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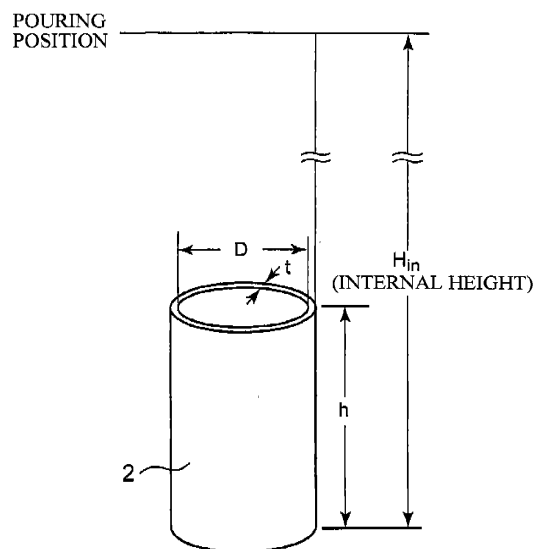
(54) **METHOD FOR PREPARING SEMI-SOLID METAL SLURRY, MOLDING METHOD, AND MOLDED PRODUCT**

(57) There are provided manufacture of semi-solid slurry which can easily manufacture semi-solid slurry or a semi-solid molding in a short time without being restricted to a type/composition of a target metal, and a semi-solid molding.

It is characteristic that, when a metal in a molten state is poured into a container or a sleeve (which will be referred to as a "container or the like" hereinafter), pouring is carried out in such a manner that the metal enters a supercooled state without generating an initial solid layer and self-mixing occurs in the container.

Nuclei are generated without producing an initial solid layer by a supercooling phenomenon which occurs by bringing the molten metal into contact with a cooling container or a cooling portion from a fixed height, and then mixing is carried out to eliminate a temperature gradient in the cooling container or the cooling portion, thereby providing a semi-solid state.

FIG.2



Description

Technical Field

5 **[0001]** The present invention relates to a manufacturing method and a molding method of semi-solid metal slurry and a molding.

Background Art

10 **[0002]** It is desirable for metal slurry used in a semi-solid molding method (a rheocast method) to have a structure in which primary crystals are maintained to be separated by a liquid crystal matrix and primary crystal particles thereof have a very fine and homogeneous non-dendritic form or preferably a spherical form. If such a structure is provided, molding (casting) in a semi-solid state with a high solid-phase ratio and a low viscosity is enabled, occurrence of a shrinkage cavity of a molded product can be suppressed, and a mechanical strength of the molded product can be improved.

15 **[0003]** The following manufacturing technologies of metal slurry are known.

[0004]

Patent Reference 1: Japanese Patent Application Laid-open No. 325652-1996

20 Patent reference 2: Japanese Patent Application Laid-open No. 138248-1999

Patent Reference 3: Japanese Patent Publication No. 3520991

25 **[0005]** The technology described in Patent Reference 1 proposes a molding method of a mushy metal which can simply and readily obtain a molding having a fine and spherical thixotropic structure at a low cost irrespective of a mechanical mixing method or an electromagnetic mixing method, and this technology crystallizes a fine primary crystal in an alloy liquid by holding an alloy in a liquid state which has a crystal nucleus and a temperature not lower than a liquidus temperature or an alloy in a solid-liquid coexistence state which has a crystal nucleus and a temperature not smaller than a molding temperature in a heat insulating container having an insulation effect for 5 seconds to 60 seconds while cooling this alloy to a molding temperature at which a predetermined liquid-phase ratio is shown, and then supplies the alloy into a molding die, thereby effecting pressure forming.

30 **[0006]** However, when the technology described in Patent Reference 1 is used to actually create slurry and then perform molding, a molding having a fine and homogeneous structure is not necessarily obtained. In particular, this tendency is prominent in alloys other than a JISAC4C-based alloy. That is, a molding having a fine and homogeneous structure is not obtained unless alloys in a solid-liquid coexistence state having an extensive temperature range are used. Further, when an alloy is directly put into a heat insulating container, there is a restriction that a crystal grain refining element must be added.

35 **[0007]** On the other hand, the technology described in Patent Reference 2 provides a semi-solid molding method which can readily stabilize and manufacture semi-solid metal slurry having fine and substantially homogeneous non-dendritic (spherical) primary crystal particles and easily fill the manufactured semi-solid metal slurry in a pressure sleeve of a molding machine to perform pressure forming by using a simple apparatus or facility without requiring special complicated processes, and it is configured to apply a motion to a molten metal by pouring the molten metal into a slurry manufacture container while maintaining at least a part of the molten metal at a temperature not greater than a liquidus temperature and to fill the slurry manufacture container in a pressure sleeve of a molding machine in a manufacturing method of semi-solid metal slurry which applies a motion to a molten metal when at least a part of the molten metal has a temperature not greater than the liquidus temperature in a process where the molten metal is cooled, and then cools the molten metal to be semi-solidified.

40 **[0008]** In the technology described in Patent Reference 2, when slurry is actually manufactured and then molded, a molding having a fine and homogeneous structure cannot be necessarily obtained. In particular, this tendency is prominent in alloys other than JISAC4C-based alloys.

45 **[0009]** Patent Reference 3 describes a manufacturing method of a metal material in a solid-liquid coexistence state, comprising: a pouring step of pouring a molten metal into a container simultaneously with applying to the container an electromagnetic field which does not form an initial solid layer in the molten metal to be poured into the container, and pouring the molten metal into this container in a state where this electromagnetic field is applied; and a cooling step of cooling the molten metal poured in the container to form a metal material in a solid-liquid coexistence state. In the technology described in Patent Reference 3, however, a facility to apply an electromagnetic field is required. Since this facility is large in size, a cost and a space for this facility are required. Further, a time to apply an electromagnetic field is needed, thereby prolonging a processing time.

Disclosure of the Invention

[0010] The present invention is provided to eliminate the above-described problems.

It is an object of the present invention to provide a manufacturing method of semi-solid metal slurry which enables processing in a short time and can form a molding having a fine and homogeneous structure without requiring a large facility.

[0011] The manufacturing method of semi-solid metal slurry according to the present invention is characterized in that, when a metal in a molten state is poured into a container or a sleeve (which will be referred to as a "container or the like" hereinafter), the metal enters a supercooled state and self-mixing occurs in the container.

[0012] The manufacturing method of semi-solid metal slurry according to the present invention is characterized in that a predetermined motion energy is given to a molten metal, the molten metal is poured into a cooling container or the like maintained at a low temperature, nuclei are generated by a supercooling phenomenon which occurs due to contact with a bottom portion of the container or the like at a high speed without producing an initial solid layer, and then the molten metal itself is self-mixed to eliminate a temperature gradient in the molten metal in the container or the like, thereby providing a semi-solid state.

[0013] It is characteristic that an energy for the self-mixing is given by a mechanical energy or a potential energy.

[0014] It is characteristic that the mechanical energy is a pressure energy. The pressure energy may apply a pressure to the molten metal in a sealed container so that the molten metal is shed to be poured into the container or the like.

[0015] It is characteristic that the motion energy is given by dropping down the molten metal from a predetermine height.

[0016] It is characteristic that a difference (H_{in}) between a pouring position of the metal in the molten state and a position of the bottom portion of the container or the like is determined to be 3.5-fold or above of a diameter (D) of the container or the like to perform pouring.

[0017] It is preferable to set a difference between the metal in the molten state and a height of the bottom portion of the cooling container to be fourfold or above of the container diameter, and more preferable to set this difference to be fivefold or above. If the difference is set to be less than 3.5-fold, a dendrite structure may be formed depending on conditions. When the difference is set to be fourfold or above, a further fine and homogeneous structure can be obtained. As an upper limit, tenfold is preferable. If the difference exceeds tenfold, the molten metal may lash, or air may be involved and the involved air may suddenly expand to shake the molten metal depending on pouring conditions. Furthermore, it becomes difficult to perform casting without spilling the molten metal.

[0018] It is to be noted that a shape of the container or the like is set while considering thermal equilibrium, but 10 mm to 200 mm is preferable and 40 to 120 is more preferable as an internal diameter. When such a dimension is adopted, a further fine and homogeneous structure can be obtained. When the internal diameter D is increased, the poured molten metal cannot sufficiently move in a lateral direction, and thermal mixing cannot be satisfactorily performed. As a result, refining of a particle diameter or homogeneity is hard to be obtained.

[0019] Incidentally, assuming that a height from the bottom portion of the container or the like to a head portion of the same (an internal height) is h, it is possible to design to achieve $h = 3 H_{in}$ to $10 H_{in}$, for example. In this case, pouring can be carried out from a position in the vicinity of the head portion of the container, and spill at the time of pouring can be reduced. On the contrary, when design to achieve $h < H_{in}$ is adopted, h-D can be reduced, and hence involvement of a gas at the time of pouring can be decreased.

[0020] It is preferable to vertically arrange the container or the like without inclination and perform pouring from the center without being taken along a side inner wall of the container or the like. In a prior art, the container or the like is inclined to calmly perform pouring along the side inner wall. However, in the present invention, it is preferable to pour quickly without being taken along the side inner wall. As a result, self-mixing is apt to occur.

Moreover, it is preferable to directly pour the molten metal into the container or the like without using a cooling member or the like.

[0021] A pouring time is also an important element. As a pouring time, a period of 1 to 10 seconds is preferable although it depends on a pouring amount. A period of 3 to 8 seconds is more preferable. A period of 3 to 5 seconds is further preferable. Considering mass productivity, a shorter pouring time is preferable, but a desired structure may not be obtained in some cases if the pouring time is less than 1 second because a molten metal mixing time in the container is short. If a pouring time exceeds 10 seconds, operability is deteriorated. Additionally, if a pouring time is long, the molten metal is newly poured when the entire metal enters a semi-solid state, and hence self-mixing is hard to occur. It is to be noted that a pouring amount is generally 200 cc to 3000 cc (e.g., 540 to 8100 kg in case of an aluminum alloy).

[0022] It is characteristic that the bottom portion of the container or the like has a concave curved surface shape as seen from the pouring side.

[0023] It is preferable to form the bottom portion of the cooling container into a concave curved surface shape as seen from a side where the molten metal is poured. When such a curved surface shape is adopted, the molten metal which has come into contact with the bottom portion of the cooling container to generate nuclei flows along the curved surface. That is, when the molten metal is poured to the center of the bottom portion of the container, the molten metal which

has reached the bottom portion flows to the outer side of the container along the curved surface of the bottom portion. When the molten metal which has flowed to the outer side comes into contact with a wall of the container, it again flows into the container. As a result, a convection of the molten metal is readily produced, thereby more excellently effecting self-mixing. Consequently, many nuclei exist on the inner side, thus obtaining a further homogeneous and fine structure. As a curvature of the curved surface, assuming that an internal diameter of the container is D, 0.5 D to 3 D is preferable, and 0.6 D to 1 D is more preferable. When the curvature is set within this range, convection is more excellently generated, self-mixing is intensively carried out, and a temperature is better uniformed in the entire container.

[0024] It is characteristic that the metal in the molten state is pressurized and poured.

As a temperature of the molten metal on an initial pouring stage, $T_C < (T_L + 100)$ is preferable. T_L : a liquidus temperature of the metal (°C) T_C : an initial temperature of the molten metal (°C)

[0025] It is characteristic that, after the pouring, pouring is carried out to satisfy the following expression.

$$T_s < T_{eq} < T_L$$

T_s : a liquidus temperature of the metal

T_L : a solidus temperature of the metal

T_{eq} : a temperature when a temperature of the container or the like becomes equal to a temperature of the metal after pouring.

[0026] It is characteristic that the container or the like is held in a heat-insulating state.

It is characteristic that a calorific capacity of the container or the like is set to a predetermined value in accordance with a heat quantity of the metal in the molten state and then pouring is carried out.

It is characteristic that a wall thickness of the container or the like is set to a predetermined value and then pouring is carried out when an internal diameter, a height and a material of the container or the like are fixed.

It is characteristic that the container or the like is formed of a non-magnetic material or a magnetic material. In the present invention, electromagnetic mixing is not performed. Therefore, a degree of freedom of selecting materials of the container or the like can be extended. There is provided a manufacturing method of semi-solid slurry according to one of claims 1 to 20.

It is characteristic that the container or the like is formed of stainless steel or copper. In particular, a material whose thermal conductivity is larger than that of stainless steel is preferable.

A period of 1 to 10 seconds is preferable as a casting time even though it varies depending on a shape of the container or the like and a casting amount. A period of 3 to 5 seconds is more preferable. When a casting time is too short, self-mixing is hard to occur. On the other hand, when a casting time is too long, a continuous flow cannot be formed, and homogeneity is hard to be obtained.

It is to be noted that the container or the like may be held in a heat insulating state.

[0027] A molding method according to the present invention is characterized by molding semi-solid metal slurry manufactured by the manufacturing method of semi-solid metal slurry according to one of the above-described claims.

[0028] A molding according to the present invention is characterized by being molded by the molding method.

[0029] Functions of the present invention will now be described based on knowledge obtained when the present invention is achieved.

The present inventor has searched reasons why a fine and homogeneous structure cannot be necessary obtained in the technologies described in Patent References 1 and 2.

[0030] In Patent References 1 and 2, generation of a crystal nucleus by a supercooling phenomenon can be recognized. However, after pouring into the container, mixing of the molten metal does not occur in the container, and a temperature gradient still remains. That is, movements of the molten metal are stopped when the molten metal is poured into the container. As a result, temperature on the container side is low, and slurry having a high temperature and a small number of nuclei is obtained on the inner side even if many nuclei are generated.

[0031] In Patent Reference 1 in particular, this tendency is prominent since pouring is calmly carried out in order to prevent air to be involved (prevent generation of a gas cavity in a molding).

[0032] On the contrary, in the present invention, a fine and homogeneous (sizes of particle diameters are not irregular and they fall within a range of 100 to 150 μm) structure is obtained by controlling a dropping start height.

Therefore, a predetermined motion energy is given to the molten metal to generate nuclei without producing an initial solid layer. Many nuclei generated at the bottom portion of the container by pouring spread in the entire container by self-mixing. That is, the initial molten metal having many nuclei moves in the container, and hence nuclei are uniformly distributed on the whole.

[0033] After all, the supercooling phenomenon is utilized to generate nuclei without producing the initial solid layer by

pouring the molten metal into the cooling container from a fixed height and bringing this metal into contact with the bottom portion of the cooling container. When the molten metal is dropped down from the fixed height, a potential energy is converted into a kinetic energy. In the container, when the kinetic energy of the molten metal is large, the molten metal lashes about in the container until the motion energy disappears. Therefore, self-mixing is performed in the container. When the molten metal performs self-mixing, a temperature gradient of the molten metal in the container is eliminated, and the entire molten metal enters a semi-solid state. As a result, slurry in which many nuclei are uniformly distributed can be obtained.

[0034] However, in order to generate self-mixing by giving the potential energy and converting it into the kinetic energy, simply pouring the molten metal from a high position is not necessary good. The present inventor has recognized and researched a factor other than the height. As a result, the present inventor has discovered that a ratio of height to diameter of the container is important. That is, the inventor has found out that self-mixing is excellently generated by setting a ratio of height to diameter at 3 or above.

[0035] As a temperature of the container or the like, room temperature to 100°C is generally preferable, but it varies depending on a type of the metal, a molten metal temperature and others. Adopting a temperature at which a cooling phenomenon occurs when pouring is carried out can suffice. It is good enough to previously check a temperature in accordance with each metal by an experiment or the like.

[0036] In the present invention, e.g., a BN spray may be applied on a container surface in advance in order to generate nuclei.

The BN spray is conventionally applied to the container in order to increase mold releasing properties, but it is applied in order to generate nuclei in the present invention.

[0037] When the molten metal is poured into the container, nuclei are also generated on a surface of the molten metal in the container. In such a case, when the molten metal is newly poured to be showered down on the molten metal surface, nuclei on the molten metal surface are mixed in the entire container by an energy (a kinetic energy of the molten metal) of the newly poured molten metal.

[0038] In the present invention, a molten metal temperature is substantially uniformly maintained by forced convection at the time of filling. Further, since a surface in a cup is always washed by the molten metal, generation of many nuclei and growth of the nuclei into a spherical shape are utilized.

In order to homogenize the above-described molten metal temperature, control over a temperature in a thermal equilibrium state after pouring is important. This point will now be described in detail hereinafter with reference to FIG. 1.

[0039] When a molten metal 1 is poured into a cup (a container or the like) 2 (FIG. 1(a)), heat of the molten metal 1 starts to move to the cup 2 (FIG. 1(b)). With this movement, a molten metal temperature is lowered, and a cup temperature is increased. It is considered that heat no longer moves and the temperature does not vary any further when the temperature of the molten metal becomes equal to the temperature of the cup (FIG. 1(c)).

A temperature T_{eq} (which will be referred to as an equilibrium temperature hereinafter) at this moment can be given by the following expression.

$$T_{eq} = \frac{T_c + \gamma T_m + H'_f f_s}{1 + \gamma} \quad - (1)$$

[0040] In this expression, T_c is a molten metal initial temperature, T_m is a cup initial temperature, H'_f is a value obtained by dividing solidification latent heat by specific heat, and f_s is a solid fraction. Further, γ is a value obtained by dividing a heat quantity required to increase a cup temperature by 1 K by a heat quantity required to increase a molten metal temperature by 1 K, and it is given by the following expression.

$$\gamma = \frac{\rho_c c_c V_c}{\rho_m c_m V_m} \quad - (2)$$

In this expression, ρ is a density, c is specific heat, V is a volume, a subscript c belongs to the molten metal, and a subscript m belongs to the cup

[0041] As apparent from Expressions (1) and (2), the equilibrium temperature T_{eq} (or a solid fraction to be obtained) is determined by initial temperatures of the cup and the molten metal, and the value γ which is the ratio of heat quantities of the cup and the molten metal. However, a relationship between a solid fraction and a temperature must be checked in advance. Furthermore, it can be understood from Expression (2) that γ can be determined by volumes alone of the cup and the molten metal when materials of the cup and the molten metal are specified.

Meanwhile, the molten metal in the cup is maintained in the semi-solid state when T_{eq} satisfies the following expression.

$$T_s < T_{eq} < T_L \quad - \quad (3)$$

In reality, since heat escapes from a cup surface or a molten metal surface into atmospheric air, a temperature lower than T_{eq} obtained by Expression (1) should be achieved, but a temperature reaches a value close to T_{eq} given by Expression (1) by insulating a cup outer surface.

[0042] Heat insulation may be carried out by covering an outer portion of the cup with a heat insulating material. An actual reached temperature is represented by the following expression.

$$\alpha T_{eq} \quad (0 < \alpha < 1) \quad - \quad (4)$$

α is a correction coefficient obtained by an experiment, and it may be previously acquired by an experiment in accordance with actual practical conditions.

For example, assuming that a cup shape is a cylindrical shape having an internal diameter D , an internal height H and a wall thickness t (fixed), the following expressions can be achieved.

$$V_c = \pi (D/2)^2 h \quad - \quad (5)$$

$$V_m = \pi (D/2t)^2 (h+t) - V_c$$

$$\therefore \frac{V_c}{V_m} = \left(1 + \frac{2t}{D}\right)^2 \left(1 + \frac{t}{h}\right) - 1 \quad - \quad (6)$$

[0043] Based on Expressions (1) and (6), assuming that the internal diameter D and the internal height h of the cup are fixed, the equilibrium temperature T_{eq} is determined by the cup wall thickness t and initial temperatures of the molten metal and the cup when considering the molten metal and the cup formed of the same material.

As remarked above, giving initial temperatures of the molten metal and the cup, a material, an amount, a solidus rate and a corresponding temperature T of a semi-solid material to be manufactured can obtain a necessary wall thickness of the cup based on Expressions (1), (2), (3), (4) and (6).

[0044] Based on this, the semi-solid material having a desired solid fraction can be manufactured, but it is important to assure a sufficient pouring height in order to crystallize a fine primary crystal with a uniform solid fraction in the cup. That is, when the molten metal is sufficiently mixed in the cup, it is possible to realize conditions under which there is no temperature difference between a part close to a cup wall surface and a cup central part, nuclei are sufficiently generated on the cup wall surface and the molten metal surface and growth of the nuclei is suppressed.

[0045] Incidentally, as a material of the container or the like, it is preferable to use a material with a good thermal conductivity such as stainless steel or copper.

Moreover, although a shape of the container or the like is set while taking thermal equilibrium and others into consideration as described above, 10 mm to 200 mm is preferable and 40 mm to 120 mm is more preferable as an internal diameter. When such a dimension is adopted, a further fine and homogeneous structure can be obtained.

[0046] It is to be noted that the following shows a specific example of a change in f_s when a degree of superheat of the molten metal is fixed and when a wall thickness t of the cup is fixed. However, α in Expression (4) is 1.

(Conditions)

[0047]

Molten metal: AC4C

$\rho = 2710 \text{ kg/m}^3$

$C = 963 \text{ J/kg} \cdot \text{K}$

$T_L = 612^\circ\text{C}$

$T_s = 555^\circ\text{C}$

$H_f = 398000 \text{ J/kg}$

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$$\begin{aligned}\therefore H_z' &= H_z / C \\ &= 413 / K\end{aligned}$$

5 Cup: stainless steel
wall thickness t
cylindrical shape
cup internal diameter D
cup height h
10 $\rho_m = 7700 \text{ kg/m}^3$
 $C_m = 500 \text{ J}\cdot\text{kg}\cdot\text{K}$
 $T_m = 25^\circ\text{C}$

$$\begin{aligned}&(\rho_m \cdot C_m) / (\rho_c \cdot C_c) \\ &= 7700 \times 500 / 2710 \times 963 \\ &= 1.48\end{aligned}$$

$$\therefore \gamma = 1.48 \left\{ \left(1 + \frac{2r}{D} \right)^2 \left(1 + \frac{t}{h} \right) - 1 \right\}$$

25 Here, a relationship between a temperature and a solid fraction is evaluated by the following expression.

$$f_s = \frac{T_L - T_{eq}}{T_L - T_s} \quad - (7)$$

30 **[0048]** When the above-described result is assigned to Expression (1), f_s is given by the following expression.

$$f_s = (587 \cdot \gamma - \delta T) / (413 + (1 + \gamma) \cdot 57) \quad - (8)$$

35 In this expression, $\delta T = T_C - T_L$, which is a degree of superheat.

[0049] A calculation example in which D, t, h and others are specific values will now be described.

(a) When superheat is fixed

$$40 \quad D = 60 \text{ mm}$$

$$h = 150 \text{ mm}$$

$$45 \quad \delta T = 50 \text{ (K)}$$

	t (mm)	fs (%)
	1	3
	2	17
50	3	31
	4	45
	5	60
	6	74

55 **[0050]** (b) When a wall thickness is fixed
D = 60 mm

t = 4 mm

δT (K)	f_s (%)
0	56
10	54
20	52
50	45
100	35

[0051] According to the present invention, the following many effects are achieved.

A large facility is not required.

Semi-solid slurry can be manufactured in a short time.

A molding having a fine and homogenous structure can be formed.

Semi-solid metal slurry can be manufactured without being restricted to a type/composition of a target metal.

That is, material selectivity can be expanded. It is possible to apply an iron alloy, an aluminum alloy, a magnesium alloy and other alloys. As for an aluminum alloy, an AC4C-based alloy alone can be subjected to semi-solid molding in the prior art, but an ADC10-based alloy which cannot be practically applied in the prior art can be applied in the present invention. For example, even an alloy having a composition in the vicinity of an eutectic point can be applied to semi-solid molding.

[0052] Semi-solid molding is possible without being restricted to a temperature of a molten metal. An accurate temperature is conventionally required, and hence a complicated control system is needed, but such a complicated control system does not have to be provided in the present invention, thereby simplifying a system.

[0053] Moreover, a refining material (e.g., Ti or B) is conventionally added in order to achieve refining of crystals, but refining of crystals can be attained without using such a refining material. Of course, a refining material may be added in the present invention, and further refining can be achieved in such a case. Additionally, effecting heat balance can readily control a solid fraction.

Brief Description of the Drawings

[0054]

FIG. 1 is a conceptual view showing a thermal equilibrium state.

FIG. 2 is a perspective view of a container used in Embodiment 1.

FIG. 3 is a graph showing a temperature measurement result in Embodiment 1.

FIG. 4 is a micrograph of a molding using a semi-solid material manufactured in Embodiment 1.

FIG. 5 is a side view showing a pouring method according to Embodiment 2.

FIG. 6 is a graph showing a relationship between a particle diameter of a crystal and H_{in}/D in Embodiment 3.

FIG. 7 is a micrograph of a test No. 3 in Embodiment 3.

FIG. 8 is a micrograph of a test No. 4 in Embodiment 4.

Description of Reference Numerals

[0055]

- 1 molten metal
- 2 container (cup)
- 10 plunger

Best Mode for Carrying out the Invention

[0056] In an embodiment according to the present invention, mixing which does not form an initial solid layer in a molten metal poured into a container or the like is produced without supplying an electromagnetic field from the outside, and the molten metal is poured into this container or the like. The molten metal which has been poured into the container is cooled to form a metal material in a solid-liquid coexistence state, thereby manufacturing semi-solid metal slurry.

An embodiment according to the present invention will now be described hereinafter with reference to the accompanying drawings.

Embodiment 1

[0057] Pouring was carried out by using a container shown in FIG. 2 under the following conditions.

- 5 Molten metal material: AC4CH
 $T_s = 610$ to 612°C
 $T_L = 555^\circ\text{C}$
Molten metal initial temperature: 670°C
Cup wall thickness t : 3 mm
10 Cup material: SUS304
Cup internal diameter: 60 mm
Cup height h : 150 mm
Cup initial temperature: 5°C
Pouring height H_{in} : 550 mm (pouring from a position 400 mm above a cup upper portion)
15 $H_{in}/D = 9.1$
Casting time: 8 seconds
Heat insulation of the cup: provided (not shown) Pouring time: 5 seconds

[0058] A change in temperature at each portion was measured immediately after pouring the molten metal. FIG. 3 shows its result. As apparent from FIG. 3, an equilibrium attained temperature is approximately 590°C and held between T_s and T_L . FIG. 4 shows a micrograph of a molding molded by using a semi-solid material obtained in this example. It can be understood from FIG. 4 that small primary crystals uniformly exist in an entire structure of the molding obtained in this example.

25 Embodiment 2

- [0059]** In FIG. 5, a bottom plunger tip 10 of a container 2 is arranged to provide a curved surface having a curvature at an end of the plunger tip. The curved surface forms a concave shape as seen from a pouring side. The curved surface has a curvature of $R = 70$ mm.
30 A molten metal was poured into this container.
Pouring conditions are the same as those in Embodiment 1.
When the semi-solid slurry obtained in this example was used to perform molding and a structure of a molding was observed, a finer and more homogeneous structure than that in Embodiment 1 was obtained.
[0060] Although the above has described the example of the aluminum alloy in the foregoing embodiment, other
35 molten metals may be used, and they demonstrated the same effects as those in the foregoing embodiment.

Embodiment 3

- [0061]** In this example, H_{in}/D was changed and then pouring was carried out.
40 H_{in} : pouring height
 D : internal diameter of a container

Other points are the same as those in Embodiment 1.

45

Test No.	H_{in}/D	Particle diameter of a crystal*
1	1	3
2	2	2.8
3	3	2.7
4	3.5	2.3
5	4	1.5
6	5	1.2
7	7	1.1
8	8	1
9	9	1
10	10	0.9

50

55

(continued)

Test No.	H_{in}/D	Particle diameter of a crystal*
11	11	**

*: A particle diameter of a crystal (a size of a spherical primary crystal) indicates a relative value of a particle diameter of a crystal with the test No. 9 being determined as a reference (1)

*: Involvement of air occurred.

FIG. 6 shows a relationship between a particle diameter of the crystal and H_{in}/D . Further, FIGS. 7 and 8 respectively show micrographs of the test No. 4 and the test No. 5.

It can be understood from each drawing that a very excellent structure can be observed when H_{in}/D is not smaller than 4.

Embodiment 4

[0062] In this example, an influence of an initial temperature of a molten metal was examined.

AC4CH was likewise used in this example. However, a liquid-phase temperature of a material in this example is 617°C. An experiment was conducted while changing a casting temperature to 610 (-7), 620 (+3), 640 (+23), 655 (+38), 670 (+53), 680 (+63), 700 (+83), 720 (+103) and 730 (+113)°C. A difference from a liquid-phase temperature is in parentheses. Other conditions are the same as those in Embodiment 1.

A particle diameter of the crystal was decreased as a temperature is increased.

However, a peak temperature was 700°C, and a saturation or slight declining tendency was demonstrated at temperatures above the peak temperature.

Embodiment 5

[0063] In this example, a pouring time was changed.

Other points are the same as those in Embodiment 1.

No.	Pouring time (sec)	Particle diameter of a crystal*	Homogeneity of a structure**
4-1	0.5	2.0	C
4-1	1	1.3	B
4-3	2	1	B
4-4	3	1	A
4-5	4	1	A
4-6	5	1	A
4-7	6	1	A
4-8	7	1	B
4-9	8	1	B
4-10	9	1	B
4-11	10	1.4	B
4-12	11	1.5	C
4-13	12	1.6	C

*: A particle diameter of a crystal (a size of a spherical primary crystal) indicates a relative value of a particle diameter of a crystal with samples Nos. 4-6 being determined as a reference (1).

** : In regard to homogeneity of a structure, with the samples Nos. 4-6 being determined as a reference (A), B indicates a case where inhomogeneity including segregation is large and C indicates a case where the same is considerably large.

Embodiment 6

[0064] In this example, a ratio of a wall thickness and an internal diameter D of a container (t/D) was changed in Embodiment 1.

A fine and homogeneous crystal structure was obtained when t/D is 0.01 to 0.08 as compared with other cases. In particular, when the diameter D of the container falls within a range of 40 to 120 mm, this tendency was prominent.

Claims

1. A manufacturing method of semi-solid metal slurry **characterized in that**, when a metal in a molten state is poured into a container or a sleeve (which will be referred to as a "container or the like" hereinafter), the metal is poured in such a manner that self-mixing occurs in the container or the like.
2. A manufacturing method of semi-solid metal slurry **characterized in that** nuclei are generated without producing an initial solid layer by a supercooling phenomenon which occurs by giving a predetermined kinetic energy to a molten metal, pouring the molten metal into a container or the like and bringing the molten metal into contact with an inner wall of the container or the like at a high speed, and then the molten metal itself is self-mixed to eliminate a temperature gradient in the molten metal in the container or the like, thereby providing a semi-solid state.
3. The manufacturing method of semi-solid metal slurry according to claim 1 or 2, wherein an energy for the self-mixing is given by a mechanical energy or a potential energy.
4. The manufacturing method of semi-solid metal slurry according to claim 3, wherein the mechanical energy is a pressure energy.
5. The manufacturing method of semi-solid metal slurry according to claim 3, wherein the potential energy is given by dropping down the molten metal from a predetermined height.
6. The manufacturing method of semi-solid metal slurry according to claim 5, wherein a difference in height (H_{in}) between the metal in the molten state and a bottom portion of the container or the like is determined to be 3.5-fold or above of a diameter (D) of the container or the like to perform pouring.
7. The manufacturing method of semi-solid metal slurry according to claim 6, wherein H_{in}/D is set to 4 to 11.
8. The manufacturing method of semi-solid metal slurry according to claim 6, wherein H_{in}/D is set to 5 to 10.
9. The manufacturing method of semi-solid slurry according to one of claims 1 to 8, wherein the diameter of the container or the like is 10 to 200 mm.
10. The manufacturing method of semi-solid slurry according to claim 9, wherein the diameter of the container or the like is 40 to 120 mm.
11. The manufacturing method of semi-solid slurry according to one of claims 1 to 10, wherein the molten metal is directly poured into the container or the like.
12. The manufacturing method of semi-solid slurry according to one of claims 1 to 11, wherein a casting time is 1 to 10 seconds.
13. The manufacturing method of semi-solid slurry according to claim 12, wherein the casting time is 3 to 5 seconds.
14. The manufacturing method of semi-solid metal slurry according to one of claims 1 to 13, wherein the bottom portion of the container or the like has a concave curved surface shape as seen from a pouring side.
15. The manufacturing method of semi-solid slurry according to claim 14, wherein a curvature radius of the concave curved surface shape is $0.5 D$ to $3 D$, where D is an internal diameter of the container or the like.
16. The manufacturing method of semi-solid slurry according to claim 15, wherein the curvature radius of the concave curved surface shape is $0.6 D$ to $1 D$.
17. The manufacturing method of semi-solid metal slurry according to one of claims 1 to 16, wherein the metal in the molten state is pressurized to be poured.

18. The manufacturing method of semi-solid slurry according to one of claims 1 to 17, wherein $T_c < (T_L + 100)$ is achieved, where T_L : a liquidus temperature of the metal (°C)
 T_C : an initial temperature of the molten metal (°C).

19. The manufacturing method of semi-solid slurry according to one of claims 1 to 18, wherein, after the pouring, pouring is carried out to satisfy the following expression:

$$T_s < T_{eq} < T_L$$

T_L : a liquidus temperature of the metal

T_s : a solidus temperature of the metal

T_{eq} : a temperature when a temperature of the container or the like becomes substantially equal to a temperature of the metal after pouring.

20. The manufacturing method of semi-solid slurry according to claim 17 or 18, wherein a calorific capacity of the container or the like is set to a predetermined value in accordance with a heat quantity of the metal in the molten state to perform pouring.

21. The manufacturing method of semi-solid slurry according to claim 20, wherein, when an internal diameter, a height and an initial temperature of the container or the like are fixed, a wall thickness of the same is set to a predetermined value to perform pouring in such a manner that a thermal equilibrium state is maintained.

22. The manufacturing method of semi-solid slurry according to claim 21, wherein $t/D = 0.01$ to 0.08 is achieved, where t is the wall thickness of the container or the like.

23. The manufacturing method of semi-solid slurry according to one of claims 1 to 22, wherein the container or the like is formed of a non-magnetic material or a magnetic material.

24. The manufacturing method of semi-solid slurry according to one of claims 1 to 23, wherein the container or the like is formed of stainless steel or copper.

25. The manufacturing method of semi-solid slurry according to one of claims 18 to 24, wherein the container or the like is heat-insulated from the outside.

26. A molding method **characterized by** molding semi-solid metal slurry manufactured by the manufacturing method of semi-solid metal slurry defined in one of claims 1 to 26.

27. A molding **characterized by** being molded by the molding method defined in claim 26.

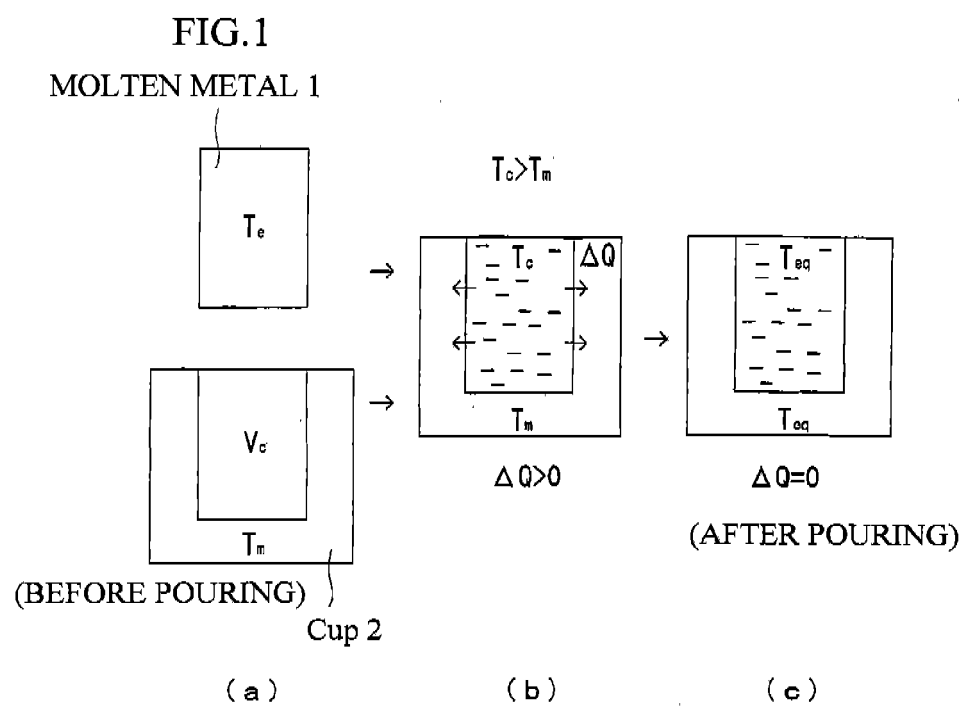


FIG.2

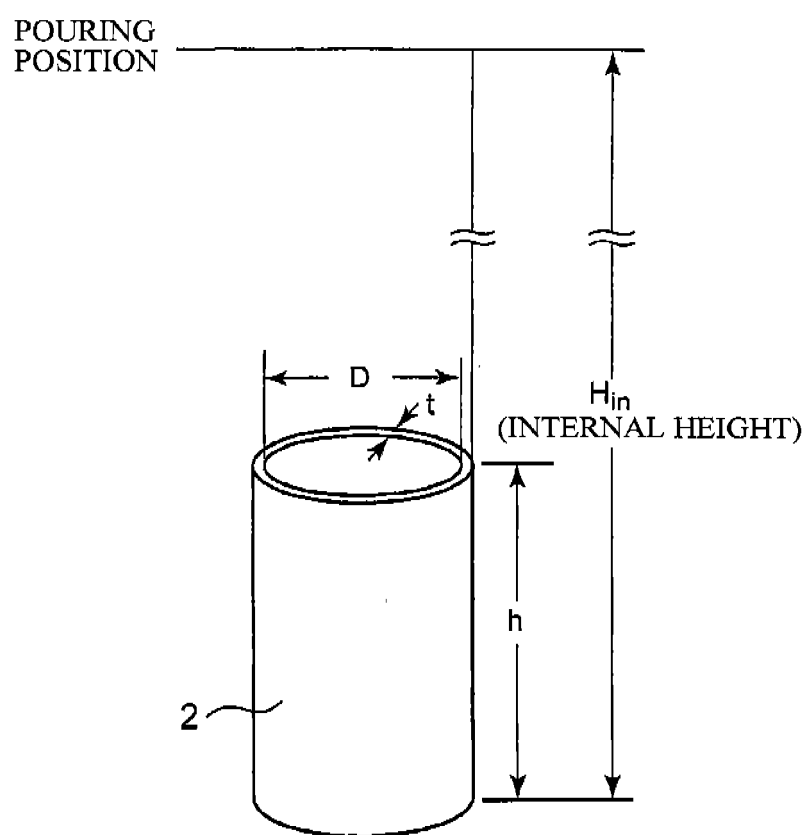


FIG.3

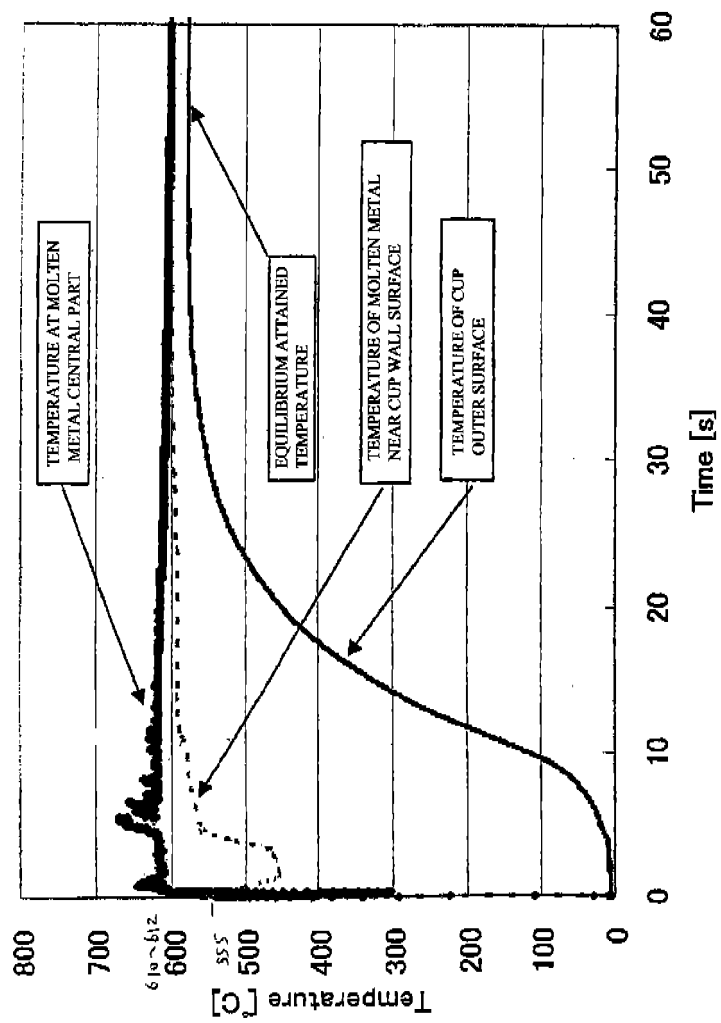


FIG.4

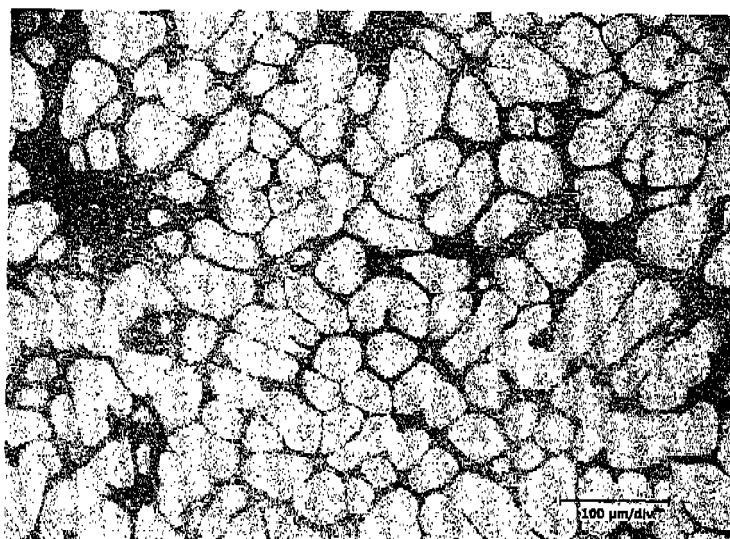


FIG.5

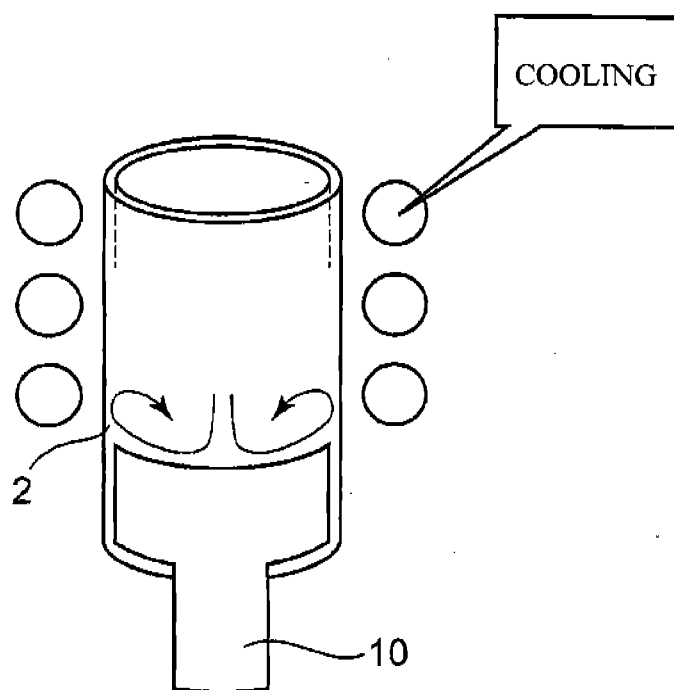


FIG.6

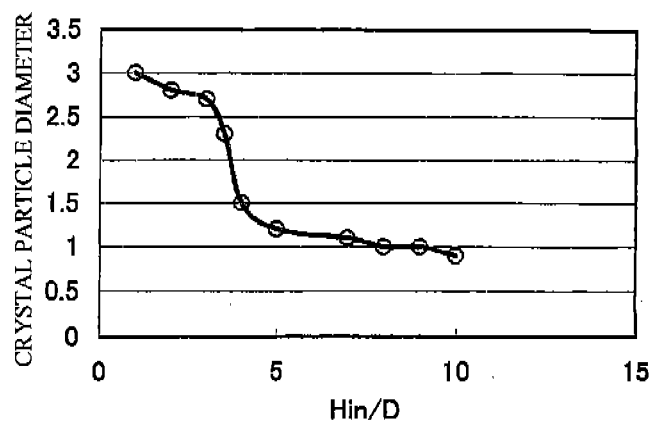


FIG.7

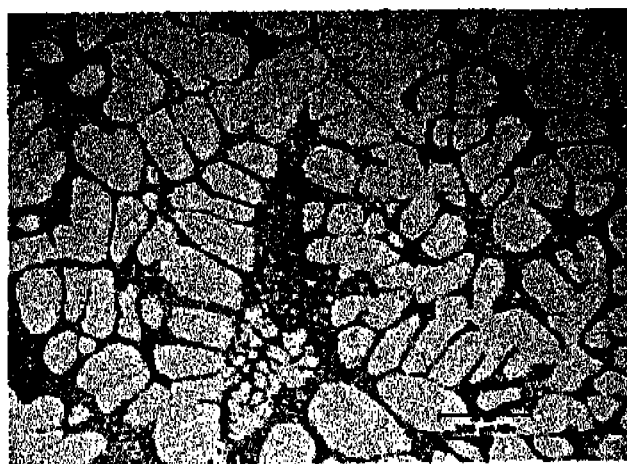
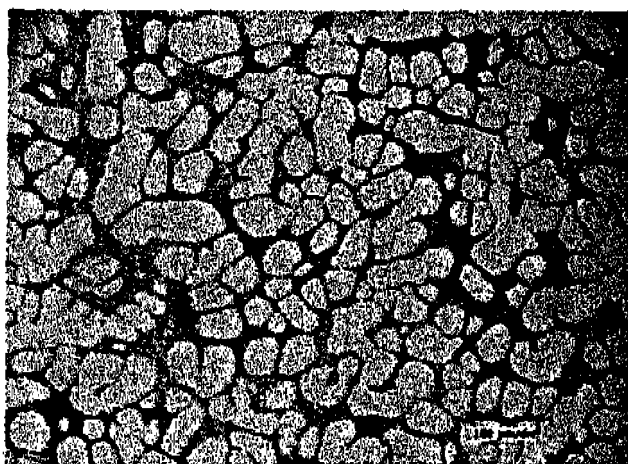


FIG.8



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2005/009150

A. CLASSIFICATION OF SUBJECT MATTER Int.Cl. ⁷ B22D17/00		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) Int.Cl. ⁷ B22D17/00		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2005 Kokai Jitsuyo Shinan Koho 1971-2005 Toroku Jitsuyo Shinan Koho 1994-2005		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 11-138248 A (Kabushiki Kaisha Ahresty), 25 May, 1999 (25.05.99), Par. Nos. [0009], [0018]; Fig. 5 (Family: none)	1-13, 17-21, 23, 24, 26, 27 <u>14-16, 22, 25</u>
Y	JP 2000-158095 A (Ryobi Ltd.), 13 June, 2000 (13.06.00), Fig. 2 (Family: none)	14-16, 22
Y	JP 08-325652 A (Ube Industries, Ltd.), 10 December, 1996 (10.12.96), Par. No. [0007] & EP 0745694 A1	25
☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.		
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Date of the actual completion of the international search 22 August, 2005 (22.08.05)		Date of mailing of the international search report 06 September, 2005 (06.09.05)
Name and mailing address of the ISA/ Japanese Patent Office		Authorized officer
Facsimile No.		Telephone No.

Form PCT/ISA/210 (second sheet) (January 2004)

REFERENCES CITED IN THE DESCRIPTION

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