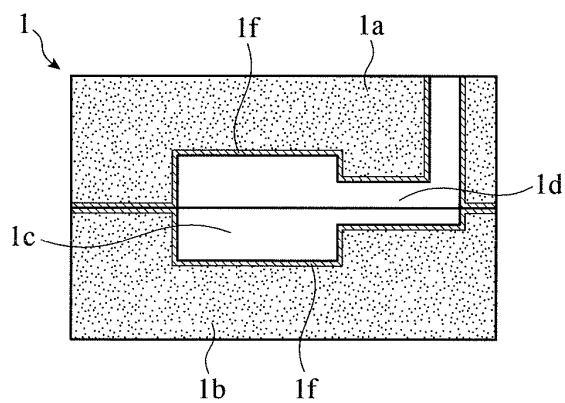


Fig. 4(a)

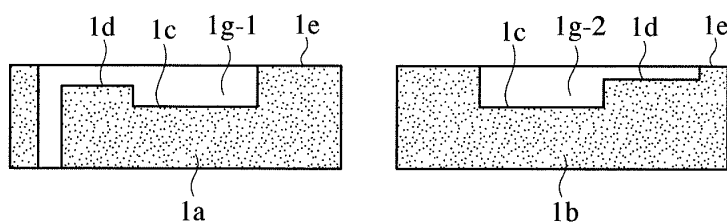


Fig. 4(b)

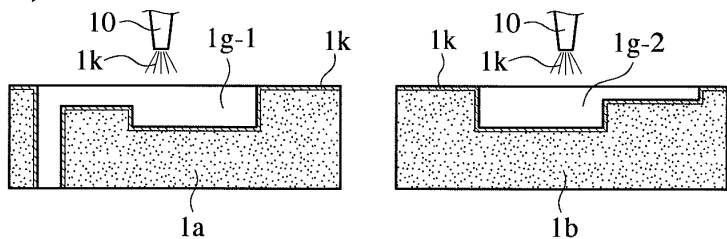


Fig. 4(c)

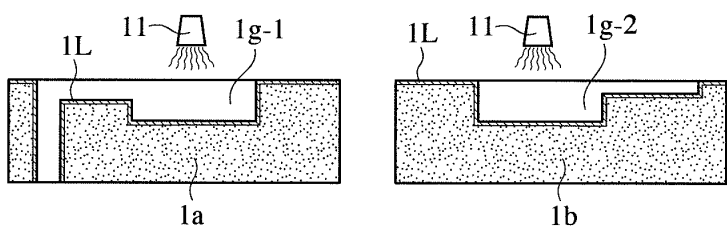


Fig. 4(d)

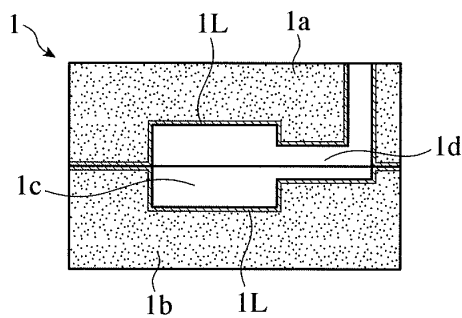


Fig. 4(e)

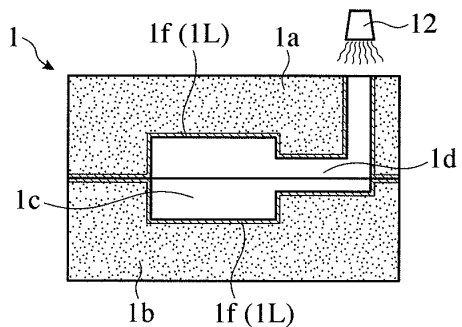


Fig. 5(a)

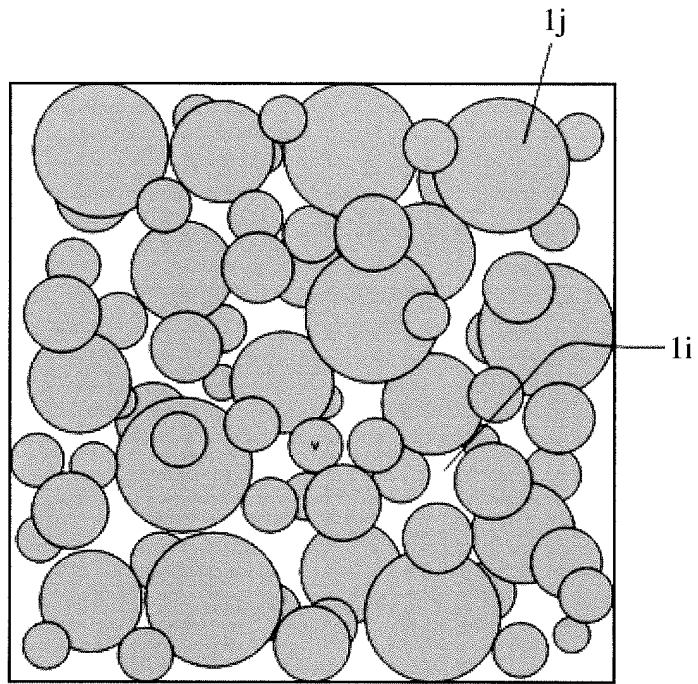


Fig. 5(b)

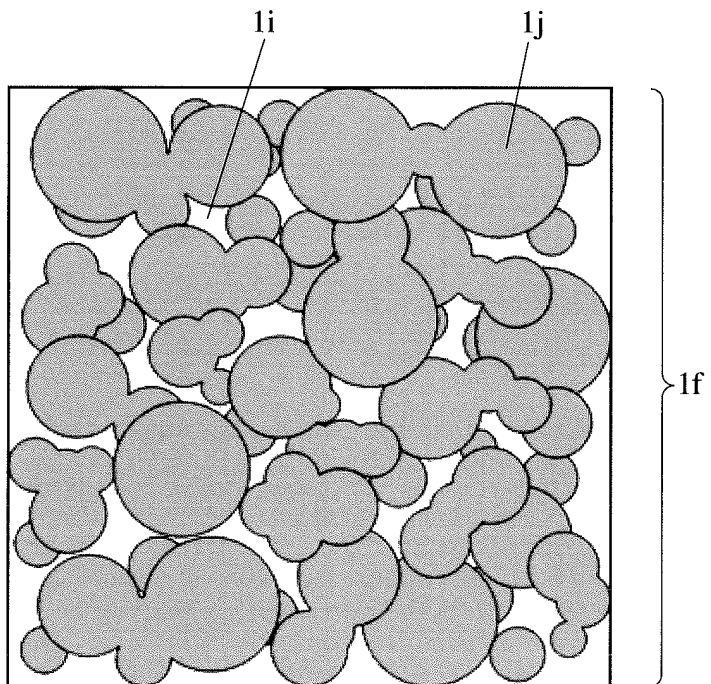


Fig. 6

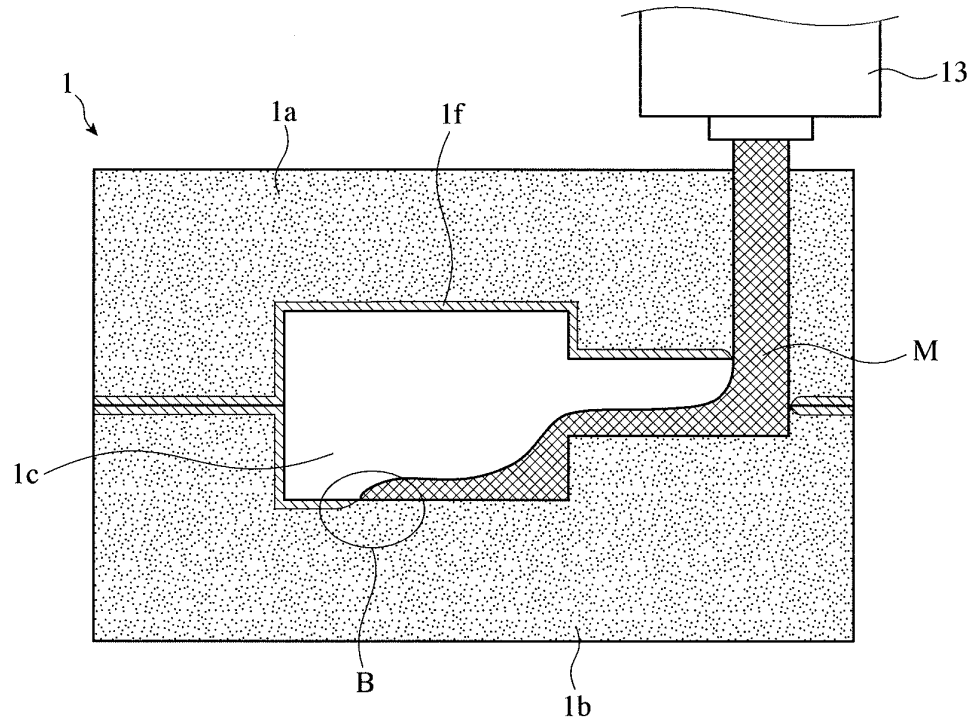


Fig. 7

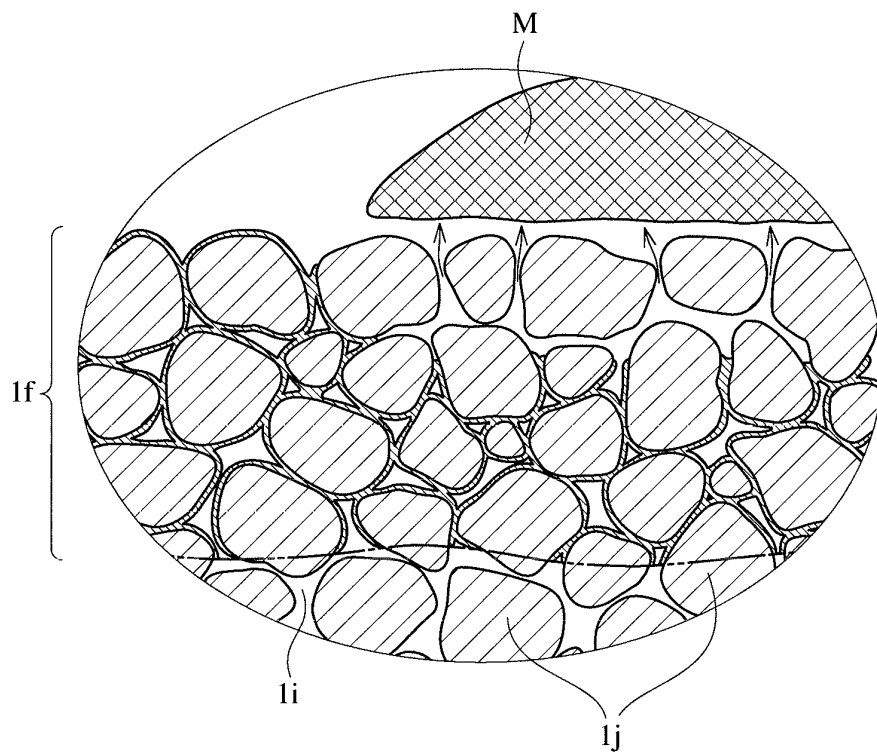


Fig. 8(a)

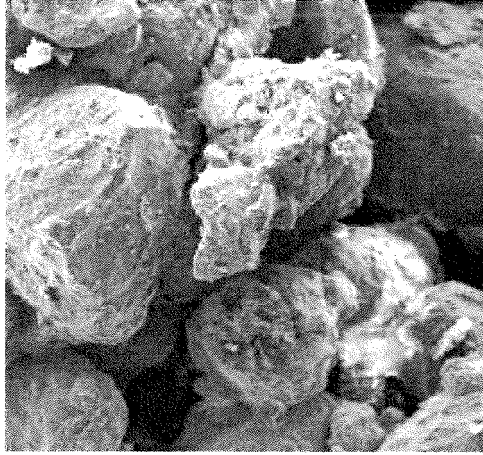
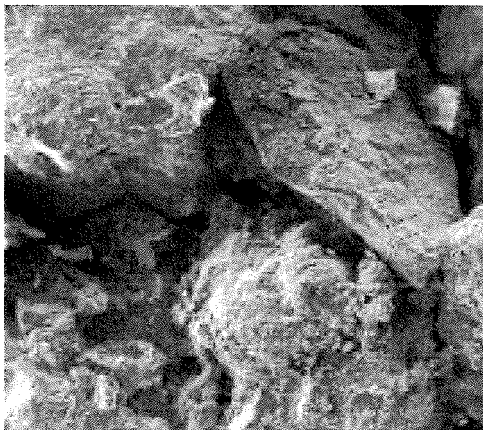


Fig. 8(b)



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2015/059156

A. CLASSIFICATION OF SUBJECT MATTER

B22C3/00(2006.01)i, B22C1/00(2006.01)i, B22C1/10(2006.01)i, B22C9/02(2006.01)i

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)

B22C3/00, B22C1/00, B22C1/10, B22C9/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2015

Kokai Jitsuyo Shinan Koho 1971-2015 Toroku Jitsuyo Shinan Koho 1994-2015

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 4-52048 A (Kurodite Kogyo Kabushiki Kaisha), 20 February 1992 (20.02.1992), claims (Family: none)	1-9
A	JP 53-32827 A (Kabushiki Kaisha Nakata Giken), 28 March 1978 (28.03.1978), claims & DE 2735640 A1	1-9
A	JP 8-257678 A (Mitsubishi Heavy Industries, Ltd.), 08 October 1996 (08.10.1996), claims; paragraphs [0006] to [0011] (Family: none)	1-9

☒ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search
04 June 2015 (04.06.15)Date of mailing of the international search report
16 June 2015 (16.06.15)Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2015/059156

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2013-103268 A (Daido Castings Co., Ltd.), 30 May 2013 (30.05.2013), paragraphs [0002] to [0008] (Family: none)	1-9

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 63177939 A [0002] [0003] [0004]
- JP 2009291801 A [0002] [0003] [0004]