(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 759 789 A1

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
07.03.2007 Bulletin 2007/10

(51) Int Cl.:
B22D 41/50 *(2006.01)*

(21) Application number: **06018010.6**

(22) Date of filing: **29.08.2006**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LT LU LV MC NL PL PT RO SE SI SK TR
Designated Extension States:
AL BA HR MK YU

(30) Priority: **30.08.2005 JP 2005248718**
23.01.2006 JP 2006014033

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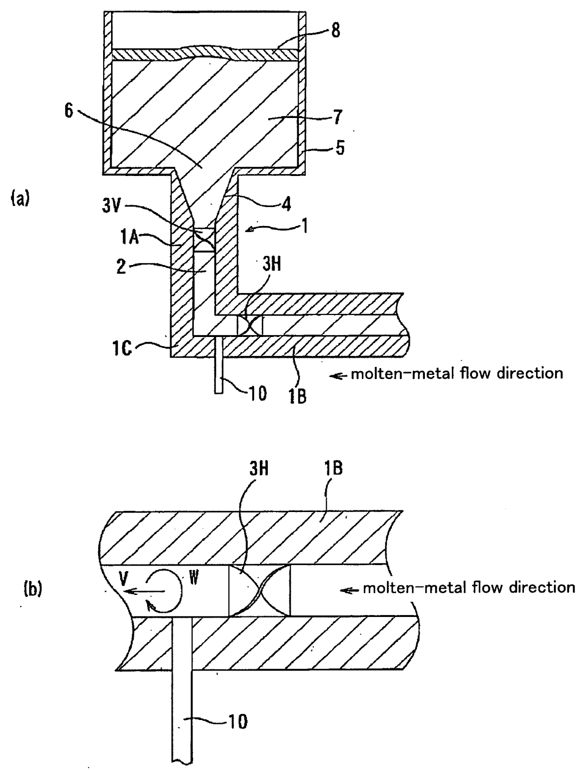
(54) **Pouring tube structure and pouring method for uphill casting**

(57) In an uphill casting process of molten metal, the present invention makes it possible to stabilize a molten metal surface in a mould during pouring without lowering a pouring rate, so as to suppress oxidization of the molten metal due to formation of "open eye" and reduce an amount of slags and nonmetallic inclusions to be dispersed into the steel and spread over the molten metal as substances causing deterioration in quality of metal ingots, to achieve enhanced quality of metal ingots. A pouring tube structure for use in an uphill casting process designed to spout molten metal into a mould 5 from an inlet port 6 located in a lower portion of the mould 5, which comprises a pouring tube internally defining a flow channel for molten metal to provide fluid transport between a molten metal transfer vessel and said inlet port and feed molten metal from said molten metal transfer vessel to said mould and a single or a plurality of swirling-flow generation means provided in said pouring tube and adapted to generate a swirling flow in said molten metal.

FIG. 1



EP 1 759 789 A1

Description

[0001] The present invention relates to a pouring tube structure and a pouring method for use in an uphill casting process designed to spout/pour molten metal into a mould from an inlet port formed in a lower portion of the mould so as to produce a metal ingot. In particular, the present invention relates to a pouring tube structure adapted to fluidically transport with an inlet port formed in a lower portion of a mould, and a pouring method using the pouring tube structure.

[0002] As a casting process for producing metal ingots, there has been known a technique of pouring molten metal into a mould and cooling/solidifying the molten metal.

[0003] This casting process is generally classified as an uphill casting process (uphill teeming or pouring process) or a downhill casting process (downhill teeming or pouring process). Among them, the uphill casting process is designed such that a pouring tube adapted to allow passage of molten metal therethrough is fluidically connected to an inlet port (opening) formed in a lower portion of a mould, and molten metal in a molten metal transfer vessel, such as a ladle, is spouted/poured from the inlet port, i.e., from a lower position of the mould, into the mould through the pouring tube.

[0004] FIG. 11 is a vertical sectional view showing a conventional pouring tube for the uphill casting process. As shown in FIG 11, a pouring tube 1 is connected to an inlet port 6 formed in a bottom of a mould 5, and molten metal is spouted/poured from the inlet port 6 into the mould 5 while passing through a space or flow channel 2 internally defined in the pouring tube 1. So far, a cylindrical-shaped tube having an approximately constant inner diameter has been typically used as the pouring tube 1.

[0005] In a process of spouting/pouring molten metal into the mould 5 through the conventional cylindrical-shaped pouring tube 1, particularly in its initial stage, a speed (energy) in an uphill or upward direction, i.e., in an axial direction of the pouring tube 1, at a terminal or upper end of the pouring tube 1 is relatively high. Thus, the poured molten metal forms a flow locally raising the surface of preceding molten metal 7 in the mould 5 and wildly agitates the molten metal 7 while taking in slag or antioxidant (powder) [hereinafter referred to collectively as "slags"] floating on the surface of the molten metal 7, and dispersing/suspending the slags over the entire molten metal in the mould. Consequently, the slags incorporated in the molten metal 7 causes deterioration in quality of metal ingots. Moreover, in the locally raised region, the slags 8 are pushed aside to form a region where the molten metal is exposed to outside, so-called "open eye" 9 (see Fig. 11), causing adverse effects, such as oxidization of the molten metal.

[0006] It can be expected that, before cooldown/solidification after the pouring into the mould, a certain amount of slags and nonmetallic inclusions causing deterioration in quality of metal ingots refloats onto the surface of the molten metal, and thereby an amount of substances to be incorporated in the molten metal as a causative factor of quality deterioration is reduced. However, the causative-substances removal effect based on the refloating onto the surface of the molten metal will be lowered when the molten metal has stronger flow in the mould.

[0007] For example, as measures against the above problem, the JP-A-09-239494 (Patent Publication 1) discloses a technique for stabilizing the surface of molten metal in a mould (hereinafter referred to as "molten metal surface"). Specifically, a pouring tube used in this technique is designed such that an inner-diameter ratio of an upper end to a principal channel of a runner (pouring tube) is set at 1.1 or more, and the inner diameter is gradually increased in an uphill or upward direction to form an inverse-tapered channel portion having a length set at 0.2 to 2.0 times of the inner diameter of the upper end, so as to distribute a pouring pressure of molten metal to reduce an upward spouting speed or a flow speed in an axially central region of the molten metal.

[0008] In this technique, if an inverse-tapered angle or opening angle (after-mentioned "θ") of the inner diameter of the inverse-tapered channel portion of the pouring tube in the vicinity of the inlet port exceeds about 12°, a vortex-like flow including a downward flow opposite to the axially upward direction of the pouring tube will be generated, i.e., a so-called "flow separation" will occur in the vicinity of the inlet port, particularly, in the vicinity of a wall surface of the inverse-tapered channel portion, even though some molten metal is spread in a direction other than an upward direction. This makes it difficult to adequately reduce the upward flow speed in the axially central region of the molten metal or to obtain a satisfactory effect required for solving the above problem.

[0009] In the uphill casting, a vessel, such as a tundish for use in continuous casting process, allowing nonmetallic inclusions, such as alumina, to refloat before pouring molten metal into a mould, is not employed. Thus, most of such nonmetallic inclusions dispersed over molten metal will flow directly into a mould. The microscopic nonmetallic inclusions are hardly expected to refloat, and highly likely to remain in a metal ingot in a dispersed state and cause deterioration in quality thereof.

[0010] In an uphill casting process of molten metal, it is an object of the present invention to stabilize a molten metal surface in a mould during pouring without lowering a pouring rate, so as to suppress oxidization of the molten metal due to formation of "open eye" and to reduce the amount of slags and nonmetallic inclusions which will be dispersed into the steel and cause deterioration in quality of metal ingots. This will result in an enhanced quality of metal ingots.

[0011] In order to achieve the above stated object, the present invention provides a pouring tube structure for use in an uphill casting process designed to spout molten metal into a mould from an inlet port located in the lower portion of the mould. The pouring tube structure comprises a pouring tube internally defining a flow channel for molten metal to provide fluid transport between a molten metal transfer vessel and the inlet port and feed molten metal from the molten metal transfer vessel to the mould, and a single or a plurality of swirling-flow generation means provided in the pouring tube and adapted to generate a swirling flow in the molten metal.

[0012] The present invention further provides a pouring method for an uphill casting process designed to spout molten metal into a mould from an inlet port formed in a lower portion of the mould. The pouring method comprises generating a swirling flow in molten metal passing through a pouring tube which internally defines a flow channel for molten metal to provide fluid transport between a molten metal transfer vessel and the inlet port and feed molten metal from the molten metal transfer vessel to the mould.

[0013] The pouring tube structure of the present invention capable of generating a swirling flow in molten metal passing through the pouring tube can achieve the following effects.

1. An upward flow speed of molten metal in an upper end of the pouring tube is lowered, and the molten metal poured from the inlet port into the mould is spread by a centrifugal force by the swirling flow. This makes it possible to minimize fluctuations of a molten metal surface, i.e., stabilize the molten metal surface, so as to drastically reduce occurrence of a phenomenon that the molten metal surface is raised in a central region of a mould, to suppress formation of "open eye".

2. In addition, slags on the molten metal surface are hardly dispersed into the molten metal. Thus, the amount of slags to be dispersed into the steel and spread over the molten metal as inclusions can be reduced to provide an enhanced quality of metal ingots.

3. The stabilization of the molten metal surface makes it possible to reduce the amount of slag to be dispersed into the molten metal, and minimize the risk that an antioxidant mold powder added onto the molten metal surface is unevenly located around a peripheral region of the molten metal surface, so as to allow a required amount of antioxidant to be drastically reduced.

[0014] Preferably, in a molten metal flow after passing through the swirling-flow generation means, a ratio (W/V) of a circumferential velocity (W) in a circumferential direction of the inlet port to a velocity (V) in an axial direction of the pouring tube, i.e., a swirl number, is 0.13 or more at the inlet port (in one embodiment of the present invention illustrated in FIG 2, an upstream or lower end of an inverse-tapered channel portion). If the swirl number is less than 0.13, almost no effect of the centrifugal force of the swirling flow can be obtained.

[0015] Representative specific embodiments of the present invention will be described below.

[0016] In a first specific embodiment of the present invention relating to the above pouring tube structure for use in an uphill casting process designed to spout molten metal into a mould from an inlet port formed in a lower portion of the mould, the pouring tube, which internally defines a flow channel for molten metal to provide fluid transport between a molten metal transfer vessel and the inlet port and feed molten metal from the molten metal transfer vessel to the mould, has, in the entire length of the flow channel, an approximately vertical channel portion extending from immediately below the inlet port in an approximately vertically downward direction, an approximately horizontal channel portion extending in an approximately horizontal direction, and a bent channel portion making a transition from the approximately vertical channel portion to the approximately horizontal channel portion. At least one of the swirling-flow generation means is located at any position in the approximately horizontal channel portion on an upstream side of the bent channel portion.

[0017] The above pouring tube structure designed to generate a swirling flow in molten metal passing through the pouring tube, by the swirling-flow generation means located in the approximately horizontal channel portion on the upstream side of the bent channel portion located below the inlet port, can achieve the following effect in addition to the aforementioned effects of the present invention: The molten metal after passing through the swirling-flow generation means flows swirling a given distance between the swirling-flow generation means and the inlet port formed in the lower portion of the mould, and, in this period, nonmetallic inclusions causing quality deterioration can be concentrated around a tube axis (the center of the flow channel) of the pouring tube to reduce dispersion of the nonmetallic inclusions over molten metal in the mould.

[0018] In the first specific embodiment, it is necessary to appropriately adjust the position and number of the swirling-flow generation means in the pouring tube, depending on actual conditions of casting equipment, properties of molten metal, a pouring rate, etc. The following description will be made based on one example where: the molten metal is molten steel at a temperature of about 1600°C; the pouring rate is about 1.3 t/min; and an inner diameter of the pouring tube is about 50 mm.

[0019] Preferably, at least one of the swirling-flow generation means is located at a position on an upstream side of and possibly closer to the bent channel portion of the pouring tube where the approximately vertical channel portion extending vertically downward from immediately below the inlet port is changed to the approximately horizontal channel portion, to generate a swirling flow in the molten metal so as to allow the molten metal with the swirling flow to be spouted into the mould.

[0020] The reason is as follows. In a case where the bent channel portion of the pouring tube has a curvature radius R of about 100 mm or less, when a swirling flow is generated in the molten metal by the swirling-flow generation means on the upstream side of the bent channel portion and then the molten metal passes through the bent channel portion, the swirling flow is apt to be attenuated or disturbed. Thus, it is required to allow the swirling flow to pass through the bent channel portion in a well-organized and undisrupted manner so as to minimize occurrence of the attenuation and turbulence. For this purpose, it is preferable that the swirling-flow generation means is located in the vicinity of the bent channel portion, specifically, at a position spaced apart from and upstream of the bent channel portion by 1500 mm or less. This makes it possible to ensure a swirl number of 0.13 or more at the inlet port so as to maintain stability in a molten metal surface.

[0021] When the distance between the swirling-flow generation means and the inlet port is set at a given value in the above manner, nonmetallic inclusions, such as alumina, having a specific gravity less than that of the molten metal can be concentrated around the tube axis (center of the flow channel) of the pouring tube by a centrifugation action of the swirling flow of the molten metal flowing through the pouring tube.

[0022] The nonmetallic inclusions concentrated around the tube axis (center of the flow channel) are brought into contact with each other in high probability, so as to be enlarged through aggregation or clustering through fusion-bonding. As compared with the original microscopic nonmetallic inclusions present over a wider region of the molten metal, the enlarged or clustered nonmetallic inclusions receive a larger buoyant force which will further facilitate the concentration around the tube axis (center of the flow channel) during flow in the pouring tube. Further, as compared with the original microscopic nonmetallic inclusions, the enlarged or clustered nonmetallic inclusions after being released from the inlet port also receive a larger buoyant force, and thereby have a larger upward flow speed to accelerate floatation. Thus, the nonmetallic inclusions are hardly dispersed in a wide range of the molten metal in the mould, and allowed to be readily separated from the molten metal. This makes it easy to facilitate absorption of the nonmetallic inclusions in powder or the like on the molten metal surface, so as to further reduce dispersion over a metal ingot to be obtained.

[0023] With a view to sufficiently obtaining the above effect of centralization, enlargement and clustering of nonmetallic inclusions based on the centrifugation action, it is preferable that the swirling flow is maintained in the range of 1000 mm or more from the bent channel portion in the upstream direction, i.e., at least one of the swirling-flow generation means is located at a position spaced apart from and upstream of the bent channel portion by 1000 mm or more.

[0024] The reason is that, if a flow of molten metal containing nonmetallic inclusions which have not been sufficiently concentrated around the tube axis (center of the flow channel) of the pouring tube passes through the bent channel portion, the nonmetallic inclusions are likely to be re-dispersed over the molten metal on a downstream side of the bent channel portion.

[0025] Thus, with a view to satisfying both the effect of generating or maintaining a swirling flow after release from the inlet port into the mould, and the effect of separating nonmetallic inclusions based on the centrifugation action, it is preferable that at least one of the swirling-flow generation means is located in the approximately horizontal channel portion of the pouring tube at a position in the range of 1000 mm to 1500 from the bent channel portion in the upstream direction.

[0026] In addition to the above or first swirling-flow generation means, at least a second one of the swirling-flow generation means may be located at any position on an upstream or downstream side of the first swirling-flow generation means. In this case, the position and number of the second swirling-flow generation means may be determined in consideration of the aforementioned requirement of obtaining a swirl number of 0.13 or more at the inlet port.

[0027] Preferably, a twisted tape-like flow control plate is used as each of the swirling-flow generation means. Alternatively, any other suitable configuration having a function of generating a swirling flow may be employed. For example, the swirling-flow generation means may be a spiral or helical groove or protrusion formed in/on an inner wall of the pouring tube, or a plate-shaped grooved member to be located inside the pouring tube.

[0028] The twisted tape-like configuration means a screw-like configuration to be obtained by positioning a flat plate in parallel relation to a molten-metal flow direction (axial direction of the pouring tube) and then twisting one of opposite edges of the flat plate extending in a direction perpendicular to the molten-metal flow direction, in a direction perpendicular to the molten-metal flow direction while fixing the other edge of the flat plate. Preferably, the twisted tape-like configuration has a twist angle ranging from 30° to 180°. If the twist angle is less than 30°, the circumferential velocity of the swirling flow will be excessively lowered to cause difficulty in obtaining the intended effect of the swirling flow. If the twist angle exceeds 180°, the swirling-flow generation means will have an excessively long length, and inclusions contained in the molten metal are likely to undesirably attach on the swirling-flow generation means.

[0029] Each of the above swirl number and the twist angle is varied depending on the dimensions, configuration, mechanism and/or operating conditions of casting equipment. Thus, it is necessary to appropriately set it at an optimal value while observing a state of the molten metal surface.

[0030] In a second specific embodiment of the present invention, the pouring tube provided with the swirling-flow generation means as in the first specific embodiment is formed with an inverse-tapered channel portion having an inner diameter gradually increasing toward the inlet port, at an upper end thereof on the side of the inlet port, so as to allow pour molten metal with a swirling flow to be poured into the mould therethrough. That is, in the pouring tube structure of the present invention, the pouring tube has an upper end on the side of the inlet port, and the upper end is formed with an inverse-tapered channel portion having an inner diameter gradually increasing toward the inlet port.

[0031] In the above pouring tube formed with the inverse-tapered channel portion, a flow along an inner surface of the inverse-tapered channel portion is generated by the centrifugation action of the swirling flow generated by the swirling-flow generation means. Specifically, the molten metal flow is gradually expanded in a radial direction of the pouring tube to additionally generate a flow along the inner surface of the inverse-tapered channel portion while smoothly maintaining a centrifugal force without occurrence of so-called "flow separation" due to vertical vortex-like flows caused by the upward flow, and then released from the inlet port. This makes it possible to largely reduce an upward spouting speed without lowering a pouring rate.

[0032] Preferably, a ratio of an inner diameter (D1) of the upper end to an inner diameter of a lower end (D2) of the inverse-tapered channel portion, i.e., an inner-diameter ratio (D1/D2), is set in the range of 1.36 to 6. If the inner-diameter ratio is less than 1.36, the effect of lowering the upward spouting speed along the axial direction of the pouring tube cannot be adequately obtained in the inverse-tapered channel portion. If the inner-diameter ratio exceeds 6, the circumferential velocity of the swirling flow generated by the swirling-flow generation means is excessively lowered to cause the risks of deterioration in the centrifugal force of the swirling flow and fluctuation around the peripheral region of the molten metal surface. With a view to stabilizing the molten metal surface, the inner-diameter ratio is preferably set to 4.2 or less.

[0033] An inverse-tapered angle or opening angle of the inverse-tapered channel portion is set preferably in the range of about 6° to 120°, more preferably at about 90° or less. If the opening angle is less than 6°, the effect of lowering the upward spouting speed along the axial direction of the pouring tube cannot be adequately obtained in the inverse-tapered channel portion. If the opening angle exceeds 120°, the circumferential velocity of the swirling flow generated by the swirling-flow generation means is excessively lowered to cause the risks of deterioration in the centrifugal force of the swirling flow and fluctuation around the peripheral region of the molten metal surface. With a view to stabilizing the molten metal surface, the opening angle is preferably set at 50° or less.

[0034] With a view to allowing the swirling flow generated by the swirling-flow generation means to further smoothly flow while minimizing occurrence of turbulence before being spouted from the inlet port into the mould, a vicinity of an intersecting point (measurement points of D2) between the inverse-tapered channel portion and a non-tapered channel portion on the side of the upper end of the pouring tube, and a vicinity of an intersecting point (measurement points of D1) between a bottom surface of the mould and the inverse-tapered channel portion, are preferably formed in a smooth shape having a certain radius R or a transition curve instead of a sharp bent or an edged shape. Further, the inner surface of the inverse-tapered channel portion is preferably formed in a smooth flat or curved shape.

[0035] Each of the above inner-diameter ratio and opening angle of the inverse-tapered channel portion is varied depending on the dimensions, configuration, mechanism and/or operating conditions of casting equipment. Thus, it is necessary to appropriately set it at an optimal value while observing a state of the molten metal surface.

[0036] In a third specific embodiment of the present invention, gas is injected from the vicinity of the swirling-flow generation means as described in the first or second specific embodiment, to additionally disperse gas bubbles over a swirling flow of molten metal in the pouring tube. That is, in the pouring tube structure of the present invention, the pouring tube includes a gas injection port in fluid communication with a region of the flow channel provided with at least one of the swirling-flow generation means.

[0037] The gas bubbles additionally dispersed over the swirling flow of molten metal makes it possible to capture nonmetallic inclusions in the molten metal so as to further enhance the effect of concentrating the nonmetallic inclusions around the tube axis (center of the flow channel), and enlarging/clustering the nonmetallic inclusions. This effect is achieved by the following mechanism. The gas bubbles themselves are capable of effectively absorbing nonmetallic inclusions dispersed over the molten metal. In addition, a difference in specific gravity between the gas bubbles and the molten metal is fairly greater than that between the nonmetallic inclusions and the molten metal, and thereby the centrifugation action of the swirling flow more strongly affects the gas bubbles than the nonmetallic inclusions. This stronger centrifugation action generates a gas bubble flow toward the tube axis (center of the flow channel) to further concentrate the gas bubbles around the tube axis (center of the flow channel) (see FIG. 8). These make it possible to further enhance the effect of centralization, enlargement and clustering of the nonmetallic inclusions, and additionally enhance the effect of floating the nonmetallic inclusions in the mould and capturing the floated nonmetallic inclusions by the mold powder or the like.

[0038] Preferably, the gas is injected at a position adjacent to and downstream of the swirling-flow generation means, specifically at a downstream edge of the swirling-flow generation means or between the downstream edge and a position spaced away from the downstream edge by 100 mm in the downward direction. The reason is as follows. The gas bubbles are concentrated toward the tube axis (center of the flow channel) by the swirling flow, to create an air-bubble curtain as a film-shaped gas-bubble aggregate which is formed along a path of the gas bubbles swirlingly moving toward the tube axis (center of the flow channel). When the gas is injected before the swirling flow starts attenuation, the air-bubble curtain is quickly stabilized to exhibit enhanced effect of capturing the nonmetallic inclusions. If the gas is injected at a position spaced away from the downstream edge of the swirling-flow generation means beyond the above upper limit of 100 mm, a distance for allowing the gas bubbles to exist in the swirling flow is excessively reduced to cause deterioration in the gas-bubbles' effect of capturing the nonmetallic inclusions, concentrating the nonmetallic inclusions around the tube axis (center of the flow channel), and enlarging/clustering the nonmetallic inclusions. Moreover, the gas is injected at a position where the swirling flow is relatively weak, and thereby likely to cause destruction of the swirling flow.

[0039] Preferably, the gas is injected from the entire circumference of the pouring tube as evenly as possible. The reason is as follows. When the gas is injected from a wider range of the pouring tube, the gas bubbles can be reduced in size to increase a contact area with the molten metal and come into contact with the molten metal at a higher frequency. This allows the gas bubbles to have an opportunity of passing through a wider range of the molten metal, i.e., to have a higher probability of contact with nonmetallic inclusions dispersed over the molten metal, so as to achieve an enhanced effect of capturing nonmetallic inclusions.

[0040] In the third specific embodiment, the gas bubbles make it possible to capture the nonmetallic inclusions more effectively and quickly. Thus, in the third specific embodiment, while the distance between the bent channel portion and the swirling-flow generation means (downstream edge of the swirling-flow generation means) is not necessarily set to 1000 mm or more as described in the first specific embodiment without the gas injection, but it is preferable to ensure that it is set to 150 mm or more.

[0041] Thus, with a view to satisfying both the effect of generating or maintaining a swirling flow after release from the inlet port into the mould, and the effect of separating nonmetallic inclusions based on the centrifugation action, it is preferable that at least one of the swirling-flow generation means are located in the approximately horizontal channel portion of the pouring tube at a position in the range of 150 mm to 1500 mm from the bent channel portion in the upstream direction.

[0042] Preferably, inert gas having no chemical influence on the molten metal, such as an oxidation reaction, is used as the gas to be injected. For example, under the conditions that a pouring rate is in the range of 0.4 to 1.8 ton/min, and a speed of molten metal in the pouring tube is in the range of 0.5 to 2 m/sec, a volume of gas to be injected is preferably set in the range of 0.0003 to 0.002 Nm^3/min, in view of maximizing the gas-bubbles' effect while maintaining the swirling flow. If the gas volume is less than 0.0003 Nm^3/min, almost no nonmetallic-inclusions capturing effect based on the gas injection can be obtained. If the gas volume exceeds 0.002 Nm^3/min, the molten metal flowing through the pouring tube has an excessively low density to cause instability in the molten metal flow, and the risk of clogging of the pouring tube due to cooling in some cases.

[0043] In a fourth specific embodiment of the present invention, the pouring tube structure is intended to further generate a stable swirling flow in the molten metal inside the pouring tube as compared with the first specific embodiment. Specifically, in the pouring tube structure for use in an uphill casting process designed to spout molten metal into a mould from an inlet port formed in a lower portion of the mould, the pouring tube, which internally defines a flow channel for molten metal to provide fluid transport between a molten metal transfer vessel and the inlet port and feed molten metal from the molten metal transfer vessel to the mould, has, in the entire length of the flow channel, an approximately vertical channel portion extending from immediately below the inlet port in an approximately vertically downward direction, an approximately horizontal channel portion extending in an approximately horizontal direction, and a bent channel portion making a transition from the approximately vertical channel portion to the approximately horizontal channel portion. At least a first one of the swirling-flow generation means is located at any position in the approximately horizontal channel portion on an upstream side of the bent channel portion, and at least a second one of the swirling-flow generation means is located at any position in the approximately vertical channel portion on a downstream side of the bent channel portion.

[0044] In the fourth specific embodiment, at least a first one of the swirling-flow generation means is located at any position in the approximately horizontal channel portion, in the same manner as the first specific embodiment, and optionally one or more of the swirling-flow generation means are located on the upstream side of the first swirling-flow generation means. In addition, at least a second one of the swirling-flow generation means is located at any position in the approximately vertical channel portion extending vertically downward from below the inlet port, is located on the downstream side of the first swirling-flow generation means, to further stably generate a swirling flow in the molten metal inside the pouring tube and allow the molten metal with the stable swirling flow to be poured into the mould.

[0045] In cases where, when the swirling-flow generation means is located only in the approximately horizontal channel portion, a generated swirling flow becomes weak during pouring into the mould due to large attenuation caused by passing through the bent channel portion on the downstream side of the swirling-flow generation means, the second swirling-flow generation means having the same configuration as that in the first specific embodiment can also be effectively located in the approximately vertical channel portion extending vertically downward from below the inlet port.

[0046] A specific configuration and function/effect of the second swirling-flow generation means are the same as those of the swirling-flow generation means described in the first specific embodiment. The level of the swirling flow during pouring into the mould may be specifically determined on a case-by-case basis depending on actual conditions of casting equipment, a pouring rate, properties of molten metal, etc., and in consideration of the aforementioned requirement of allowing the swirling flow to have a swirl number of 0.13 or more during pouring into the mould. Respective configurations and positions of the first and second swirling-flow generation means may be adjusted to meet the above conditions and this requirement.

[0047] In a fifth specific embodiment of the present invention, the pouring tube provided with the plurality of swirling-flow generation means as in the fourth embodiment is formed with an inverse-tapered channel portion having an inner diameter gradually increasing toward the inlet port, in an upper end thereof on the side of the inlet port.

[0048] As in the second specific embodiment, in the fifth specific embodiment, based on the inverse-tapered channel portion, a flow along an inner surface of the inverse-tapered channel portion is created by a centrifugal force of the swirling flow generated by the swirling-flow generation means. Specifically, the molten metal is spouted from the inlet port after the swirling flow thereof is expanded to flow along the inner surface of the inverse-tapered channel portion while smoothly maintaining the centrifugal force without occurrence of the so-called "flow separation". This makes it possible to distribute an upward spouting speed to be concentrated around the center of the flow channel, in a lateral direction of the mould, so as to largely reduce the upward spouting speed without lowering the pouring rate. The conditions, such as shape, of this inverse-tapered channel portion, are the same as those in the second specific embodiment.

[0049] In a sixth specific embodiment of the present invention, gas is injected in a vicinity of each of the plurality of swirling-flow generation means as in the fourth specific embodiment to disperse gas bubbles over the molten metal in the pouring tube and allow the molten metal with the gas bubbles to be poured into the mould.

[0050] As with the third specific embodiment, in the sixth specific embodiment, the gas bubbles dispersed over the swirling flow of the molten metal makes it possible to further enhance the gas-bubbles' effect of capturing the nonmetallic inclusions, concentrating the nonmetallic inclusions around the tube axis (center of the flow channel), and enlarging/clustering the nonmetallic inclusions. In addition, the gas bubbles receiving a larger buoyant force than that received by the nonmetallic inclusions can accelerate the effect of floating the nonmetallic inclusions in the molten metal flow after being released from the inlet port into the mould.

[0051] In the same manner as that in the third specific embodiment, preferably, the gas is injected at a position adjacent to and downstream of the upstreammost swirling-flow generation means, and from the entire circumference of the pouring tube. The reason is that, in addition to the reason described in the third specific embodiment, the sixth embodiment is primarily intended to provide a compensation function when the function/effect of the pouring tube structure according to the third specific embodiment is not sufficient.

[0052] The gas injection port may be provided in the vicinity of each of the plurality of swirling-flow generation means. In this case, the same effect as that in the pouring tube structure designed to inject the gas only at a position adjacent to and downstream of the upstreammost swirling-flow generation means can be obtained.

[0053] If the swirling flow becomes weak during pouring into the mould due to large attenuation caused by passing through the bent channel portion on the downstream side of the approximately horizontal channel portion, or the injected gas bubbles are increased in size and unevenly distributed, it is preferable to reduce the volume of gas to be injected in the vicinity of the swirling-flow generation means located in the approximately vertical channel portion, as compared with the pouring tube structure designed to inject the gas at a single position. In the pouring tube structure having the plurality of gas injection ports, the total volume of gas to be injected is likely to be excessively increased so as to cause difficulty in obtaining the effect of forming a desirable swirling flow against the intended purpose. Thus, it is preferable to adjust a ratio between respective gas volumes from the plurality of gas injection positions so as to keep the total volume of gas to be injected from being changed depending on the number of gas injection positions. The optimal ratio may be specifically determined on a case-by-case basis depending on actual conditions of casting equipment, a pouring rate, properties of molten metal, an intended quality of metal ingots, etc.

[0054] In the sixth specific embodiment, the level of the swirling flow during pouring into the mould and the level of gas distribution may be specifically determined on a case-by-case basis depending on actual conditions of casting equipment, pouring rate, properties of molten metal, an intended quality of metal ingots etc., and in consideration of the aforementioned requirement of allowing the swirling flow to have a swirl number of 0.13 or more during pouring into the mould. Respective configurations and positions of the plurality of swirling-flow generation means may be adjusted to meet the above conditions and this requirement.

[0055] Preferably, inert gas having no chemical influence on the molten metal, such as oxidation reaction, is used as the gas to be injected. For example, under the conditions that a pouring rate is in the range of 0.4 to 1.8 ton/min, and a speed of molten metal in the pouring tube is in the range of 0.5 to 2 m/sec, the total volume of gas to be injected is preferably set in the range of about 0.0003 to 0.002 Nm^3/min, in view of the balance between maximization of the gas-bubbles' effect and maintenance of the swirling flow.

[0056] In the above specific embodiments of the present invention, respective features of the first to third specific embodiments may be implemented all together to provide further enhanced effect of reducing nonmetallic inclusions to be contained in the molten metal in the mould, and further enhanced ingot quality, as compared with the cases of implementing the features individually.

[0057] Further, the fourth to sixth specific embodiments, where at least one of the swirling-flow generation means is located in both the approximately vertical channel portion and the approximately horizontal channel portion, may be implemented all together to provide further enhanced effect of reducing nonmetallic inclusions to be contained in the molten metal in the mould, and further enhanced ingot quality, as compared with the cases of implementing the features individually. It is noted that each of the fourth to sixth specific embodiments is primarily intended to provide a compensation function when the function/effect of the pouring tube structures according to the first to third specific embodiments is not sufficiently obtained due to the bent channel portion on the downstream side of the downstreammost swirling-flow generation means etc., and therefore not necessarily implemented if the function/effect can be sufficiently obtained in the pouring tube structures according to the first to third specific embodiments.

[0058] In a seventh specific embodiment of the present invention relating to the pouring tube structure for use in an uphill casting process designed to spout molten metal into a mould from an inlet port formed in a lower portion of the mould, the swirling-flow generation means for generating a swirling flow in the molten metal is located in the pouring tube internally defining a flow channel for molten metal to provide fluid transport between a molten metal transfer vessel and the inlet port and feed molten metal from the molten metal transfer vessel to the mould, at a position adjacent to the inlet port.

[0059] In the seventh specific embodiment, a swirling flow is generated in the vicinity of the inlet port by the swirling-flow generation means located in the pouring tube at a position adjacent to the inlet port. Thus, an upward flow speed of the molten metal spouted from the inlet port is lowered, and the molten metal is spread based on a centrifugal force generated by the swirling flow, so as to reduce fluctuation of a molten metal surface and stabilize the molten metal surface to effectively suppress the phenomenon that the molten metal surface is locally raised, i.e., formation of "open eye". In addition, an amount of slags on the molten metal surface to be taken in the molten metal can be reduced. This makes it possible to reduce mixing and dispersion of the slags as inclusions into the molten metal so as to provide enhanced quality of metal ingots. Further, the stabilization of the molten metal surface makes it possible to reduce slags to be dispersed into the molten metal, and cut the risk that an antioxidant mold powder added onto the molten metal surface is unevenly located around a peripheral region of the molten metal surface, so as to allow a required amount of antioxidant to be drastically reduced.

[0060] In the seventh specific embodiment, the level of the swirling flow during pouring into the mould and the level of gas distribution may be specifically determined on a case-by-case basis depending on actual conditions of casting equipment, pouring rate, properties of molten metal, intended quality of metal ingots etc., and in consideration of the aforementioned requirement of allowing the swirling flow to have a swirl number of 0.13 or more during pouring into the mould. The configuration and positioning of the swirling-flow generation means may be adjusted to meet the above conditions and this requirement.

[0061] In an eighth specific embodiment of the present invention, the pouring tube provided with the swirling-flow generation means located adjacent to the inlet port as in the seventh specific embodiment is formed with an inverse-tapered channel portion having an inner diameter gradually increasing toward the inlet port, at an upper end thereof on the side of the inlet port, in the same manner as that in the second and fifth specific embodiments. In this case, the swirling-flow generation means is located at an upstream region of the inverse-tapered channel portion.

[0062] As with the second and fifth specific embodiments, in the eighth specific embodiment, based on the inverse-tapered channel portion, a flow along an inner surface of the inverse-tapered channel portion is created by a centrifugal force of the swirling flow generated by the swirling-flow generation means. Specifically, the molten metal is spouted from the inlet port after the swirling flow thereof is expanded to flow along the inner surface of the inverse-tapered channel portion while smoothly maintaining the centrifugal force without occurrence of the so-called "flow separation". This makes it possible to distribute an upward spouting speed to be concentrated around the center of the flow channel, in a lateral direction of the mould, so as to largely reduce the upward spouting speed without lowering the pouring rate. The conditions, such as shape of this inverse-tapered channel portion, are the same as those in the second and fifth specific embodiments.

[0063] In a ninth specific embodiment of the present invention, gas is injected in a vicinity of the swirling-flow generation means located adjacent to the inlet port as in the seventh specific embodiment to disperse gas bubbles over the molten metal in the pouring tube and allow the molten metal with the gas bubbles to be poured into the mould.

[0064] As with the third and sixth specific embodiments, in the ninth specific embodiment, the gas bubbles dispersed over the swirling flow of the molten metal makes it possible to further enhance the gas-bubbles' effect of capturing the nonmetallic inclusions, concentrating the nonmetallic inclusions around the tube axis (center of the flow channel), and enlarging/clustering the nonmetallic inclusions. In addition, the gas bubbles receiving a larger buoyant force that that received by the nonmetallic inclusions can accelerate the effect of floating the nonmetallic inclusions in the molten metal flow after being released from the inlet port into the mould.

[0065] Preferably, the gas is injected at a position adjacent to and downstream of the swirling-flow generation means, and from the entire circumference of the pouring tube. The reason is the same as that described in the third specific embodiment.

[0066] In the ninth specific embodiment, the level of the swirling flow during pouring into the mould and the level of gas distribution may be specifically determined on a case-by-case basis depending on actual conditions of casting equipment, pouring rate, properties of molten metal, intended quality of metal ingots etc., and in consideration of the aforementioned requirement of allowing the swirling flow to have a swirl number of 0.13 or more during pouring into the mould. The configuration and positioning of the swirling-flow generation means may be adjusted to meet the above conditions and this requirement.

[0067] Preferably, inert gas having no chemical influence on the molten metal, such as oxidation reaction, is used as the gas to be injected. For example, under the conditions that a pouring rate is in the range of 0.4 to 1.8 ton/min, and a speed of molten metal in the pouring tube is in the range of 0.5 to 2 m/sec, a total volume of gas to be injected is preferably set in the range of about 0.0003 to 0.002 Nm^3/min, in view of the balance between maximization of the gas-bubbles' effect and maintenance of the swirling flow.

[0068] In the present invention, the flow channel in the pouring tube is not limited to a specific sectional shape in a direction perpendicular to the molten-metal flow direction. In view of making it easy to form a swirling flow, restraining the attenuation of swirling flow, eliminating a portion causing stagnation in flow and facilitating centralization of nonmetallic inclusion without uneven distribution, the sectional shape of the flow channel is formed preferably in a shape without a corner having a certain radius R, more preferably in a circular shape.

[0069] As above, the present invention provides the following effects.

1. An upward spouting speed of molten metal poured into the mould can be drastically reduced without lowering a pouring rate. This makes it possible to stabilize a molten metal surface so as to reduce an amount of nonmetallic inclusions and slags composed of antioxidant to be taken in the molten metal, and dispersion of them over the molten metal, while suppressing formation of "open eye" so as to prevent oxidation of the molten metal.

2. In addition, the reduction in dispersion of nonmetallic inclusions causing deterioration in quality of metal ingots makes it possible to achieve enhanced quality of metal ingots.

3. Further, the frequency of contact between nonmetallic inclusions and an inner wall of the pouring tube during feeding of molten metal can be reduced to suppress wear damages of the inner wall of the pouring tube due to ablation and chemical corrosion so as to maintain a stable molten metal flow and provide enhanced durability of a material of the pouring tube.

4. The conventional pouring tube structure having only the inverse-tapered channel portion in the pouring tube could sufficiently obtain the effect of stabilizing a molten metal surface only if the opening angle is set in a relatively narrow range of about 12° or less. In contrast, according to the present invention, the opening-angle range can be drastically increased as compared with conventional pouring tube structure to cope with a wide range of operating conditions. This makes it possible to reduce an inner diameter of the inlet port formed in a refractory member so as to achieve enhanced durability of the refractory member and allow molten metal to be poured into the mould while keeping a stable molten metal surface over a long span of time.

5. Even in cases where the approximately vertical channel portion or the swirling-flow generation means cannot be formed/located in a portion of the pouring tube located in a space between the bottom of the mould and equipment or the ground therebelow due to narrowness of the space, the swirling-flow generation means can be located in the approximately horizontal channel portion to obtain the above effects 1 to 4.

[0070] With reference to the drawings, a preferred embodiment of the present invention will now be described.

FIG 1 shows a mould and a part of a pouring tube structure according to one embodiment of the present invention in the vicinity of the mould, wherein FIG. 1(a) is a general vertical sectional view, and FIG. 1(b) is an enlarged vertical sectional view of a part of the pouring tube structure in the vicinity of a flow control plate 3H.
FIG 2 is an enlarged vertical sectional view showing an inverse-tapered portion and an inlet port in FIG. 1;
FIG 3 shows one example of the flow control plate, wherein FIG. 3(a) is a front view (wherein a twist angle (θs) is an arbitrary value), and FIG 3(b) is a side view (wherein the twist angle (θs) is 180°);
FIG 4 is a top view showing another example of the flow control plate;
FIG. 5 is a vertical sectional view showing a pouring tube structure according to another embodiment of the present invention;
FIG 6 is a photograph showing a section of a water surface in a water model test in EXAMPLE I (Inventive Example (6) in Table 1);
FIG. 7 is a photograph showing a section of a water surface in a water model test in EXAMPLE I (Comparative Example (1) in Table 1);

FIG 8 is a photograph showing a pouring tube in a state when only air is injected into a swirling water flow in a water-model experimental apparatus in EXAMPLE I using the pouring tube of the present invention;

FIG. 9 is a photograph showing a section of a water surface in a water model test in EXAMPLE III (Inventive Example (23) in Table 2);

FIG. 10 is a photograph showing a section of a water surface in a water model test in EXAMPLE III (Comparative Example (3) in Table 2); and

FIG 11 is a vertical sectional view showing a conventional pouring tube for the uphill casting process.

[0071] As shown in FIG 1, a pouring tube 1 is connected to an inlet port 6 formed in a bottom of a mould 5. Molten metal is fed upward through a space or flow channel 2 internally defined in the pouring tube 1, and spouted/poured from the inlet port 6 into the mould 5.

[0072] The pouring tube 1 has an approximately vertical channel portion 1A extending from immediately below the inlet port 6 of the mould 5 in an approximately vertically downward direction, an approximately horizontal channel portion 1B extending in an approximately horizontal direction and a bent channel portion 1C making a transition from the approximately vertical channel portion 1A to the approximately horizontal channel portion 1B. The flow control plate 3H serving as swirling-flow generation means is located in the approximately horizontal channel portion 1B on an upstream side of the bent channel portion 1C at space 2, a position spaced apart from the bent channel portion by about 300 mm. An upper end of the flow channel 2 on a downstream side of the bent channel portion 1C (upper end of the approximately vertical channel portion 1A on the downstream side of the bent channel portion 1C) is formed as an inverse-tapered channel portion 4 having an inner diameter gradually increasing toward the inlet port 6. The flow control plate 3H is operable to generate a swirling flow in the molten metal passing through the flow channel 2 and allow the molten metal with the swirling flow to be spouted/poured from the inlet port 6 into the mould 5. The pouring tube 1 has a plurality of gas injection ports 10 arranged along a circumferential direction thereof at a position immediately downstream of the flow control plate 3H.

[0073] The pouring tube structure illustrated in FIG 1(a) further includes a flow control plate 3V located in the approximately vertical channel portion 1A. However, if an intended effect can be obtained only by the flow control plate 3H, the flow control plate 3V may be omitted.

[0074] FIG. 2 is an enlarged vertical sectional view showing the inverse-tapered portion in FIG. 1. The inverse-tapered portion 4 is formed in an inverse-tapered shape which has an inner diameter gradually increasing from a lower end (inner diameter D2) to an upper end (inner diameter D1) thereof to define an inverse-tapered angle or opening angle (θ), the upper end is fluidically connected to the inlet port 6.

[0075] FIG 3 shows one example of the flow control plate, wherein FIG 3(a) is a front view, and FIG 3(b) is a side view. The flow control plate 3 has a screw-like configuration, i.e., a twisted tape-like configuration, having a twist angle (θs) which is equivalent to a state after a flat plate is horizontally positioned parallel to a flow direction of molten metal in the flow channel 2 (molten-metal flow direction) and then a left edge 3a of the flat plate is twisted in a direction perpendicular to the molten-metal flow direction with respect to a right edge of the flat plate 3b.

[0076] FIG 4 is a top view showing another example of the flow control plate. In this flow control plate 3, a plate having a certain thickness in the molten-metal flow direction is formed with a plurality of grooves 3d each slightly inclined from an outer periphery to a central region thereof, and a circular space 3p formed in the central region to which the grooves 3d are gathered. These grooves 3d are operable to give a circumferential velocity to molten metals passing therethrough, and move the molten metals toward the central region while increasing the circumferential velocity so as to form a swirling flow which swirls counterclockwise.

[0077] FIG 5 is a vertical sectional view showing a pouring tube structure according another embodiment of the present invention. As shown in FIG. 5, a pouring tube 1 is connected to an inlet port 6 formed in a bottom of a mould 5. Molten metal is fed upward through a space or flow channel 2 internally defined in the pouring tube 1, and spouted/poured from the inlet port 6 into the mould 5.

[0078] In this pouring tube structure, a flow control plate 3 serving as swirling-flow generation means is located in the flow channel 2 at a position adjacent to the inlet port 6, and an upper end of the flow channel 2 on a downstream side of the flow control plate 3 (upper end of the pouring tube 1) is formed as an inverse-tapered channel portion 4 having an inner diameter gradually increasing toward the inlet port 6. The flow control plate 3 is operable to generate a swirling flow in the molten metal passing through the flow channel 2 and allow the molten metal with the swirling flow to be spouted/poured from the inlet port 6 into the mould 5. Each of the inverse-tapered channel portion and flow control plate 3 has the same structure as that illustrated in FIGS. 2 and 3.

[0079] The following experimental test was performed using pouring tube structures having the aforementioned features of the present invention as Inventive Examples.

[EXAMPLE I]

[0080] According to an experimental test based on numerical simulation and water-model simulation, respective influences of a position of the swirling-flow generation means, the inverse-tapered portion and the gas injection on stability of a water surface used as an equivalent of the molten metal surface and the number of organic particles used as an equivalent of inclusions were checked.

[0081] In this test, a tube used as the pouring tube illustrated in FIG 1 was formed with a bent portion (bent channel portion) having a curvature radius of about 120 mm, and a single flow control plate serving as the swirling-flow generation means was located in an approximately horizontal portion (approximately horizontal channel portion) of the tube at a position spaced apart from the bent portion by about 150 mm to about 1000 mm in an upstream direction. The twisted tape-like flow control plate as shown in FIG. 3 was used as the swirling-flow generation means. An axial length (L) and a twist angle (θs) of the flow control plate were set in the range of 30 to 120 mm and in the range of 30° to 180°, respectively.

[0082] An inverse-tapered portion (inverse-tapered channel portion) was formed in the tube in a position corresponding to the upper end of the pouring tube. An opening angle (θ) and an inner-diameter ratio (D1/D2) of an upper end (D1) to a lower end (D2) of the inverse-tapered portion were variously changed.

[0083] Twelve holes each having a diameter of 0.5 mm and serving as the gas injection port were formed in the tube at a position adjacent to a downstream edge of the swirling-flow generation means and arranged along a circumferential direction of the tube at even intervals, to inject air therethrough while changing a total volume of the air. A flow speed of the water just before passing through the flow control plate was set in the range of 0.7 to 1.5 m/s.

[0084] In this test, a swirl number was obtained from both a numerical calculation result and a flow-speed measurement result using a laser flowmeter in a water-model experimental apparatus. The state of "open eye" was evaluated by checking a state of the water surface based on visual observation and a video image, and classifying a combination of a sensory evaluation result from the visual observation and a measure value from the video image, into a plurality of ranks.

[0085] The organic particles used as nonmetallic inclusions had a diameter of about 1 mm and a specific gravity of about 0.8, and a water-repellent was splayed to coat surfaces thereof so as to lower water wettability thereof. The number of residual particles in a case used as an equivalent of the mould was measured by releasing the organic particles into water from a water supply port at a rate of 200 particles/min, and measuring behaviors of particles used as an equivalent of powder on the molten metal surface and the organic particles spouted from an inlet port of the case, in the case using a video image. Respective flow paths of the particles (inclusions) and gas bubbles in the water inside the tube were estimated by numerical analytical simulation. The result of the above test was represented by a relative index on the basis of 100 representing a value of Comparative Example (Comparative Example (1) in Table 1) based on the conventional pouring tube structure.

[0086] Table 1 shows the above result. FIG. 6 is a photograph showing a section of a water surface in the water model test for Inventive Example (6) in Table 1, and FIG. 7 is a photograph showing a section of a water surface in the water model test for Comparative Example (1) in Table 1.

TABLE 1

	Opening Angle (θ)	Inner Diameter Ratio (D1/D2)	Swirl Number (W/V)	Total Volume of Gas (Nm^3/ min.)	State of Surface ※1	Number of Residual Inclusions ※2
Comparative Example (1)	0°	1. 0	0	-	×	100
Comparative Example (2)	1 2° ~20°	1. 3	0	-	×	92
Inventive Example (1)	0°	1. 0	0. 13~1. 0	-	A	65
Inventive Example (2)	6°	1. 36	0. 13~1. 0	-	B	50
Inventive Example (3)	10°	1. 6	0. 13~0. 8	-	B	40
Inventive Example (4)	16. 8°	2. 0	0. 3~1. 0	-	C	30

(continued)

	Opening Angle (θ)	Inner Diameter Ratio (D1/D2)	Swirl Number (W/V)	Total Volume of Gas (Nm^3/ min.)	State of Surface ※1	Number of Residual Inclusions ※2
Inventive Example (5)	20°	2. 2	0. 3~1. 0	-	C	30
Inventive Example (6)	32. 8°	2. 2~3. 0	0. 3~1. 0	-	C	30
Inventive Example (7)	40°	2. 2~3. 47	0. 4~1. 5	-	C	30
Inventive Example (8)	50°	2. 2~4. 2	0. 5~1. 7	-	C	30
Inventive Example (9)	90°	2. 2~6. 0	0. 5~2. 5	-	D	35
Inventive Example (10)	0°	1.0	0. 13~1. 0	0. 0003	A	60
Inventive Example (11)	0°	1.0	0. 13~1. 0	0. 0004	A	55
Inventive Example (12)	0°	1. 0	0. 13~1. 0	0. 002	A	50
Inventive Example (13)	20°	2. 2	0. 13~1. 0	0. 002	C	20
Inventive Example (14)	32. 8°	2. 2~3. 0	0. 3~1. 0	0. 0003	C	15
Inventive Example (15)	40°	2. 2~3. 47	0. 4~1. 5	0. 0004	C	15
Inventive Example (16)	90°	2. 2~6	0. 5~2. 5	0. 002	D	30
Inventive Example (17)	6°	1. 36	turbulence, unstable	0.003	-	-

※ 1 × : NG (large "open eye" and "exposed surface region" are observed at high frequency)
A : Stable ("open eye" is small but "exposed surface region" is observed occasionally)
B : More Stable ("open eye" and "exposed surface region" is smaller and observed at lower frequency)
C : Most Stable ("open eye" and "exposed surface region" are almost not observed)
D : Stable ("open eye" and "exposed surface region" is smaller and almost not observed but slight turbulence is observed in peripheral region)

※ 2 Index on the basis of 100 representing a value of Comparative Example (1)

[0087] Among Inventive Examples using the pouring tube structure of the present invention to generate a swirling flow by the flow control plate, even in Inventive Example (1) in Table 1, wherein: the opening angle (θ) of the inverse-tapered channel portion is 0° (zero degree); the inner-diameter ratio (D1/D2) is 1.0; and the swirl number (W/V) is in the range of 0.13 to 1.0, i.e., even in the case where a swirl flow is generated using a pouring tube structure having no inverse-tapered channel portion in an upper end of a flow channel thereof, the effect of reducing "open eye" and stabilizing the molten metal surface was observed.

[0088] As shown in Inventive Examples (2) to (4), wherein the upper end of the flow channel in the pouring tube is formed as the inverse-tapered channel portion, when the opening angle (θ) was increased up to 16.8° and the inner-diameter ratio (D1/D2) was increased up to 2.0, the molten metal surface was more stabilized as the opening angle and/or the inner-diameter ratio were increased. As shown in Inventive Examples (5) to (8), the molten metal surface was extremely stabilized when the opening angle (θ) was increased up to 50° and the inner-diameter ratio (D1/D2) was increased up to 4.2. As shown in Inventive Example (9), while the molten metal surface was stabilized almost without "open eye" and "exposed surface region in the molten metal surface (hereinafter referred to as "exposed surface region")" when the opening angle (θ) was increased up to 90° and the inner-diameter ratio (D1/D2) was increased up to 6, a slight turbulence was observed in a peripheral region thereof.

[0089] In Comparative Example (1) in Table 1, wherein: the opening angle (θ) is 0°; the inner-diameter ratio (D1/D2) is 1.0; and the swirl number (W/V) is zero, i.e., in the case where there is no swirling flow (no flow control plate is used), and the pouring tube has neither the inverse-tapered channel portion formed in the upper end thereof nor the gas injection port, a large "open eye" was formed due to a high upward flow speed in the axial direction of the pouring tube, and the molten metal surface was unstable.

[0090] In Comparative Example (2) in Table 1, wherein: the opening angle (θ) is in the range of 12° to 20°, the inner-diameter ratio (D1/D2) is 1.3; and the swirl number (W/V) is zero, i.e., in the case where the inverse-tapered channel portion is formed in the upper end of the pouring tube, but there is no swirling flow and the pouring tube has no gas injection port, a large "open eye" was formed due to a high upward flow speed in the axial direction of the pouring tube, and the molten metal surface was unstable, even though the number of organic particles as nonmetallic inclusions in the mould was slightly reduced as compared with Comparative Example (1).

[0091] As seen in the test result, in this test conditions, the swirl number (W/V) can be set preferably in the range of 0.13 to 2.5, more preferable in the range of 0.3 to 1.7. The opening angle (θ) of the inverse-tapered channel portion can be preferably set in the range of 6° to 90°, and the inner-diameter ratio (D1/D2) can be preferably set in the range of 1.36 to 6. More preferably, the opening angle (θ) of the inverse-tapered channel portion can be set in the range of 16.8° to 50°, and the inner-diameter ratio (D1/D2) can be set in the range of 2 to 4.2.

[0092] The volume of air as the gas to be injected in Table 1 is a value converted to a volume of argon gas at a pouring rate of about 1.3 t/min in actual casting equipment. As seen in Table 1, when this deemed volume of argon gas is set at 0.0003 Nm^3/min or more, the number of residual organic particles as nonmetallic inclusions starts significantly decreasing. However, when the deemed volume of argon gas is 0.003 Nm^3/min, the swirling flow starts being disturbed, and the molten metal surface (water surface) starts being destabilized. Thus, it is proved that the volume of argon gas to be injected can be preferably set in the range of about 0.0003 to 0.002 Nm^3/min.

[Example II]

[0093] A pouring test was performed using casting equipment employing the pouring tube structure of the present invention illustrated in FIG. 5.

[0094] In this test, molten steel at a temperature of 1580° was used as the molten metal. The pouring rate was 1.3 t/min, and a pouring volume was 10 t. In the flow control plate, the length (L) was set at 60 mm, and the twist angle (θs) was set at 60°. In the inverse-tapered portion, the opening angle (θ) was set at 32°, and the inner-diameter ratio (D1/D2) was set at 3.

[0095] As Comparative Example, a pouring test was performed under the same conditions as those in the above EXAMPLE II, except that the conventional pouring tube formed with a flow channel having substantially no inverse-tapered portion or an inverse-tapered portion with an inverse-taper angle of up to 6°, as shown in FIG. 11, was used as the pouring tube.

[0096] As the result, Inventive Examples had almost no "open eye"/"exposed surface region", and an amount of antioxidant to be supplied onto the molten metal surface was reduced to a small value. In contrast, an "open eye" having a diameter of about 200 mm was formed in Comparative Example.

[EXAMPLE III]

[0097] An average circumferential velocity (W) after passing through the flow control plate, an average velocity in the axial direction of the pouring tube and a flow in the mould were calculated from both a numerical calculation result and a measurement result in a water-model experimental apparatus (a flow-speed measurement using a laser flowmeter and an "open eye" measurement using a video image), to obtain the following simulation result.

[0098] In this test, a swirl number (WN) of a molten metal flow after passing through the flow control plate and a state of the molten metal surface were checked by variously changing an opening angle (θ) and an inner-diameter ratio (D1/D2) of an upper end (D1) to a lower end (D2) in the inverse-tapered portion, under the following conditions: a length (L) of the flow control plate = 30 to 60 mm; a twist angle (θs) of the flow control plate = 30 to 120°; a flow speed of water before passing through the flow control plate = 0.7 to 1.5 m/s.

[0099] Table 2 shows the test result. FIG 9 is a photograph showing a section of the water model test for Inventive

Example (23) in Table 2, and FIG. 10 is a photograph showing the water model test for Comparative Example (3) in Table 2.

TABLE 2

	Opening Angle (θ)	Inner Diameter Ratio (D1/D2)	Swirl Number (W/V)	State of Surface ※1
Comparative Example (3)	12°~20°	1.0~1.3	0	×
Inventive Example (18)	0°	1. 0	0. 13~1. 0	A
Inventive Example (19)	6°	1. 36	0. 13~1. 0	B
Inventive Example (20)	10°	1. 6	0. 13~0. 8	B
Inventive Example (21)	16. 8°	2. 0	0. 3~1. 0	C
Inventive Example (22)	20°	2. 2	0. 3~1. 0	C
Inventive Example (23)	32. 8°	2. 2~3. 0	0. 3~1. 0	C
Inventive Example (24)	40°	2. 2~3. 47	0. 4~1. 5	C
Inventive Example (25)	50°	2. 2~4. 2	0. 5~1. 7	C
Inventive Example (26)	90°	2. 2~6	0. 5~2. 5	D

※ 1 × : NG (large "open eye" and "exposed surface region" are observed at high frequency)
A : Stable ("open eye" is small but "exposed surface region" is observed occasionally)
B : More Stable ("open eye" and "exposed surface region" is smaller and observed at lower frequency)
C : Most Stable ("open eye" and "exposed surface region" are almost not observed)
D : Stable ("open eye" and "exposed surface region" is smaller and almost not observed but slight turbulence is observed in peripheral region)

[0100] Among Inventive Examples using the pouring tube structure of the present invention to generate a swirling flow by the flow control plate, even in Inventive Example (18) in Table 2, wherein: the opening angle (θ) of the inverse-tapered channel portion is 0° (zero degree); the inner-diameter ratio (D1/D2) is 1.0; and the swirl number (W/V) is in the range of 0.13 to 1.0, i.e., even in the case where a swirl flow is generated using a pouring tube structure having no inverse-tapered channel portion in an upper end of a flow channel thereof, the effect of reducing "open eye" and stabilizing the molten metal surface was observed.

[0101] As shown in Inventive Examples (19) to (21), wherein the upper end of the flow channel in the pouring tube is formed as the inverse-tapered channel portion, when the opening angle (θ) was increased up to 16.8° and the inner-diameter ratio (D1/D2) was increased up to 2.0, the molten metal surface was more stabilized as the opening angle and/or the inner-diameter ratio were increased. As shown in Inventive Examples (22) to (25), the molten metal surface was extremely stabilized when the opening angle (θ) was increased up to 50° and the inner-diameter ratio (D1/D2) was increased up to 4.2. As shown in Inventive Example (26), while the molten metal surface was stabilized almost without "open eye" and "exposed surface region" when the opening angle (θ) increased up to 90° and the inner-diameter ratio (D1/D2) was increased up to 6, a slight turbulence was observed in a peripheral region thereof.

[0102] In Comparative Example (3) in Table 2, wherein: the opening angle (θ) is in the range of 12 to 20°; the inner-diameter ratio (D1/D2) is in the range of 1.0 to 1.3; and the swirl number (W/V) is zero, i.e., in the case where there is no swirling flow (no flow control plate is used), a large "open eye" was formed due to a high upward flow speed in the axial direction of the pouring tube, and the molten metal surface was unstable.

[0103] As seen in the test result, in this test conditions, the swirl number (W/V) can be set preferably in the range of

0.13 to 2.5, more preferable in the range of 0.3 to 1.7. The opening angle (θ) of the inverse-tapered channel portion can be preferably set in the range of 6° to 90°, and the inner-diameter ratio (D1/D2) can be preferably set in the range of 1.36 to 6. More preferably, the opening angle (θ) of the inverse-tapered channel portion can be set in the range of 16.8° to 50°, and the inner-diameter ratio (D1/D2) can be set in the range of 2 to 4.2.

[0104] The present invention can be applied to casting of steel ingots based on uphill casting of molten steel, and a pouring operation to a mould for uphill casting of cast metal and any other molten metal.

Claims

1. A pouring tube structure for use in an uphill casting process designed to spout molten metal into a mould from an inlet port formed in a lower portion of said mould, comprising:

   a pouring tube internally defining a flow channel for molten metal to provide fluid transport between a molten metal transfer vessel and said inlet port and feed molten metal from said molten metal transfer vessel to said mould; and
   a single or a plurality of swirling-flow generation means provided in said pouring tube and adapted to generate a swirling flow in said molten metal.

2. The pouring tube structure as defined in claim 1, wherein:

   said pouring tube has, in the entire length of said flow channel, an approximately vertical channel portion extending from immediately below said inlet port in an approximately vertically downward direction, an approximately horizontal channel portion extending in an approximately horizontal direction, and a bent channel portion making a transition from said approximately vertical channel portion to said approximately horizontal channel portion; and
   at least one of said swirling-flow generation means is located at any position in said approximately horizontal channel portion on an upstream side of said bent channel portion.

3. The pouring tube structure as defined in claim 1, wherein:

   said pouring tube has, in the entire length of said flow channel, an approximately vertical channel portion extending from immediately below said inlet port in an approximately vertically downward direction, an approximately horizontal channel portion extending in an approximately horizontal direction, and a bent channel portion making a transition from said approximately vertical channel portion to said approximately horizontal channel portion;
   at least a first one of said swirling-flow generation means is located at any position in said approximately horizontal channel portion on an upstream side of said bent channel portion; and
   at least a second one of said swirling-flow generation means is located at any position in said approximately vertical channel portion on a downstream side of said bent channel portion.

4. The pouring tube structure as defined in claim 1, 2 or 3, wherein said swirling-flow generation means is located in the flow channel of said pouring tube at a position adjacent to said inlet port.

5. The pouring tube structure as defined in either one of claims 1 to 4, wherein said pouring tube has an upper end on the side of said inlet port, said upper end being formed with an inverse-tapered channel portion having an inner diameter gradually increasing toward said inlet port.

6. The pouring tube structure as defined in either one of claims 1 to 5, wherein said pouring tube includes a gas injection port in fluid communication with a region of the flow channel provided with at least one of said swirling-flow generation means.

7. The pouring tube structure as defined in either one of claims 1 to 6, wherein each of said swirling-flow generation means consists of a twisted tape-like flow control plate formed in a screw-like configuration having a twist angle which is equivalent to a state after a flat plate is positioned parallel to a molten-metal flow direction and then one of opposite edges of said flat plate extending in a direction perpendicular to said molten-metal flow direction is rotationally twisted by an angle ranging from 30° to 180° in a direction perpendicular to said molten-metal flow direction while fixing the other edge of said flat plate.

8. A pouring method for an uphill casting process designed to spout molten metal into a mould from an inlet port formed in a lower portion of said mould, comprising generating a swirling flow in molten metal passing through a pouring tube which internally defines a flow channel for molten metal to provide fluid transport between a molten metal transfer vessel and said inlet port and feed molten metal from said molten metal transfer vessel to said mould.

9. The pouring method as defined in claim 8, wherein said pouring tube has, in the entire length of said flow channel, an approximately vertical channel portion extending from immediately below said inlet port in an approximately vertically downward direction, an approximately horizontal channel portion extending in an approximately horizontal direction, and a bent channel portion making a transition from said approximately vertical channel portion to said approximately horizontal channel portion, wherein:

said swirling flow is generated at either one or both of any position in said approximately horizontal channel portion on an upstream side of said bent channel portion, and any position in said approximately vertical channel portion on a downstream side of said bent channel portion.

10. The pouring method as defined in claim 8, wherein said swirling flow is generated in the flow channel of said pouring tube at a position adjacent to said inlet port.

11. The pouring method as defined in either one of claims 8 to 10, which includes allowing a flow of molten metal passing through an upper end of said pouring tube on the side of said inlet port to be gradually expanded in a radial direction of said pouring tube as the molten metal flows upward.

12. The pouring method as defined in either one of claims 8 to 11, which includes mixing gas bubbles into the swirling flow of the molten metal.

FIG. 1

(a)

(b)

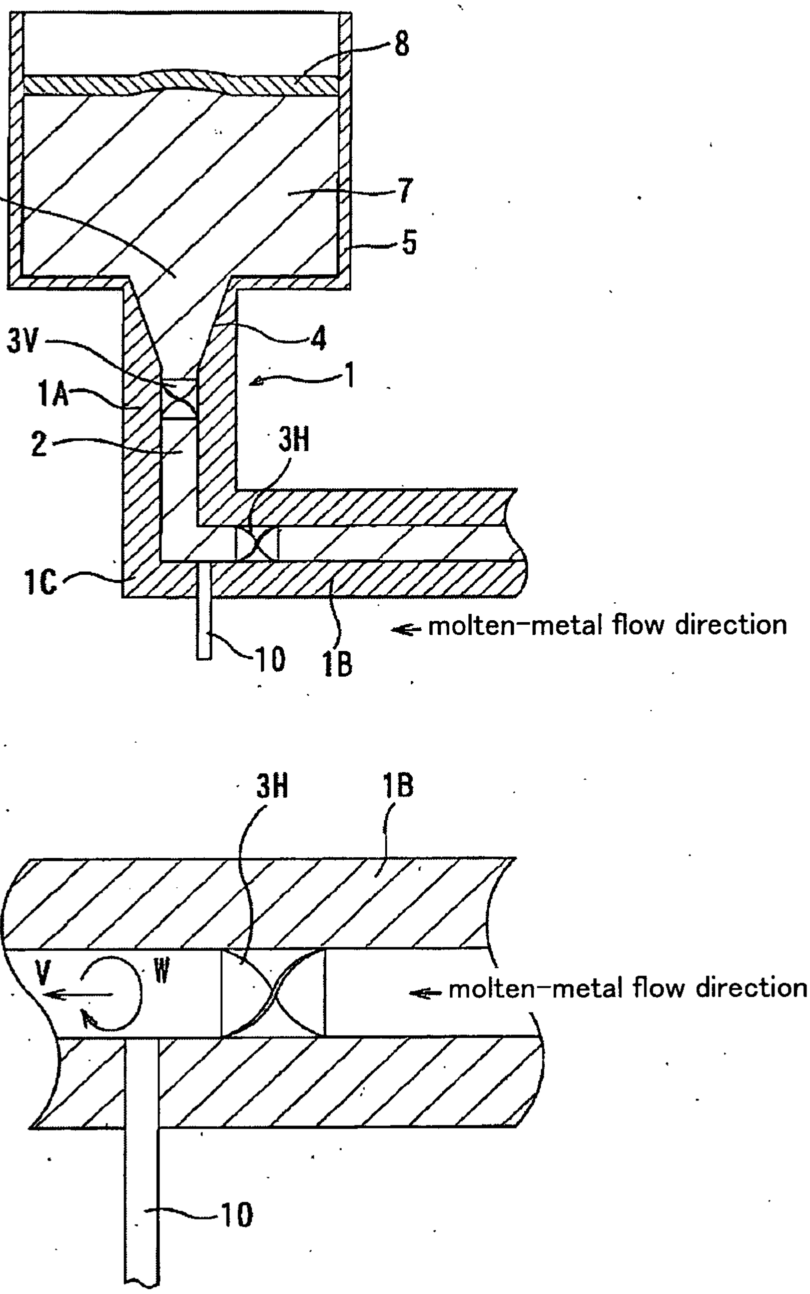

8
6
7
5
3V
4
1A
1
2
3H
1C
molten-metal flow direction
10
1B
3H
1B
V
W
molten-metal flow direction
10

FIG. 2

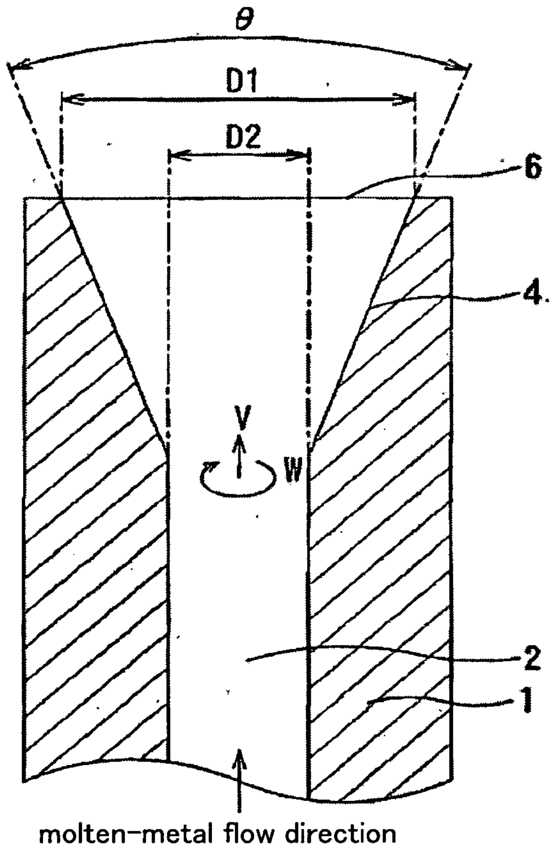


FIG. 3

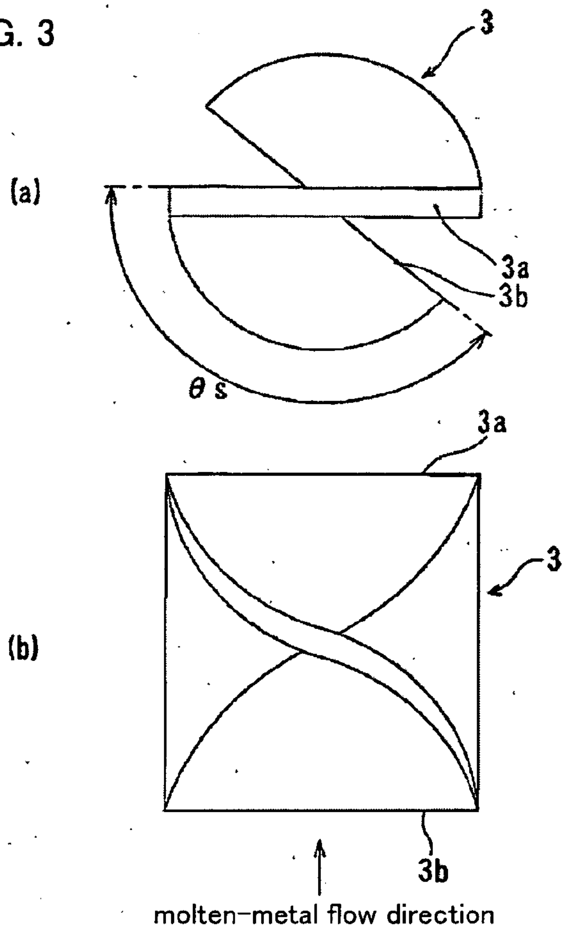

3
(a)
3a
3b
θ s
3a
3
(b)
3b
molten-metal flow direction

FIG. 4

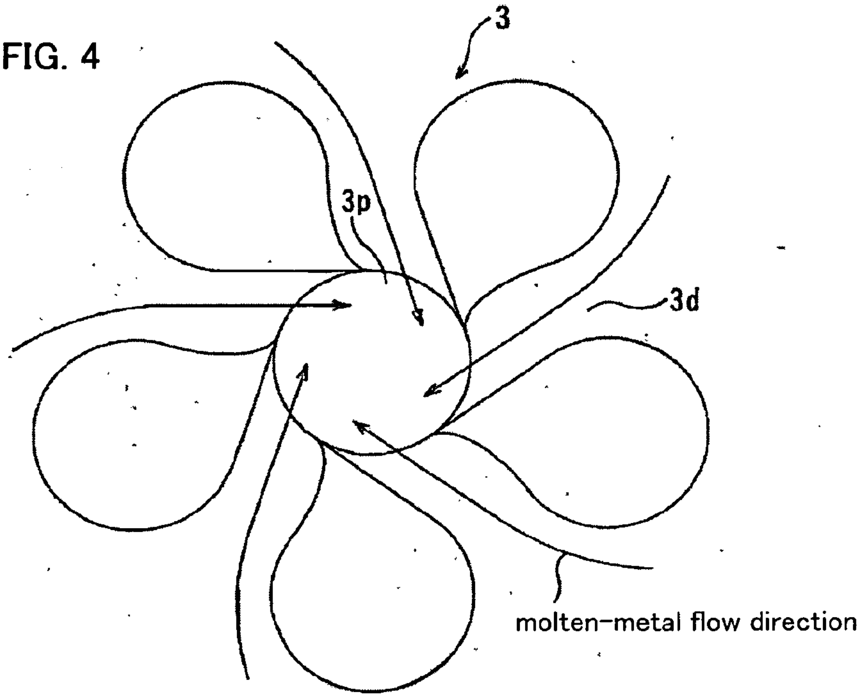

3
3p
3d
molten-metal flow direction

FIG. 5

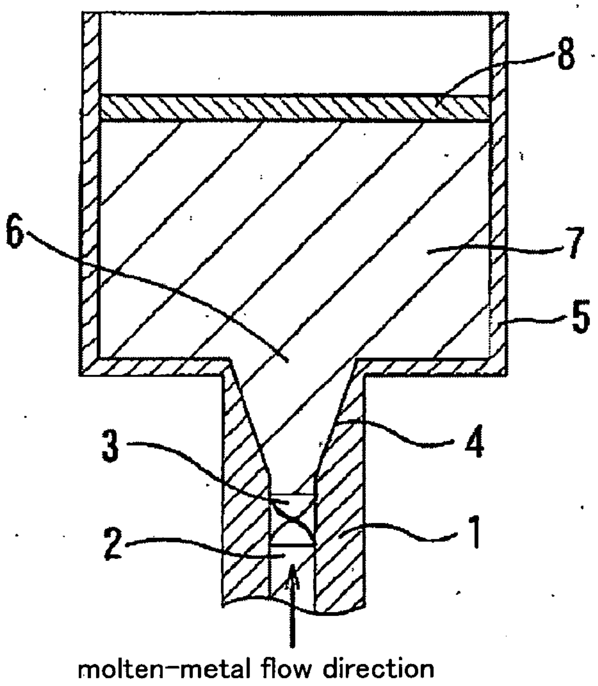


FIG. 8

FIG. 7

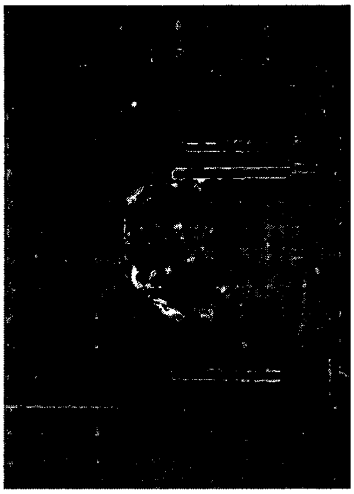


FIG. 10

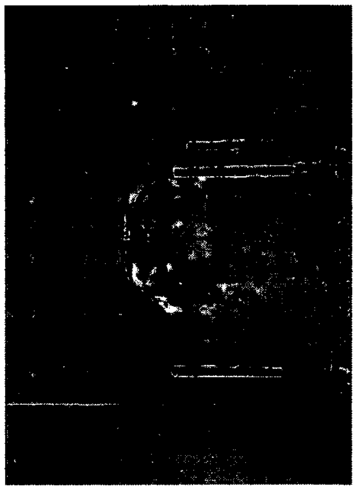


FIG. 6

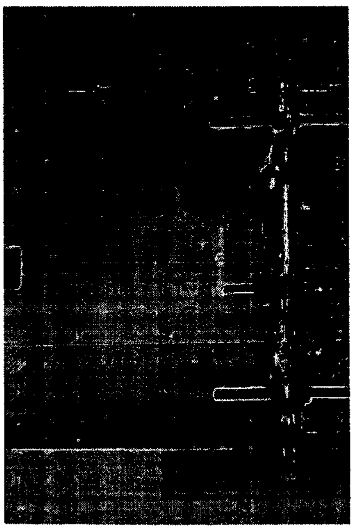


FIG. 9

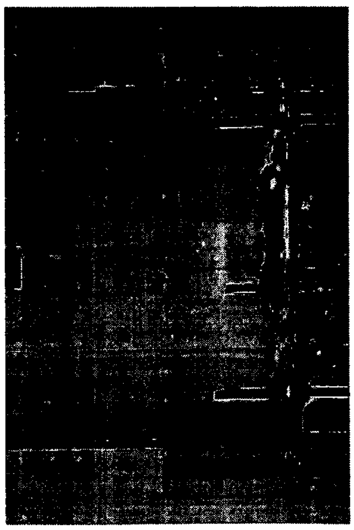
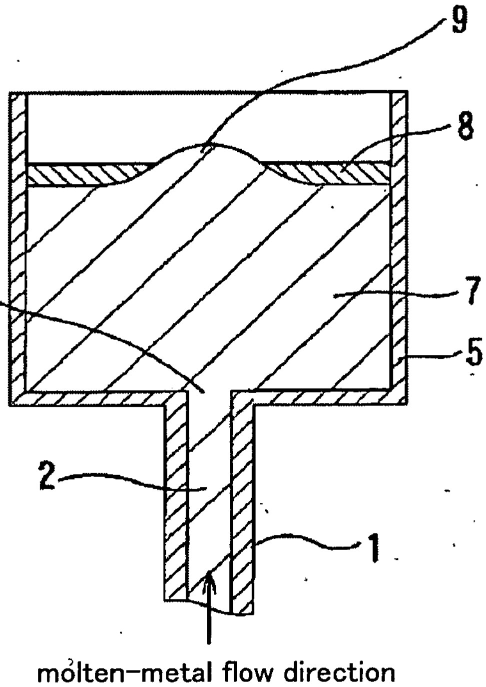


FIG. 11



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EUROPEAN SEARCH REPORT

Application Number
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	18 January 2007	Lombois, Thierry

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