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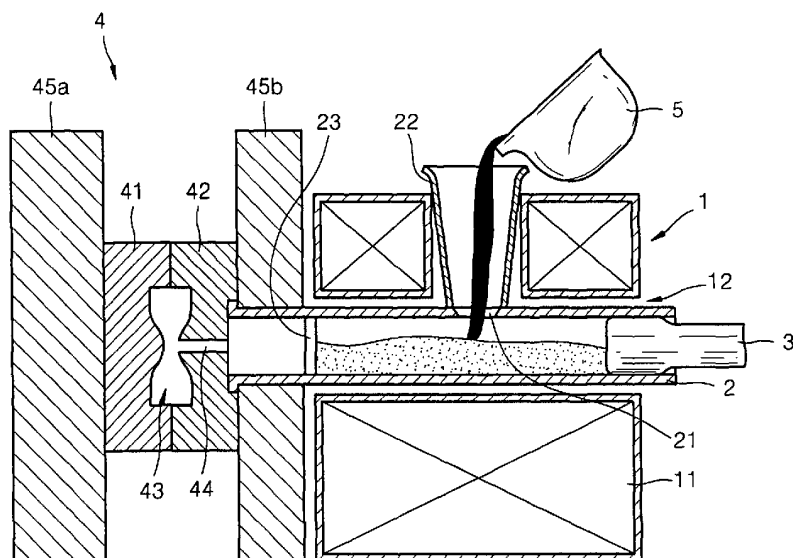
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(54) **Method and apparatus for pressure diecasting a semi-solid metallic slurry**

(57) Provided are a die casting method and apparatus for rheocasting that ensure the manufacture of products with a fine, uniform, spherical particle structure, with improvements in energy efficiency and mechanical properties, cost reduction, convenience of casting, and shorter manufacturing time. The die casting method involves applying an electromagnetic field to a slurry man-

ufacturing domain in a sleeve (2) having an end through which a plunger (3) is inserted and the other end connected to a casting die (4) with a mold cavity (43), loading a molten metal into the slurry manufacturing domain to manufacture a semi-solid metallic slurry, and moving the plunger toward the casting die to push the metallic slurry into the mold cavity.

FIG. 2



Description

BACKGROUND OF THE INVENTION

[0001] This application claims priority from Korean Patent Application No. 2002-58163 filed on September 25, 2002, No. 2002-63162 filed on October 16, 2002, No. 2003-3250 filed on January 17, 2003 and No. 2003-13515 filed on March 4, 2003, in the Korean Intellectual Property Office, the disclosures of which are incorporated herein in their entirety by reference.

1. Field of the Invention

[0002] The present invention relates to a die casting method and apparatus for rheocasting, and more particularly, to a die casting method and apparatus for rheocasting that ensure the manufacture of products with a fine, uniform, spherical particle structure.

2. Description of the Related Art

[0003] Rheocasting refers to a process of manufacturing billets or mold products from semi-solid metallic slurries having a predetermined viscosity through casting or forging. Semi-solid metallic slurries consist of spherical solid particles suspended in a liquid phase in an appropriate ratio at temperature ranges for semi-solid state, and thus, they change form easily by a small force due to their thixotropic properties and can be cast easily like a liquid due to their high fluidity.

[0004] Such rheocasting is closely related with thixocasting. Thixocasting refers to a process involving reheating billets manufactured through rheocasting back into a metal slurry and casting or forging it to manufacture final products.

[0005] Such rheocasting and thixocasting are more advantageous than general molding processes, such as casting or forging, using molten metal. For example, semi-solid or semi-molten slurries used in rheocasting or thixocasting have fluidity at a lower temperature than molten metal, so that the die casting temperature can be lowered in rheocasting or thixocasting, thereby ensuring an extended lifespan of the die. In addition, when a semi-solid or semi-molten metallic slurry is extruded through a cylinder, turbulence is less likely to occur, and less air is incorporated during casting, thereby preventing formation of air pockets in final products.

Besides, the use of semi-solid or semi-molten metallic slurries leads to reduced shrinkage during solidification, improved working efficiency, mechanical properties, and anti-corrosion, and lightweight products. Therefore, such semi-solid or semi-molten metallic slurries can be used as new materials in the fields of automobiles, airplanes, and electrical, electronic information communications equipment.

[0006] In conventional rheocasting, molten metal is stirred at a temperature of lower than the liquidus tem-

perature while cooling, to break up dendritic structures into spherical particles suitable for rheocasting, for example, by mechanical stirring, electromagnetic stirring, gas bubbling, low-frequency, high-frequency, or electromagnetic wave vibration, electrical shock agitation, etc.

[0007] As an example, U.S. Patent No. 3,948,650 discloses a method and apparatus for manufacturing a liquid-solid mixture. In this method, molten metal is vigorously stirred while cooled to be solidified. A semi-solid metallic slurry manufacturing apparatus disclosed in this patent uses a stirrer to induce flow of the solid-liquid mixture having a predetermined viscosity to break up dendritic crystalline structures or disperse broken dendritic crystalline structures in the liquid-solid mixture. In this method, dendritic crystalline structures formed during cooling are broken up and used as nuclei for spherical particles. However, due to generation of latent heat of solidification at the early stage of cooling, the method causes problems of low cooling rate, manufacturing time increase, uneven temperature distribution in a mixing vessel, and non-uniform crystalline structure. Mechanical stirring applied in the semi-solid metallic slurry manufacturing apparatus inherently leads to non-uniform temperature distribution in the mixing vessel. In addition, the apparatus is operated in a chamber, thereby making it difficult to continuously perform subsequent processes.

[0008] U.S. Patent No. 4,465,118 discloses a method and apparatus for manufacturing a semi-solid alloy slurry. This apparatus includes a coiled electromagnetic field application portion, a cooling manifold, and a vessel, which are sequentially formed inward, wherein molten metal is continuously loaded down into the vessel, and cooling water is flowed through the cooling manifold to cool the outer wall of the vessel. In manufacturing a semi-solid alloy slurry, molten metal is injected through a top opening of the vessel and cooled by the cooling manifold, thereby resulting in a solidification zone in the vessel. Cooling is sustained while a magnetic field is applied by the electromagnetic field application portion to break up dendritic crystalline structures formed in the solidification zone and to pull an ingot from the slurry through a lower end of the apparatus. The basic technical idea of this method and apparatus is to break up dendritic crystalline structures after solidification by applying vibration. However, many problems, such as complicated processing and non-uniform particle structure, arise with this method. In the manufacturing apparatus, since molten metal is continuously supplied downward to grow an ingot, it is difficult to control the state of the metal ingot and the overall process. Moreover, the vessel is cooled using water prior to applying an electromagnetic field, so that there is a great temperature difference between the peripheral and core regions of the vessel.

[0009] Other types of rheocasting and thixocasting described later are available. However, all of the methods are based on the technical idea of breaking up den-

drifted crystalline structures after formation, to generate nuclei of spherical particles, and arise such problems described in conjunction with the above patents.

[0010] U. S. Patent No. 4,694,881 discloses a method for manufacturing thixotropic materials. In this method, an alloy is heated to a temperature at which all metallic components of the alloy are present in a liquid phase, and the resulting molten metal is cooled to a temperature between its liquidus and solidus temperatures. Then, the molten metal is subjected to a sufficient shearing force to break dendritic structures formed during the cooling of the molten metal, so that thixotropic materials are manufactured.

[0011] Japanese Patent Laid-open Application No. 11-33692 discloses a method for producing a metallic slurry for rheocasting. In this method, a molten metal is supplied into a vessel at a temperature near its liquidus temperature or 50°C above its liquidus temperature. Next, when at least a portion of the molten metal reaches a temperature lower than the liquidus temperature, i. e., the molten metal is cooled below a liquidus temperature range, the molten metal is subjected to a force, for example, ultrasonic vibration. Finally, the molten metal is slowly cooled into a metallic slurry, for rheocasting, containing spherical particles. This method also uses a physical force, such as ultrasonic vibration, to break up the dendrites grown at the early stage of solidification. In this method, if the casting temperature is greater than the liquidus temperature, it is difficult to form spherical particle structures and to rapidly cool the molten metal. Furthermore, this method leads to a non-uniformity of surface and core structures.

[0012] Japanese Patent Laid-open Application No. 10-128516 discloses a casting method of thixotropic metal. This method involves loading a molten metal into a vessel and vibrating the molten metal using a vibrating bar dipped in the molten metal to directly transfer its vibrating force to the molten metal. A molten alloy containing nuclei, which is a semi-solid and semi-liquid state, at temperatures lower than its liquidus temperature is formed and cooled to a temperature at which it has a predetermined liquid fraction and held from 30 seconds to 60 minutes to allow nuclei in the molten alloy to grow larger, thereby resulting in thixotropic metal. This method provides relatively large particles of about 100μm and takes a considerably long processing time, and cannot be performed in a larger vessel than a predetermined size.

[0013] U.S. Patent No. 6,432,160 discloses a method for making a thixotropic metal slurry. This method involves simultaneously controlling the cooling and the stirring of molten metal to form a thixotropic metal slurry. In particular, after loading a molten metal into a mixing vessel, a stator assembly positioned around the mixing vessel is operated to generate a magnetomotive force sufficient to stir the molten metal in the vessel rapidly. Next, the temperature of the molten metal is rapidly dropped by means of a thermal jacket equipped around

the mixing vessel for precise control of the temperature of the mixing vessel and the molten metal. The molten metal is continuously stirred during cooling cycle in a controlled manner. When the solid fraction of the molten metal is low, high stirring rate is provided. As the solid fraction increases, a greater magnetomotive force is applied.

[0014] Most of the above-described conventional methods and apparatuses for manufacturing semi-solid metal slurries use shear force to break dendritic structures into spherical structures during a cooling process. Since a force such as vibration is applied after the temperature of at least a portion of the molten metal drops below its liquidus temperature, latent heat is generated due to the formation of initial solidification layers. As a result, there are many disadvantages such as reduced cooling rate and increased manufacturing time. In addition, due to a non-uniform temperature between the inner wall and the center of the vessel, it is difficult to form fine, uniform spherical metal particles. This structural non-uniformity of metal particles will be greater if the temperature of the molten metal loaded into the vessel is not controlled.

SUMMARY OF THE INVENTION

[0015] The present invention provides a die casting method and apparatus for rheocasting that ensure the manufacture of products with a fine, uniform, spherical particle structure, with improvements in energy efficiency and mechanical properties, cost reduction, convenience of casting, and shorter manufacturing time.

[0016] The present invention provides a method of manufacturing quality products using a semi-solid slurry in a short time.

[0017] In accordance with an aspect of the present invention, there is provided a die casting method for rheocasting, the method comprising: applying an electromagnetic field to a slurry manufacturing domain in a sleeve having an end through which a plunger is inserted and the other end connected to a casting die with a mold cavity and loading a molten metal into the slurry manufacturing domain to manufacture a semi-solid metallic slurry; and moving the plunger toward the casting die to push the metallic slurry into the mold cavity.

[0018] According to specific embodiments of the above die casting method, the sleeve may be horizontally positioned. In this case, the slurry manufacturing domain is defined by a door installed near the other end of the sleeve and the plunger inserted through the end of the sleeve. Alternatively, the sleeve may be inclined such that the end through which the plunger is inserted faces downward. In this case, the slurry manufacturing domain is defined by only the plunger inserted through one end of the sleeve. Alternatively, at least a portion of the sleeve may be inclined at an angle such that the end through which the plunger is inserted faces downward. In this case, the slurry manufacturing domain is defined

by only the plunger inserted through one end of the sleeve. The sleeve may be vertically positioned such that the end through which the plunger is inserted faces downward. In this case, the slurry manufacturing domain is defined by only the plunger inserted through one end of the sleeve.

[0019] According to more specific embodiments of the above die casting methods, applying the electromagnetic field to the slurry manufacturing domain may be performed prior to, at the start, or in the middle of loading the molten metal into the sleeve. Applying the electromagnetic field to the sleeve may be sustained until the molten metal in the slurry manufacturing domain has a solid fraction of 0.001-0.7, preferably, 0.001-0.4, more preferably, 0.001-0.1.

[0020] An alternative die casting method according to the present invention may further comprises cooling the molten metal loaded into the slurry manufacturing domain under the electromagnetic field. In this case, cooling the molten metal may be sustained until the molten metal in the slurry manufacturing domain has a solid fraction of 0.1-0.7. In addition, cooling the molten metal is performed at a rate of 0.2-5.0°C/sec, preferably, 0.2-2.0°C/sec.

[0021] In accordance with another aspect of the present invention, there is provided a die casting apparatus for rheocasting, the apparatus comprising: a stirring unit which includes a space and applies an electromagnetic field to the space; a sleeve which is accommodated in the space of the stirring unit and into which a molten metal is loaded; a plunger which is inserted through an end of the sleeve to push a semi-solid slurry manufactured in the sleeve; and a casting die connected to the other end of the sleeve, the casting die including a movable die and a fixed die which form a mold cavity when combined together and casting a product from the slurry pushed into the mold cavity by the plunger.

[0022] According to specific embodiments of the above die casting apparatus, the sleeve may be horizontally positioned. In this case, a door is further installed close to the other end of the sleeve connected to the casting die so as to close a through hole of the casting die during the manufacture of the slurry and to open the through hole when the manufactured slurry is pushed toward the casting die by the plunger. Alternatively, at least a portion of the sleeve may be inclined at an angle such that the end of the sleeve through which the plunger is inserted faces downward. Alternatively, the sleeve may comprise a first sleeve having the end through which the plunger is inserted and being able to pivot downward and a second sleeve horizontally positioned, wherein the first sleeve can be positioned at an angle to be placed in the space of the stirring unit or can be positioned to be aligned with the second sleeve. Alternatively, the sleeve may be vertically arranged to direct the end through which the plunger is inserted downward, be movable up and down, and be raised together with the plunger after the manufacture of the slurry to

couple to the casting die and allow the plunger to push the manufactured slurry into the mold cavity of the casting die.

[0023] According to more specific embodiments of the die casting apparatus, the stirring unit may apply the electromagnetic field prior to, at the start, or in the middle of loading the molten metal into the sleeve.

[0024] The stirring unit may apply the electromagnetic field until the molten metal in the sleeve has a solid fraction of 0.001-0.7, preferably, 0.001-0.4, more preferably, 0.001-0.1.

[0025] In another die casting apparatus according to the present invention, the sleeve may comprise a temperature control element. This temperature control element may include at least one of a cooler and an electrical heater. The temperature control element may cool the molten metal in the sleeve to reach a solid fraction of 0.1-0.7. The temperature control element cools the molten metal in the sleeve at a rate of 0.2-5.0°C/sec, preferably, 0.2-2.0°C/sec.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] The above and other features and advantages of the present invention will become more apparent by describing in detail exemplary embodiments thereof with reference to the attached drawings in which:

FIG. 1 is a graph of temperature profile applied in a die casting method for rheocasting according to the present invention;

FIGS. 2 and 3 illustrate the structure of a die casting apparatus for rheocasting according to an embodiment of the present invention;

FIG. 4 is a partial sectional view of an example of a sleeve applicable to a die casting apparatus according to the present invention;

FIG. 5 illustrates the structure of a die casting apparatus for rheocasting according to another embodiment of the present invention;

FIGS. 6 and 7 illustrate the structure of a die casting apparatus for rheocasting according to another embodiment of the present invention; and

FIGS. 8 and 9 illustrate the structure of a die casting apparatus for rheocasting according to still another embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0027] The present invention will be described more fully in the following exemplary embodiments of the invention with reference to the accompanying drawings.

[0028] Unlike the above-described conventional techniques, a die casting method for rheocasting according to the present invention involves manufacturing a semi-solid metallic slurry from a molten metal in a sleeve and die casting products from the semi-solid metallic slurry using a casting die. In particular, according to the

present invention, an electromagnetic field is applied prior to the completion of loading the molten metal into the sleeve. In other words, electromagnetic stirring is performed prior to, at the start or in the middle of loading the molten metal into the sleeve, to prevent formation of dendritic structures. Ultrasonic waves instead of the electromagnetic field can be applied for stirring.

[0029] In particular, an empty sleeve is located in a space of a die casting apparatus. An electromagnetic field is applied to a predetermined slurry manufacturing domain of the sleeve. The intensity of the applied electromagnetic field is strong enough to stir molten metal.

[0030] FIG. 1 is a graph of temperature profile applied in a die casting method for rheocasting according to the present invention. As shown in FIG. 1, molten metal is loaded into the slurry manufacturing domain of the sleeve at a temperature T_p . As described above, the molten metal may be loaded into the slurry manufacturing domain while an electromagnetic field is applied to the domain. However, the present invention is not limited to this, and electromagnetic stirring may be performed at the start or in the middle of loading the molten metal into the sleeve.

[0031] Due to the electromagnetic stirring initiated prior to the completion of loading molten metal into the slurry, the molten metal does not grow into dendritic structures near the inner wall of the sleeve at the early stage of solidification, and numerous micronuclei are concurrently generated throughout the slurry manufacturing domain because the temperature of the entire molten metal rapidly drops to a temperature lower than its liquidus temperature.

[0032] Applying an electromagnetic field to the slurry manufacturing domain prior to or at the start of loading molten metal into the sleeve leads to active stirring of the molten metal at the center and the inner wall regions of the sleeve and rapid heat transfer throughout the entire molten metal in the sleeve, thereby suppressing the formation of solidification layers near the inner wall of the sleeve at the early stage of cooling. In addition, such active stirring of the molten metal induces smooth convection heat transfer between the higher temperature molten metal and the lower temperature inner sleeve wall, so that the entire molten metal can be cooled rapidly. Due to the electromagnetic stirring, particles in the molten metal scatter upon loading into the sleeve and disperse throughout the sleeve as nuclei, so that there is rare a temperature difference in the slurry manufacturing domain during cooling. However, in conventional techniques where molten metal is stirred after the completion of loading into a sleeve, the temperature of the molten metal suddenly drops as soon as it contacts the low temperature inner sleeve wall, so that dendritic crystals grow from solidification layers formed near the inner slurry vessel wall at the early stage of cooling.

[0033] The principles of the present invention will become more apparent when described in connection with latent heat of solidification. In a die casting method for

rheocasting according to the present invention, molten metal does not solidify near the inner sleeve wall at the early stage of cooling, and no latent heat of solidification is generated. Accordingly, the amount of heat to be dissipated from the molten metal for cooling is equivalent only to the specific heat of the molten metal that corresponds to about 1/400 of the latent heat of solidification. Therefore, dendrites, which are generated frequently near the inner sleeve wall at the early stage of cooling when using conventional methods, are not formed, and the entire molten metal throughout the slurry manufacturing domain can be uniformly cooled. It takes merely about 1-10 seconds from the loading of the molten metal. As a result, numerous nuclei are created and disperse uniformly throughout the entire molten metal in the slurry manufacturing domain. The increased density of nuclei shortens the distance between the nuclei, and spherical particles instead of dendritic particles are grown.

[0034] The same effects can be achieved even when an electromagnetic field is applied in the middle of loading the molten metal into the sleeve. In other words, solidification layers are hardly formed near the inner sleeve wall even when electromagnetic stirring begins in the middle of loading the molten metal into the sleeve.

[0035] It is preferable that the temperature, T_p , of the molten metal be maintained in a range from its liquidus temperature to 100°C above the liquidus temperature (melt superheat = 0~100°C) at the time of being loaded into the sleeve. According to the present invention, since the entire slurry manufacturing domain containing the molten metal is cooled uniformly, it allows for the loading of the molten metal into the sleeve at a temperature of 100°C above its liquidus temperature, without the need to cool the temperature of the molten metal to near its liquidus temperature.

[0036] On the other hand, in conventional methods, an electromagnetic field is applied to a slurry vessel after the completion of loading molten metal into the slurry vessel and a portion of the molten metal has reached below its liquidus temperature. Accordingly, latent heat is generated due to the formation of solidification layers near the inner wall of the vessel at the early stage of cooling. Because the latent heat of solidification is about 400 times greater than the specific heat of the molten metal, it takes much time to drop the temperature of the entire molten metal below its liquidus temperature. Therefore, in these conventional methods, the molten metal is loaded into the vessel after the molten metal has cooled to a temperature near its liquidus temperature or to a temperature of 50°C above its liquidus temperature. However, in practice, controlling the overall manufacturing procedure is not easy when there is such a need to wait for a temperature drop of the molten metal to a predetermined level.

[0037] According to the present invention, the electromagnetic stirring may be stopped at any point after at least a portion of the molten metal in the sleeve reaches

a temperature lower than its liquidus temperature T_l , i. e., after nuclei are created in the molten metal at a solid fraction of about 0.001, as illustrated in FIG. 1. For example, an electromagnetic field may be applied to the slurry manufacturing domain of the sleeve throughout all processes of loading molten metal into the domain, cooling the molten metal into a semi-solid slurry, and pushing the semi-solid slurry into a casting die. This is because, once nuclei are distributed uniformly throughout the sleeve, the electromagnetic stirring does not affect the growth of crystalline particles from the nuclei in the metallic slurry.

[0038] Therefore, the electromagnetic stirring can be sustained only during the manufacture of the metallic slurry, until the solid fraction of the molten metal reaches at least 0.001-0.7. However, the electromagnetic stirring may be sustained until the solid fraction of the molten metal in the slurry manufacturing domain reaches the range of, preferably, 0.001-0.4, more preferably, 0.001-0.1, for energy efficiency.

[0039] After loading a molten metal into the slurry manufacturing domain and allowing nucleation of a uniform distribution in the molten metal, the slurry manufacturing domain is cooled to accelerate the growth of the nuclei. This cooling may be concurrent with the loading of the molten metal into the slurry manufacturing domain. As described above, the electromagnetic stirring may be sustained throughout all the cooling process.

[0040] Alternatively, the cooling process may be sustained just prior to pushing a resulting semi-solid metallic slurry into the casting die, preferably, sustained until the molten metal has a solid fraction of 0.1-0.7, this point of time being denoted as t_2 in FIG. 1. In this case, the molten metal may be cooled at a rate of 0.2-5.0°C/sec. However, the cooling rate of the molten metal may be varied in the range of 0.2-2.0°C/sec depending on a desired nuclei distribution and granularity.

[0041] Immediately after the manufacture of a semi-solid metallic slurry having a predetermined solid fraction according to the above-described method, the semi-solid metallic slurry is pushed into a mold cavity of a casting die for die casting.

[0042] According to the above-described method according to the present invention, a semi-solid metallic slurry can be manufactured within a short time, merely in 30-60 seconds from loading the molten metal into the sleeve for a metallic slurry with a solid fraction of 0.1-0.7. In addition, products having a uniform, dense spherical particle structure can be manufactured through die casting of the semi-solid metallic slurry formed by the method.

[0043] The above-described die casting method for rheocasting can be applied to a horizontal sleeve, a slant sleeve, and a vertical sleeve.

[0044] For example, in a horizontal sleeve, the slurry manufacturing domain may be defined by a door and a plunger installed at each end of the sleeve. In a slant sleeve, the slurry manufacturing domain may be defined

by only a plunger installed at one end of the sleeve. In a vertical sleeve into which a plunger is inserted through its bottom end to be perpendicular to the ground, the slurry manufacturing domain may be defined by only the plunger. These structural variations of die casting apparatuses depending on the position of the sleeve will be described later.

[0045] The above-described die casting method for rheocasting can be implemented using a die casting apparatus according to an embodiment of the present invention illustrated in FIGS. 2 and 3.

[0046] Referring to FIG. 2, a die casting apparatus for rheocasting according to an embodiment of the present invention includes a stirring unit 1 having a space 12 and a coiled electromagnetic field application portion 11 arranged around the space 12; a sleeve 2 accommodated in the space 12 of the stirring unit 1; a plunger 3 inserted into an end of the sleeve 2; and a casting die 4 connected to the other end of the sleeve 2.

[0047] In the stirring unit 1, the space 12 and the coiled electromagnetic field application portion 11 are fixed by means of a frame (not shown). The coiled electromagnetic field application portion 11 emanates a predetermined intensity of electromagnetic field towards the space 12 so as to stir the molten metal loaded into the sleeve 2 in the space 12 and is electrically connected to a controller (not shown) which controls the intensity of the electromagnetic field generated by the coiled electromagnetic field application portion 11, its operating duration, etc. Any coiled apparatus for electromagnetic stirring may be used for the coiled electromagnetic field application portion 11 without limitations. In addition, the stirring unit 1 may be implemented to be able to apply ultrasonic waves, instead of the electromagnetic field, for stirring.

[0048] As shown in FIG. 2, the coiled electromagnetic field application portion 11 is installed below the sleeve 2 and around a slurry funnel 22 formed to extend above a slurry loading hole 21 of the sleeve 2. Accordingly, molten metal can be thoroughly stirred prior to being loaded into the sleeve 2.

[0049] In the die casting apparatus according to the present invention, the sleeve 2 serves as a slurry vessel in which a semi-solid metallic slurry is manufactured from molten metal with electromagnetic field stirring and as a channel along which the manufactured semi-solid metallic slurry is readily guided into the casting die 4.

[0050] The sleeve 2 is cylindrical and is accommodated in the space 12 of the stirring unit 1, wherein the plunger 3 is inserted into an end of the sleeve 2, and the casting die 4 is connected to the other end of the sleeve 2. The slurry loading hole 21 is formed on the top of the sleeve 2, and the slurry funnel 22 extends from the slurry loading hole 21 to above the stirring unit 1. The slurry funnel 22 makes it easier to pour molten metal from a loading unit 5 via the slurry loading hole 21 into the sleeve 2.

[0051] The sleeve 2 may be made of a metallic mate-

rial or an insulating material, such as alumina or aluminum nitride. For a metallic sleeve 2, a metal having a higher melting point than the molten metal to be loaded therein is preferable. Although not illustrated in FIG. 2, a thermocouple may be installed in the sleeve 2 connected to the controller (not shown) to provide temperature information on the sleeve 2 to the controller.

[0052] In the embodiment of the present invention illustrated in FIGS. 2 and 3, the sleeve 2 is horizontally positioned, with a door 23 installed near the end connected to the casting die 4. The door 23 is shut while a semi-solid metallic slurry is manufactured in the sleeve 2 and is opened when the resulting semi-solid metallic slurry is pushed toward the casting die 4 by the plunger 2. When both ends of the sleeve 2 are blocked by the plunger 3 and the draw door 23, the sleeve 2 can serve as a slurry vessel for manufacturing slurry.

[0053] Although the sleeve 2 is illustrated in FIGS. 2 and 3 as having a simple structure only for containing molten metal, the sleeve 2 may further comprise a temperature control element 24, as illustrated in FIG. 4. The temperature control element 24 is comprised of a cooler and/or a heater. A preferred cooler may be a cooling water pipe 25 additionally attached to surround the sleeve 2, like a water jacket. A preferred heater may be an external electrical heater (not shown). The cooling water pipe 25 may be fitted into a support block 26 placed on an outer wall of the sleeve 2. It is obvious that a thermocouple (not shown) can be installed in the sleeve 2.

[0054] The molten metal loaded in the sleeve 2 can be cooled at an appropriate rate by the cooling water pipe 25 and the electrical heater (not shown). It will be obvious that the sleeve 2 and the temperature control element 24 illustrated in FIG. 4 can be applied to all of the following embodiments of a die casting apparatus for rheocasting according to the present invention.

[0055] The plunger 3 inserted through an end of the sleeve 2 is connected to an additional pressing apparatus (not shown) to be able to reciprocate forward and backward like a piston. Once the manufacture of a semi-solid slurry is completed in the sleeve 2, the plunger 3 is moved toward the casting die 4 to push the semi-solid slurry into the casting die 4.

[0056] The casting die 4 connected to the other end of the sleeve 2 includes a movable die 41 and a fixed die 42. The movable die 41 and the fixed die 42 form a mold cavity 43 when combined together. The fixed die 42 has a through hole 44 via which the semi-solid slurry is injected from the sleeve 2 into the mold cavity 43. The movable die 41 and the fixed die 42 are supported by respective support plates 45a and 45b which are connected to the die casting apparatus via mechanical equipment. After casting is completed, the movable die 41 is separated from the fixed die 42 to release a product from the mold cavity 43.

[0057] The operation of the die casting apparatus for rheocasting, having the above-described structure, according to the present invention will be described with

reference to FIGS. 1 through 3.

[0058] The coiled electromagnetic field application portion 11 of the stirring unit 1, shown in FIG. 2, applies an electromagnetic field having a predetermined frequency to the space 12 at a predetermined intensity. As a nonlimiting example, a 60-Hz electromagnetic field may be applied at a voltage of 250V and an intensity of 500 Gauss.

[0059] In this state, a molten metal prepared in a separate furnace (not shown) is transferred into a loading unit 5, for example, a ladle, and loaded into the slurry manufacturing domain of the sleeve 2 under an electromagnetic field. Alternatively, the furnace may be connected to the sleeve 2 to directly load molten metal into the sleeve 2. As described above, the molten metal can be loaded into the sleeve 2 at a temperature of 100°C above its liquidus temperature,

[0060] When a fully molten liquid metal is loaded into the sleeve 2 with electromagnetic stirring, fine particles are uniformly distributed over the sleeve 2 and grow fast without forming dendritic structures.

[0061] Alternatively, the electromagnetic field may be applied at the start or in the middle of loading the molten metal into the sleeve 2, as described above.

[0062] In addition, the application of the electromagnetic field may be sustained just prior to pushing a resulting semi-solid slurry into the mold cavity 43, for example, sustained until the solid fraction of the molten metal reaches at least 0.001-0.7, preferably 0.001-0.4, more preferably 0.001-0.1, for energy efficiency. The duration of applying an electromagnetic field can be experimentally determined for practical application.

[0063] After the termination of applying the electromagnetic field or while the electromagnetic field is applied, the molten metal in the sleeve 2 is cooled at a predetermined rate into a semi-solid metallic slurry having a solid fraction of 0.1-0.7. The cooling rate is controlled by the temperature control element 24 (see FIG. 3) installed on the outer wall of the sleeve 2, for example, to be 0.2-5°C/sec, preferably, 0.2-2°C/sec.

[0064] After the manufacture of a semi-solid metallic slurry is completed, the door 23 is opened, and the plunger 3 is moved toward the casting die 4 to push the semi-solid metallic slurry via the through hole 44 into the mold cavity 43 of the casting die 4, as illustrated in FIG. 3, followed by rapid cooling to manufacture a product having a shape conforming to the shape of the mold cavity 43.

[0065] Products having a fine, uniform particle structure can be manufactured in a simple way when using the above-described die casting apparatus for rheocasting according to the present invention. In addition, due to a sharp reduction in time required to manufacture a semi-solid metallic slurry, the overall processing time required to manufacture products is reduced with energy saving and higher productivity effects.

[0066] FIG. 5 illustrates the structure of a die casting apparatus for rheocasting according to another embod-

iment of the present invention, which differs from the previous embodiment in that the sleeve 2 is inclined such that the end that serves as the entrance of the plunger 3 faces downward. The following description will be focused on this difference from the previous embodiment.

[0067] The die casting apparatus of FIG. 5 does not require a door for blocking the flow of molten metal not completely processed into a semi-solid slurry into the casting die 4 because the sleeve 2 is inclined. Since a molten metal loaded via the slurry loading hole 21 flows downward toward the plunger 3, without the probability of overflowing and entering the casting die 4, there is no need to install a separate door in the sleeve 2. However, it is preferable that an additional barrier for blocking the semi-solid metallic slurry in the sleeve 2 from flowing out through the slurry loading hole 21 when the plunger 3 is moved towards the casting die 4. The inclination angle of the sleeve 2 may be varied according to design requirements, but is limited to such a degree that molten metal does not overflow and stays within the sleeve 2 during the manufacture of a semi-solid metallic slurry.

[0068] As shown in FIG. 5, the casting die 4 connected to the other end of the sleeve 2 away from the plunger 3 is also inclined as a whole. However, this inclination of the casting die 4 causes limitations when equipping other necessary die casting machines. Accordingly, an alternative die casting apparatus for rheocasting according to the present invention may be constructed, as illustrated in FIGS. 6 and 7, where the casting die 4 is horizontally arranged, and only the slurry manufacturing domain of the sleeve can be positioned at an angle with respect to the casting die 4.

[0069] In particular, referring to FIGS. 6 and 7, the sleeve 2 is comprised of a first sleeve 23 which can be positioned at an angle θ and a second sleeve 24 fixed to the casting die 4, wherein the first sleeve 23 serves as a slurry manufacturing domain and is positioned in the space 12 of the stirring unit 1. The first sleeve 23 is hinged to the second sleeve 24 at an angle θ , preferably, of less than 90 degrees. When the first sleeve 23 is positioned at 90 degrees with respect to the ground, as shown in FIG. 6, molten metal is loaded into the first sleeve 23 and processed into a semi-solid metallic slurry therein. After the manufacture of the semi-solid metallic slurry is completed, the first sleeve 23 is positioned to be aligned with the second sleeve 24, and the plunger 3 is moved toward the casting die 4 to push the semi-solid metallic slurry into the mold cavity 43 for casting, as shown in FIG. 7. The die casting apparatus of FIGS. 6 and 7 does not require a separate slurry loading hole.

[0070] FIGS. 8 and 9 illustrate the structure of a die casting apparatus for rheocasting according to another embodiment of the present invention. In the die casting apparatus of FIGS. 8 and 9, the sleeve 2 is vertically positioned to be movable up and down in connection with an additional driving apparatus (not shown). The

plunger 3 is inserted upward through a bottom end of the sleeve 2. The sleeve 2 is separated from the casting die 4.

[0071] In particular, the sleeve 2 is comprised of a main sleeve 2a, a movable sleeve 2b, and a fixed sleeve 2c. The main sleeve 2a, with the bottom end through which the plunger 3 is inserted upward and a top open end through which molten metal is loaded, serves as a slurry manufacturing domain. The bottom end of the main sleeve 2a contacts the movable sleeve 2b connected to the driving apparatus (not shown). The movable sleeve 2b pushes the main sleeve 2a up after the manufacture of a semi-solid slurry has been completed, to couple it to the fixed sleeve 2c attached to the fixed die 42. The main sleeve 2a and the movable sleeve 2b may be formed as a single body. The main sleeve 2a is positioned in the space 12 of the stirring unit 1 installed on a supporting structure 13, with the coiled electromagnetic field application portion 11 installed to surround the space 12.

[0072] The casting die 4 is also vertically positioned such that its through hole 44 faces the vertically positioned sleeve 2. The fixed die 42 has a stepped bottom end portion, and the fixed sleeve 2c and a support member 46 are attached to the stepped bottom end portion of the casting die 42. The main sleeve 2a is fitted into the fixed sleeve 2a and tightly supported by the support member 46.

[0073] In operating the die casting apparatus having the above-described structure, the main sleeve 2a is separated from the casting die 4 and placed in the space 12 of the stirring unit 1, as illustrated in FIG. 8. Next, an electromagnetic field is applied to the space 12 by the coiled electromagnetic field application portion 11, and a molten metal is loaded via the loading unit 5 into the main sleeve 2a. The main sleeve 2a can serve as a slurry manufacturing domain due to the plunger 2a blocking its bottom end.

[0074] The molten metal loaded into the main sleeve 2a is processed into a semi-solid metallic slurry via a cooling process, as described in the previous embodiments.

[0075] After the completion of manufacturing the semi-solid metallic slurry, the movable sleeve 2b and the plunger 3 are raised to fit the main sleeve 21 into the fixed sleeve 2c attached to the casting die 4. Next, the plunger 3 is accelerated to reach the fixed die 42 and push the semi-solid metallic slurry into the mold cavity 43 of the casting die 4 for casting.

[0076] The above die casting apparatus for rheocasting according to the present invention described with reference to FIGS. 8 and 9 has a simplified structure without a door serving as a barrier between the sleeve 2 and the casting die 4 and in which the sleeve 2 serves as a slurry manufacturing domain.

[0077] As described above, a die casting method and apparatus for rheocasting according to the present invention are compatible with various kinds of metals and

alloys, for example, aluminum, magnesium, zinc, copper, iron, and alloys of the foregoing metals.

[0078] A die casting method and apparatus for rheocasting according to the present invention provide the following effects.

[0079] First, products having a uniform, fine, spherical particle structure can be manufactured.

[0080] Second, densely populated, uniform spherical particles can be formed with molten metal as a starting material in a short time through electromagnetic stirring initiated at a temperature above the liquidus temperature of a source metal to generate more nuclei throughout the sleeve.

[0081] Third, products manufactured using the die casting apparatus according to the present invention have improved mechanical properties.

[0082] Fourth, the duration of electromagnetic stirring is greatly shortened, thereby saving energy for the stirring.

[0083] Fifth, the simplified overall process and the reduced casting duration improve productivity.

[0084] While the present invention has been particularly shown and described with reference to exemplary embodiments thereof, it will be understood by those of ordinary skill in the art that various changes in form and details may be made therein without departing from the spirit and scope of the present invention as defined by the following claims.

Claims

1. A die casting method for rheocasting, the method comprising:

applying an electromagnetic field to a slurry manufacturing domain in a sleeve having an end through which a plunger is inserted and the other end connected to a casting die with a mold cavity and loading a molten metal into the slurry manufacturing domain to manufacture a semi-solid metallic slurry; and
moving the plunger toward the casting die to push the metallic slurry into the mold cavity.

2. The die casting method of claim 1, wherein the sleeve is horizontally positioned, and the slurry manufacturing domain is defined by a door installed near the other end of the sleeve and the plunger inserted through the end of the sleeve.

3. The die casting method of claim 1, wherein the sleeve is inclined such that the end through which the plunger is inserted faces downward, and the slurry manufacturing domain is defined by only the plunger inserted through one end of the sleeve.

4. The die casting method of claim 1, wherein at least

a portion of the sleeve is inclined at an angle such that the end through which the plunger is inserted faces downward, and the slurry manufacturing domain is defined by only the plunger inserted through one end of the sleeve.

5. The die casting method of claim 1, wherein the sleeve is vertically positioned such that the end through which the plunger is inserted faces downward, and the slurry manufacturing domain is defined by only the plunger inserted through one end of the sleeve.

6. The die casting method of any one of claims 1 through 5, wherein applying the electromagnetic field to the slurry manufacturing domain is performed prior to loading the molten metal into the sleeve.

7. The die casting method of any one of claims 1 through 5, wherein applying the electromagnetic field to the slurry manufacturing domain is performed at the start of loading the molten metal into the sleeve.

8. The die casting method of any one of claims 1 through 5, wherein applying the electromagnetic field to the slurry manufacturing domain is performed in the middle of loading the molten metal into the sleeve.

9. The die casting method of any one of claims 1 through 5, wherein applying the electromagnetic field to the sleeve is sustained until the molten metal in the slurry manufacturing domain has a solid fraction of 0.001-0.7.

10. The die casting method of claim 9, wherein applying the electromagnetic field to the sleeve is sustained until the molten metal in the slurry manufacturing domain has a solid fraction of 0.001-0.4.

11. The die casting method of claim 10, wherein applying the electromagnetic field to the sleeve is sustained until the molten metal in the slurry manufacturing domain has a solid fraction of 0.001-0.1.

12. The die casting method of any one of claims 1 through 5, further comprising cooling the molten metal loaded into the slurry manufacturing domain under the electromagnetic field.

13. The die casting method of claim 12, wherein cooling the molten metal is sustained until the molten metal in the slurry manufacturing domain has a solid fraction of 0.1-0.7.

14. The die casting method of claim 12, wherein cooling

the molten metal is performed at a rate of 0.2-5.0°C/sec.

15. The die casting method of claim 14, wherein cooling the molten metal is performed at a rate of 0.2-2.0°C/sec. 5
16. A die casting apparatus for rheocasting, the apparatus comprising:
a stirring unit which includes a space and applies an electromagnetic field to the space;
a sleeve which is accommodated in the space of the stirring unit and into which a molten metal is loaded;
a plunger which is inserted through an end of the sleeve to push a semi-solid slurry manufactured in the sleeve; and
a casting die connected to the other end of the sleeve, the casting die including a movable die and a fixed die which form a mold cavity when combined together and casting a product from the slurry pushed into the mold cavity by the plunger. 10
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17. The die casting apparatus of claim 16, wherein the sleeve is horizontally positioned, and a door is further installed close to the other end of the sleeve connected to the casting die so as to close a through hole of the casting die during the manufacture of the slurry and to open the through hole when the manufactured slurry is pushed toward the casting die by the plunger. 30
18. The die casting apparatus of claim 16, wherein at least a portion of the sleeve is inclined at an angle such that the end of the sleeve through which the plunger is inserted faces downward. 35
19. The die casting apparatus of claim 16, wherein the sleeve comprises a first sleeve having the end through which the plunger is inserted and being able to pivot downward and a second sleeve horizontally positioned, and the first sleeve can be positioned at an angle to be placed in the space of the stirring unit and can be positioned to be aligned with the second sleeve. 40
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20. The die casting apparatus of claim 16, wherein the sleeve is vertically arranged to direct the end through which the plunger is inserted downward, is movable up and down, and is raised together with the plunger after the manufacture of the slurry to couple to the casting die and allow the plunger to push the manufactured slurry into the mold cavity of the casting die. 50
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21. The die casting apparatus of claim 16, wherein the

stirring unit applies the electromagnetic field prior to loading the molten metal into the sleeve.

22. The die casting apparatus of claim 16, wherein the stirring unit applies the electromagnetic field at the start of loading the molten metal into the sleeve.
23. The die casting apparatus of claim 16, wherein the stirring unit applies the electromagnetic field in the middle of loading the molten metal into the sleeve.
24. The die casting apparatus of claim 16, wherein the stirring unit applies the electromagnetic field until the molten metal in the sleeve has a solid fraction of 0.001-0.7.
25. The die casting apparatus of claim 24, wherein the stirring unit applies the electromagnetic field until the molten metal in the sleeve has a solid fraction of 0.001-0.4.
26. The die casting apparatus of claim 25, wherein the stirring unit applies the electromagnetic field until the molten metal in the sleeve has a solid fraction of 0.001-0.1.
27. The die casting apparatus of claim 20, wherein the sleeve comprises a temperature control element.
28. The die casting apparatus of claim 27, wherein the temperature control element comprises at least one of a cooler and an electrical heater.
29. The die casting apparatus of claim 27, wherein the temperature control element cools the molten metal in the sleeve to reach a solid fraction of 0.1-0.7.
30. The die casting apparatus of claim 27, wherein the temperature control element cools the molten metal in the sleeve at a rate of 0.2-5.0°C/sec.
31. The die casting apparatus of claim 30, wherein the temperature control element controls the molten metal in the sleeve at a rate of 0.2-2.0°C/sec.

FIG. 1

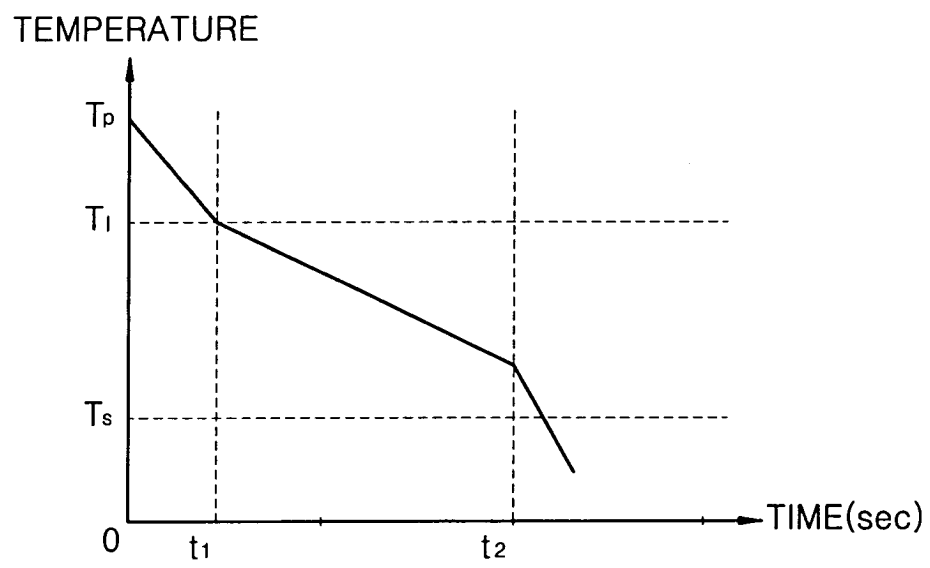


FIG. 2

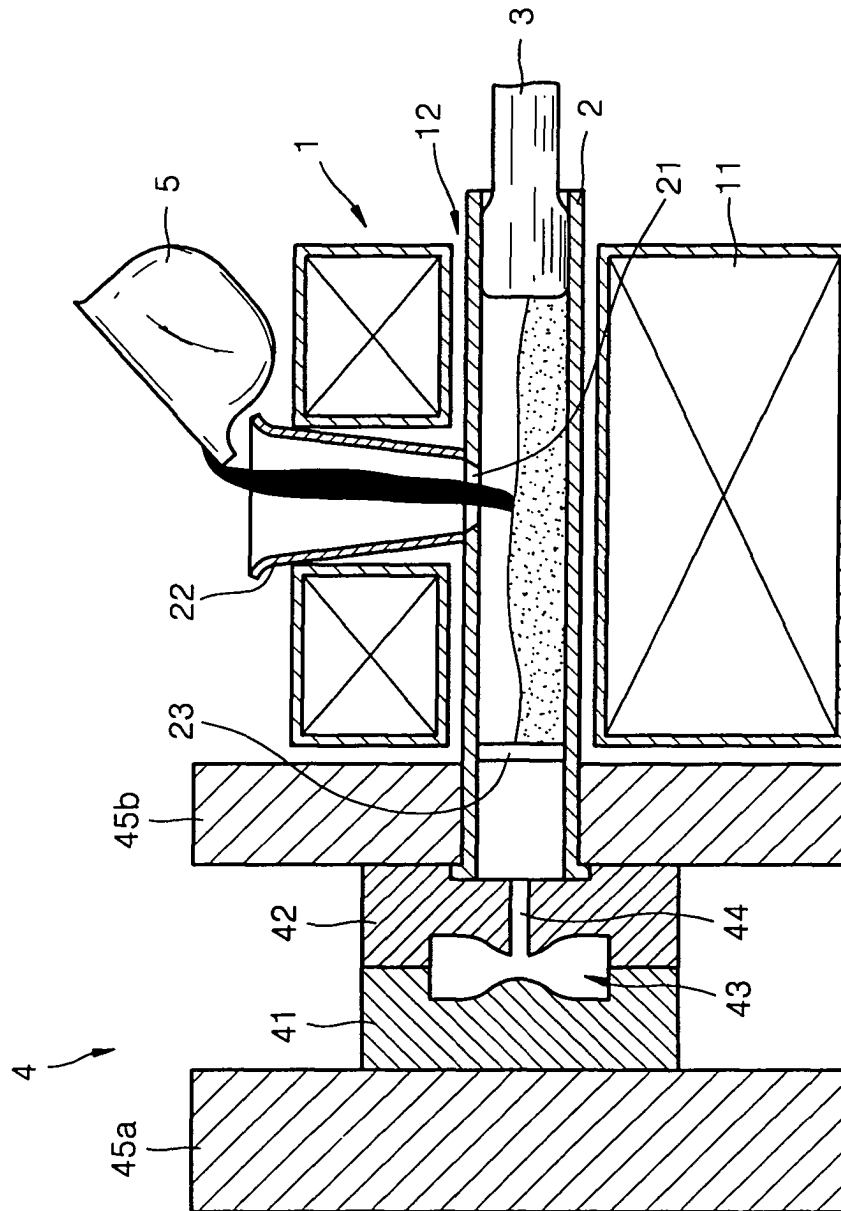


FIG. 3

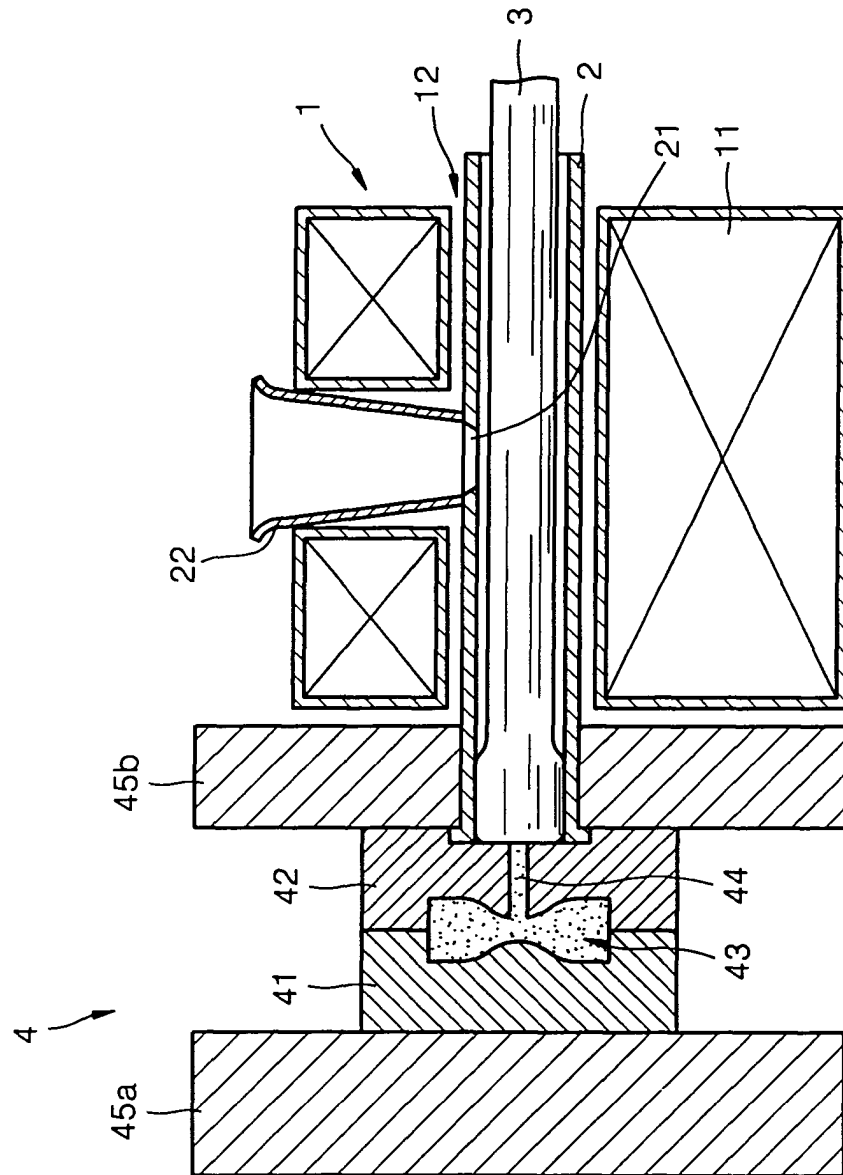


FIG. 4

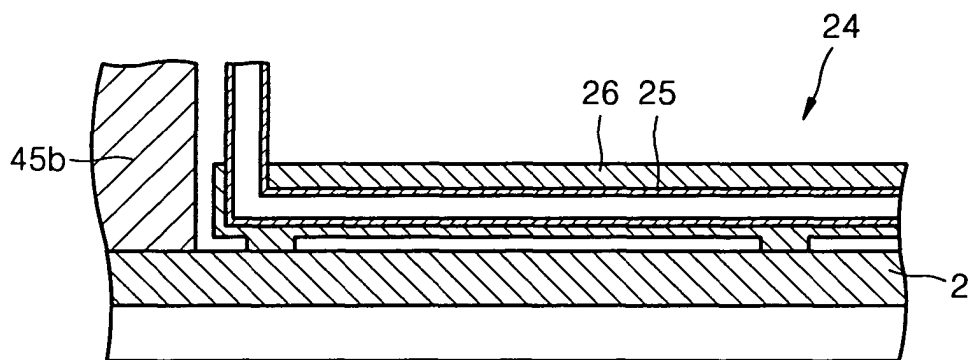


FIG. 5

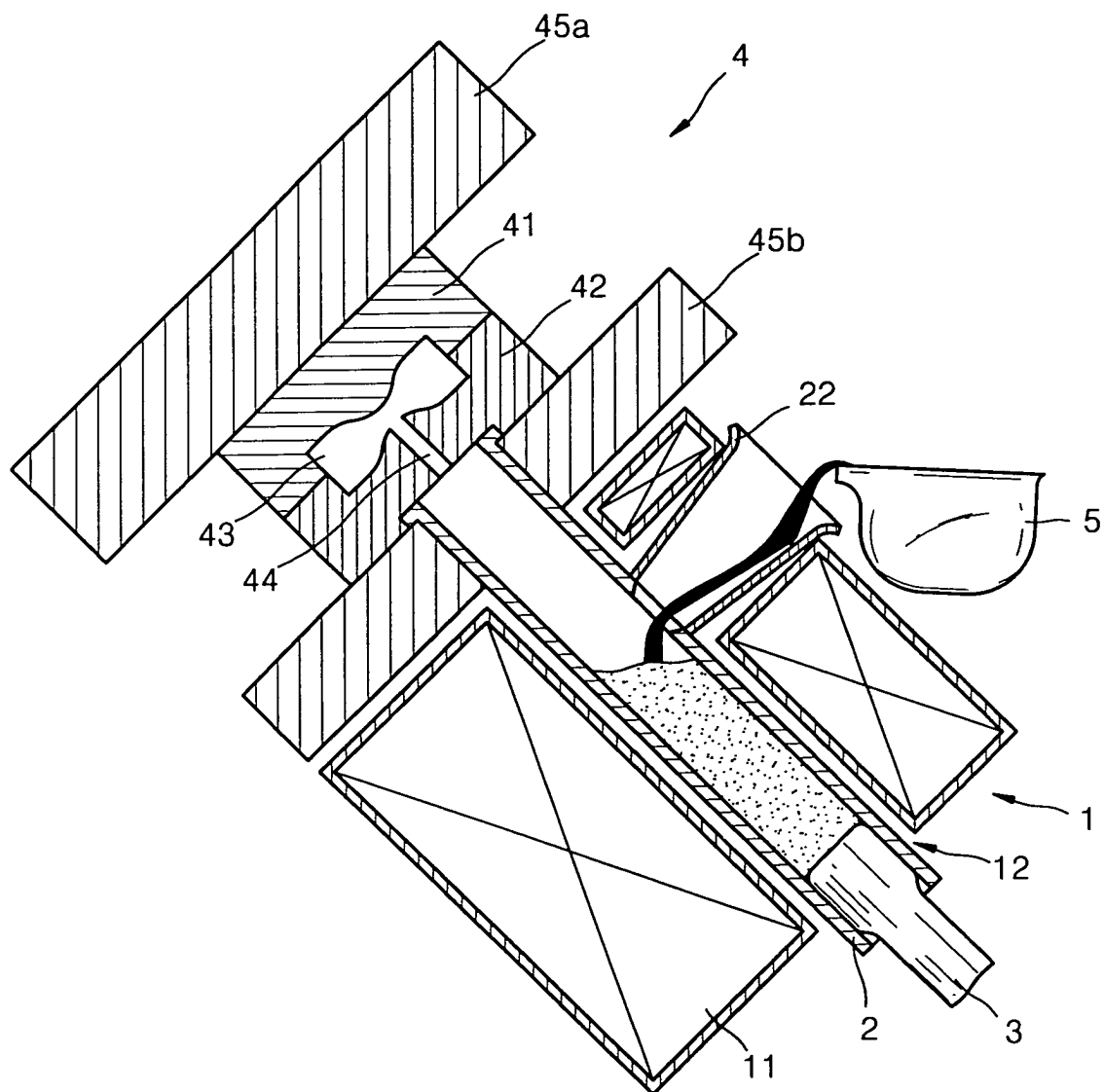


FIG. 6

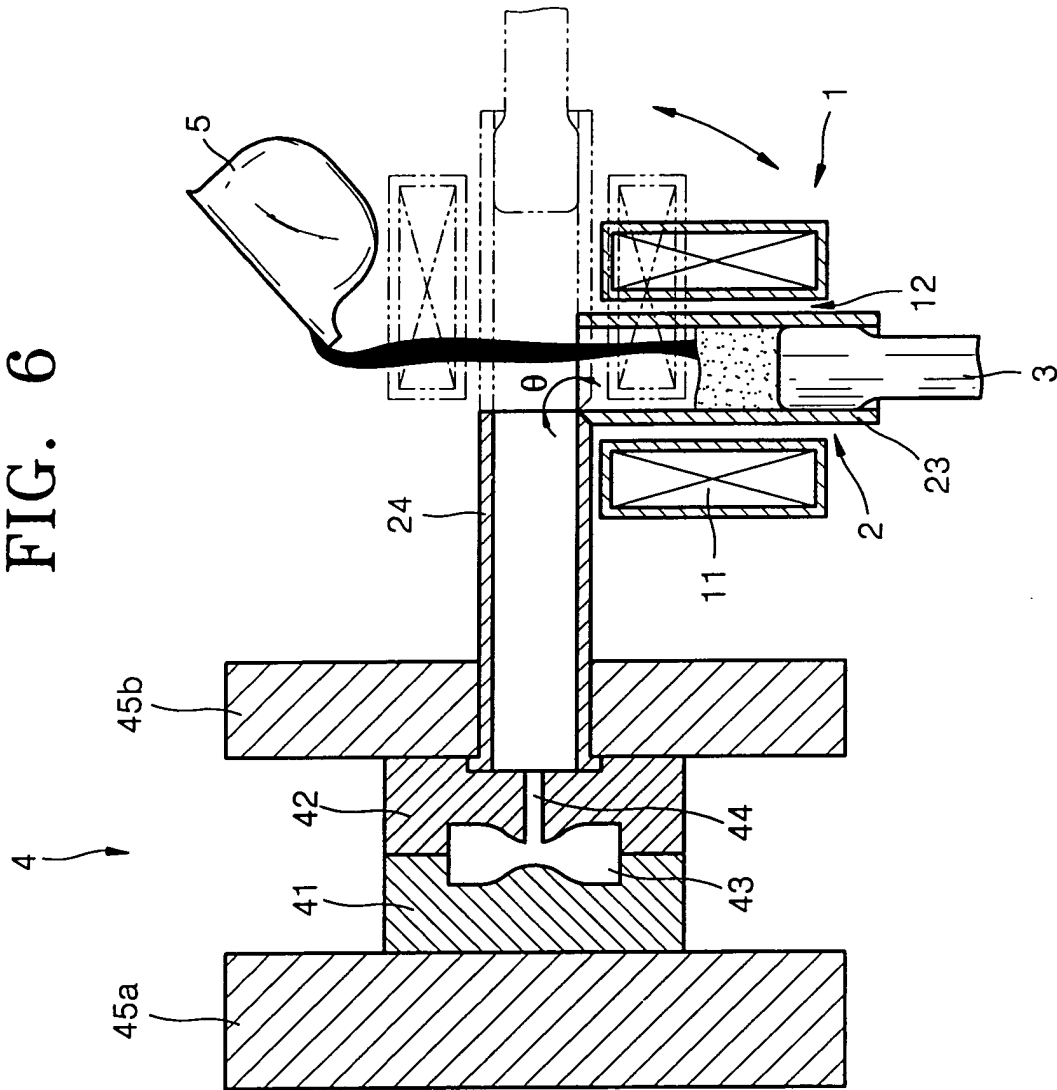


FIG. 7

