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(54) **Apparatus for casting a directionally solidified article**

Vorrichtung zum Giessen eines gerichtet erstarrten Giesskörpers

Appareil pour la coulée d'une pièce solidifiée directionnellement

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Description

FIELD OF INVENTION

[0001] The invention relates to an apparatus for casting a directionally solidified article.

STATE OF THE ART

[0002] The directional solidification process is a version of investment casting in which a cavity resembling the desired finished piece is defined by a ceramic shell mould. The mould is placed on a cooling surface, preheated to a desired temperature in a high temperature environment, filled with a liquid alloy, and withdrawn from the high temperature environment into a lower temperature environment (defined by a vacuum or liquid coolant or cooling by other means) at a specific rate so as to induce solidification of the liquid alloy in a directional fashion, starting at the cooling plate.

[0003] In general such a casting furnace is known for example from US 3,532,155, furnaces working with gas cooling are known from the US-Patent US 3,690,367 or the European patent application EP-A1-749,790, and an LMC furnace is described in US 3,763,926.

[0004] Another casting furnace is disclosed in the international publication WO99/12679.

[0005] One disadvantage of the above mentioned casting furnaces is that despite the presence of a baffle between heating and cooling zones, thermal radiation coming from the heating chamber reflects off of the cooling chamber walls and onto the parts being cast, thus reducing the temperature gradient across the liquid solid interface. This effect becomes even worse as metal vapor deposits accumulate on the walls of the cooling chamber.

SUMMARY OF THE INVENTION

[0006] It is object of the present invention to find an apparatus for manufacturing a directionally solidified articles using a casting furnace to allow a better cooling by providing a greater thermal gradient over the solidification front during the casting process.

[0007] In the present invention a casting furnace is provided according to claim 1 characterised in that the bottom portion of the cooling chamber has a base which is larger than the upper portion of the cooling chamber.

[0008] One advantage of this new arrangement is that radiation coming from the heating chamber would be reflected downwards into the depths of the cooling chamber. The result of the new form of the cooling chamber is therefore an improved cooling of the solidifying article. For that purpose the positive downward taper in at least one part of the cooling chamber is preferred between 1% and 50%.

[0009] Another advantage is that due to the new shape, the surface of the upper portion of the cooling

chamber remains clean of metal vapour deposits because of the lack of line-of-sight visibility to the metal vapour coming from the hot zone with the result of a better cooling efficiency and therefore a better thermal gradient across the liquid solid front.

[0010] The surface of the cooling chamber might be purposefully blackened and/or roughened to increase its ability to absorb thermal radiation.

[0011] A further advantage of the new arrangement of the cooling chamber is that the bottom plate is not an integral part of the cooling chamber but is for reasons of cleaning removable. In case of shell leakage or failure the alloy will be collected at the bottom of the cooling chamber due to the new form. The form avoids the contact of the leaked alloy with the walls of the cooling chamber and avoids at the same time a decreased cooling efficiency.

BRIEF DESCRIPTION OF DRAWINGS

[0012] This invention is illustrated in the accompanying drawings, in which

Fig. 1 is a first embodiment of a casting furnace according to the invention,

Fig. 2 is a second embodiment of a casting furnace according to the invention and

Fig. 3 is a third embodiment of a casting furnace according to the invention.

[0013] The drawings show only the elements important for the invention. Same elements will be numbered in the same ways in different drawings.

DETAILED DESCRIPTION OF THE INVENTION

[0014] The present invention relates an apparatus of manufacturing a single crystal or a directionally solidified article using a casting furnace as seen in figure 1, 2 and 3.

[0015] Figure 1 shows a casting furnace 1 comprising a heating chamber 2 and a cooling chamber 3. The heating chamber 2 includes heating elements 2a. Both the heating chamber 2 and the cooling chamber 3 are separated by a baffle 4 to avoid radiation coming from the heating chamber 3 to the cooling chamber 2. The baffle 4 could possibly be water-cooled. There is a shell mould 5 arranged within the heating chamber 2 and the cooling chamber 3. The cooling chamber 3 comprises an upper portion 3b, a bottom portion 3c, cooling elements 3a within a wall 3d and a bottom plate 3e.

[0016] In the first step of the method for solidifying the directionally solidified article the shell mould 5 placed within the heating chamber 2 will be filled with a liquid alloy 6a through a feed opening 7 at the top of the heating chamber 2. The shell mould 5 is in the heating chamber 2 in a position which is shown in the figures with a dotted line. After filling the shell mould 5 it is withdrawn

continuously at a predetermined rate from the heating chamber 2 to the cooling chamber 3 through an aperture 9 in the baffle 4. The direction of withdrawal 8 is indicated with an arrow. As soon as the shell mould 5 reaches the cooling chamber 2 solidification of the liquid alloy 6a begins. The solidified alloy 6b is found at the lower portion of the shell mould 5, which already reached the cold zone. Approximately at the border between the heating chamber 2 and the cooling chamber 3 is the solidification front 10. The solidification front 10 grows from the bottom of the shell mould 5 to the top in opposite direction of the withdrawal direction 8. The described casting process takes place in a vacuum atmosphere or an atmosphere of inert gas such as He, Ar or combination thereof.

[0017] The cooling chamber 3 comprises cooling elements 3d using water as a cooling medium within the walls 3e of the cooling chamber 3. The upper portion 3b of the cooling chamber 3 is open to the baffle 4 and the heating chamber 2. The cooling of the shell mould 5 within the cooling chamber 3 takes place by thermal radiation to the walls 3d.

[0018] As illustrated in figure 1 and according to the invention the cooling chamber 3 is formed with the bottom portion 3c having a greater base than the upper portion 3b. In the figure 1 the cooling chamber 3 has a positive downward taper. The preferred embodiment according to the invention the taper is 1% up to 50%. In the embodiment according to figure 3, again, the cooling chamber 3 has a bottom portion 3c which is greater than the upper portion 3b, but is formed with a curved profile. Even a similar profile as figure 3 with an increased taper relative to the bottom portion is possible.

[0019] Figure 2 shows a casting furnace 1 comprising a heating chamber 2 and a cooling chamber 3 similar to the casting furnace of figure 1. But in difference to figure 1 the cooling chamber 3 has the truncated cone only in the upper portion 3b of the cooling chamber 3. The cooling elements 3a are in this embodiment not included in the walls 3d but only attached to the wall 3d of the cooling chamber 3. As a cooling medium within the cooling elements 3a there could be used any fluid cooling medium.

[0020] One advantage of this new arrangement is that radiation 11 coming from the heating chamber 2 would be reflected downwards into the depths of the cooling chamber 3 rather than being reflected back at that portion of the shell mould just inside the cooling zone. In all figures 1 to 3 this effect is shown with the arrows for the radiation 11 coming from the heating chamber 2 through the aperture 9 in the baffle 4. The radiation 11 coming from the heating chamber 2 is due to the 3 dimensional form of the casting furnace 1 around the casting furnace 1 shown in the figures 1 to 3 as dotted lines. This is valid not only for the radiation 11 coming from the heating chamber 2 but also from the shell mould 5 itself. The result of the new form of the cooling chamber 3 is therefore an improved cooling of the solidifying article.

[0021] In a casting process as discussed herein one problem is always that condensation of deposits from vapour species coming from the hot zone onto the walls of the cooling chamber 3 occurs, e.g. graphite from the heaters, metallic gas from alloy evaporated from the liquid alloy being solidified, SiO, SiO₂ and other metallic oxides volatilized from the shell mould. These deposits form substantially only in that portion of the cold zone where there is a direct line-of-sight visibility to the hot zone, where the vapour phases exist in equilibrium. In the cold zone, the vapour phases condense to solid immediately upon coming into contact with a cold surface, hence only those portions with line-of-sight visibility to the hot zone can directly be contacted by vapour coming from the hot zone. Unfortunately it is this same portion of the cold zone, in which radiation cooling of the solidifying component to the cold zone walls is most important to maintain the desired thermal gradient in the solidifying article. The deposits form as a loosely held collection of flakes and sheets and so severely impede proper functioning of the cold zone walls so that the furnace must be shut down periodically to remove these deposits. The deposits that form effectively as loosely held sheets and flakes block the direct from solidifying the article and can become substantially hotter than the underlying surface of the sold zone inner wall.

[0022] Thus, a further advantage of the positive downward taper of the cooling chamber 3, and especially the new form according to figure 2 or 3, is that it removes the line-of-sight visibility of the upper-most portion of the cold zone and allow better absorption of thermal radiation directly onto the surface of the cooling chamber. In this way the surface remains clean. It might be purposefully blackened and/or roughened to increase its ability to absorb thermal radiation. The lack of deposits on this critical portion of the cold zone will also allow operation of the furnace with no down time for cleaning deposits leading to reduced costs in both production time and service maintenance.

[0023] A further advantage of the new arrangement of the cooling chamber is that the bottom plate 3e is not an integral part of the cooling chamber 3 but will be a separate piece fitting tightly onto the bottom portion 3c of the cooling chamber 3. In case of shell leakage of failure the alloy 12 will be collected at the bottom of the cooling chamber 3 due to the new form. The form avoids therefore the contact of the leaked alloy with the walls of the cooling chamber, which would lead as well to a undesired decreased cooling efficiency. As seen from figure 1 it is easy to open the bottom plate 3e from underneath to allow any collected alloy 12 from the shell failure or leakage to fall out by gravity. Therefore this improvement saves a lot of time in preparing the furnace for the next casting run in the event of a shell mould leakage or breakage.

[0024] At the bottom of the shell mould 5 there might be provided a starter section for producing a specific crystallographic orientation of the article when starting

the solidification.

[0025] As seen from figure 3 but in general applicable to all embodiments within this description there might be a base plate 13 at the bottom of the shell mould 5. The base plate 13 can be cooled in addition. Furthermore, and as seen from figure 3 as well, there might be a withdrawal mechanism 14 to allow the withdrawal of the shell mould 5 from the bottom of the casting furnace 1.

NUMBERING

[0026]

- 1 Casting furnace
- 2 Heating chamber
- 2a Heating elements
- 3 Cooling chamber
- 3a Cooling Elements
- 3b Upper portion of cooling chamber 3
- 3c Bottom portion of cooling chamber 3
- 3d Walls of cooling chamber 3
- 3e Bottom plate of cooling chamber 3
- 4 Baffle
- 5 Shell mould
- 6a Liquid alloy
- 6b Solidified alloy
- 7 Feed opening
- 8 Direction of withdrawal
- 9 Aperture
- 10 Solidification front
- 11 Radiation
- 12 Collected alloy within cooling chamber 3
- 13 Base plate of shell mould 5
- 14 Withdrawal mechanism for shell mould 5

Claims

- 1. Casting furnace (1) for producing a single crystal or a directionally solidified article comprising an upper heating chamber (2), a lower cooling chamber (3), the cooling chamber (3) comprising cooling elements (3a), an upper portion (3b), a bottom portion (3c), walls (3d) and a bottom plate (3e), and a shell mould (5) to be moved from the heating to the cooling chamber (2,3) during the casting of the article, **characterised in that** the bottom portion (3c) of the cooling chamber (3) has a base which is larger than the upper portion (3b) of the cooling chamber (3).
- 2. Casting furnace (1) of claim 1, **characterised in that** the cooling chamber (3) is shaped partially or in a whole as truncated cone with its bottom portion (3c) having a base which is larger than the upper portion (3b).

- 3. Casting furnace (1) of claim 2, **characterised in that** the truncated cone has a taper of 1% up to 50 % in at least one portion of the cooling chamber (3).
- 4. Casting furnace (1) of claim 1, **characterised in that** the walls (3d) of the cooling chamber (3) are shaped curved with its bottom portion (3c) having a base which is larger than the upper portion (3b) or with an increased taper relative to the bottom portion.
- 5. Casting furnace (1) of one of the claims 1 to 4, **characterised in that** the bottom plate (3e) of the cooling chamber (3) is removable.
- 6. Casting furnace (1) of one the claims 1 to 4, **characterised in that** the walls of the cooling chamber (3) are blackened and/or roughened.
- 7. Casting furnace (1) of one the claims 1 to 4, **characterised in that** a baffle (4) with an aperture (9) therein separates the heating chamber (2) and the cooling chamber (3).
- 8. Casting furnace (1) of one the claims 1 to 4, **characterised in that** the cooling chamber (3) is cooled by any fluid coolant, the cooling elements (3a) arranged in or around the walls (3d) of the cooling chamber (3).
- 9. Casting furnace (1) of one the claims 1 to 4, **characterised in that** at the bottom of the shell mould (5) is a provided a starter section for producing a specific crystallographic orientation of the article.
- 10. Casting furnace (1) of one the claims 1 to 4, **characterised in that** there is a base plate (13) at the shell mould (5) which is possible to cool.
- 11. Casting furnace (1) of one the claims 1 to 4, **characterised in that** there is provided a withdrawal mechanism (14) connected from the bottom of the casting furnace (1) with the shell mould (5) to withdraw the shell mould (5) during casting.

Patentansprüche

- 1. Gießofen (1) zur Herstellung eines Einkristalls oder eines gerichtet erstarrten Gegenstands, umfassend eine obere Heizkammer (2), eine untere Kühl-

- kammer (3), wobei die Kühlkammer (3) Kühlelemente (3a), ein Oberteil (3b), ein Bodenteil (3c), Wände (3d) und eine Bodenplatte (3e) umfaßt, und ein Formmaskenwerkzeug (5) zur Bewegung von der Heizkammer (2) zur Kühlkammer (3) während des Gießens des Gegenstands, **dadurch gekennzeichnet, daß** der Bodenteil (3c) der Kühlkammer (3) eine Basis aufweist, die größer ist als der Oberteil (3b) der Kammer (3).
2. Gießofen (1) nach Anspruch 1, **dadurch gekennzeichnet, daß** die Kühlkammer (3) teilweise oder ganz als ein Kegelstumpf geformt ist, wobei sein Bodenteil (3c) eine Basis aufweist, die größer ist als der Oberteil (3b).
3. Gießofen (1) nach Anspruch 2, **dadurch gekennzeichnet, daß** der Kegelstumpf mindestens in einem Teil der Kühlkammer (3) eine Verjüngung von 1% bis 50% aufweist.
4. Gießofen (1) nach Anspruch 1, **dadurch gekennzeichnet, daß** die Wände (3d) der Kühlkammer (3) gekrümmt geformt sind, wobei sein Bodenteil (3c) eine Basis aufweist, die größer ist als der Oberteil (3b) oder eine größere Verjüngung relativ zum Bodenteil aufweist.
5. Gießofen (1) nach einem der Ansprüche 1 bis 4, **dadurch gekennzeichnet, daß** die Bodenplatte (3e) der Kühlkammer (3) entfernt werden kann.
6. Gießofen (1) nach einem der Ansprüche 1 bis 4, **dadurch gekennzeichnet, daß** die Wände der Kühlkammer (3) geschwärzt und/oder aufgeraut sind.
7. Gießofen (1) nach einem der Ansprüche 1 bis 4, **dadurch gekennzeichnet, daß** ein Leitblech (4) mit einer Öffnung (9) darin die Heizkammer (2) und die Kühlkammer (3) trennt.
8. Gießofen (1) nach einem der Ansprüche 1 bis 4, **dadurch gekennzeichnet, daß** die Kühlkammer (3) durch ein beliebiges Kühlfluid gekühlt wird, wobei die Kühlelemente (3a) in den Wänden (3d) oder um die Wände der Kühlkammer (3) herum angeordnet sind.
9. Gießofen (1) nach einem der Ansprüche 1 bis 4, **dadurch gekennzeichnet, daß** am Boden des Formmaskenwerkzeugs (5) ein Starterabschnitt zum Erzeugen einer speziellen Kristallorientierung des Gegenstands vorgesehen ist.
10. Gießofen (1) nach einem der Ansprüche 1 bis 4, **dadurch gekennzeichnet, daß** an dem Formmaskenwerkzeug (5) eine Basisplatte (13) vorliegt, die gekühlt werden kann.
11. Gießofen (1) nach einem der Ansprüche 1 bis 4, **dadurch gekennzeichnet, daß** ein Herausziehmechanismus (14) vorgesehen ist, der vom Boden des Gießofens (1) mit dem Formmaskenwerkzeug (5) verbunden ist, um das Formmaskenwerkzeug (5) während des Gießens herauszuziehen.

Revendications

1. Four de coulée (1) pour produire un cristal unique ou une pièce solidifiée d'une façon directionnelle, comprenant une chambre de chauffage supérieure (2), une chambre de refroidissement inférieure (3), la chambre de refroidissement (3) comprenant des éléments de refroidissement (3a), une partie supérieure (3b), une partie inférieure (3c), des parois (3d) et une plaque de fond (3e), et un moule en coquille (5) à déplacer de la chambre de chauffage à la chambre de refroidissement (2, 3) durant la coulée de la pièce, **caractérisé en ce que:**

la partie inférieure (3c) de la chambre de refroidissement (3) comprend une base qui est plus grande que la partie supérieure (3b) de la chambre de refroidissement (3).

2. Four de coulée (1) suivant la revendication 1, **caractérisé en ce que:**

la chambre de refroidissement (3) est configurée partiellement ou entièrement comme un cône tronqué dont la partie inférieure (3c) comprend une base qui est plus grande que la partie supérieure (3b).

3. Four de coulée (1) suivant la revendication 2, **caractérisé en ce que:**

le cône tronqué présente une conicité allant de 1 % à 50 % dans au moins une partie de la chambre de refroidissement (3).

4. Four de coulée (1) suivant la revendication 1, **caractérisé en ce que:**

les parois (3d) de la chambre de refroidissement (3) ont une forme incurvée, avec la partie inférieure (3c) de celle-ci qui comprend une base qui est plus grande que la partie supérieure (3b), ou avec une conicité plus prononcée par

rapport à la partie de fond.

5. Four de coulée (1) suivant l'une quelconque des revendications 1 à 4,

caractérisé en ce que: 5

la plaque de fond (3e) de la chambre de refroidissement (3) est amovible.

6. Four de coulée (1) suivant l'une quelconque des revendications 1 à 4, 10

caractérisé en ce que:

les parois de la chambre de refroidissement (3) 15
sont noircies et/ou rendues rugueuses.

7. Four de coulée (1) suivant l'une quelconque des revendications 1 à 4,

caractérisé en ce que: 20

une chicane (4) dans laquelle une ouverture (9)
est ménagée sépare la chambre de chauffage
(2) et la chambre de refroidissement (3).

8. Four de coulée (1) suivant l'une quelconque des revendications 1 à 4, 25

caractérisé en ce que:

la chambre de refroidissement (3) est refroidie 30
par un agent de refroidissement fluide quelconque, les éléments de refroidissement (3a) étant
agencés dans ou autour des parois (3d) de la
chambre de refroidissement (3).

9. Four de coulée (1) suivant l'une quelconque des revendications 1 à 4, 35

caractérisé en ce que:

une section d'amorçage est prévue au fond du 40
moule en coquille (5) pour produire une orientation cristallographique spécifique de la pièce.

10. Four de coulée (1) suivant l'une quelconque des revendications 1 à 4,

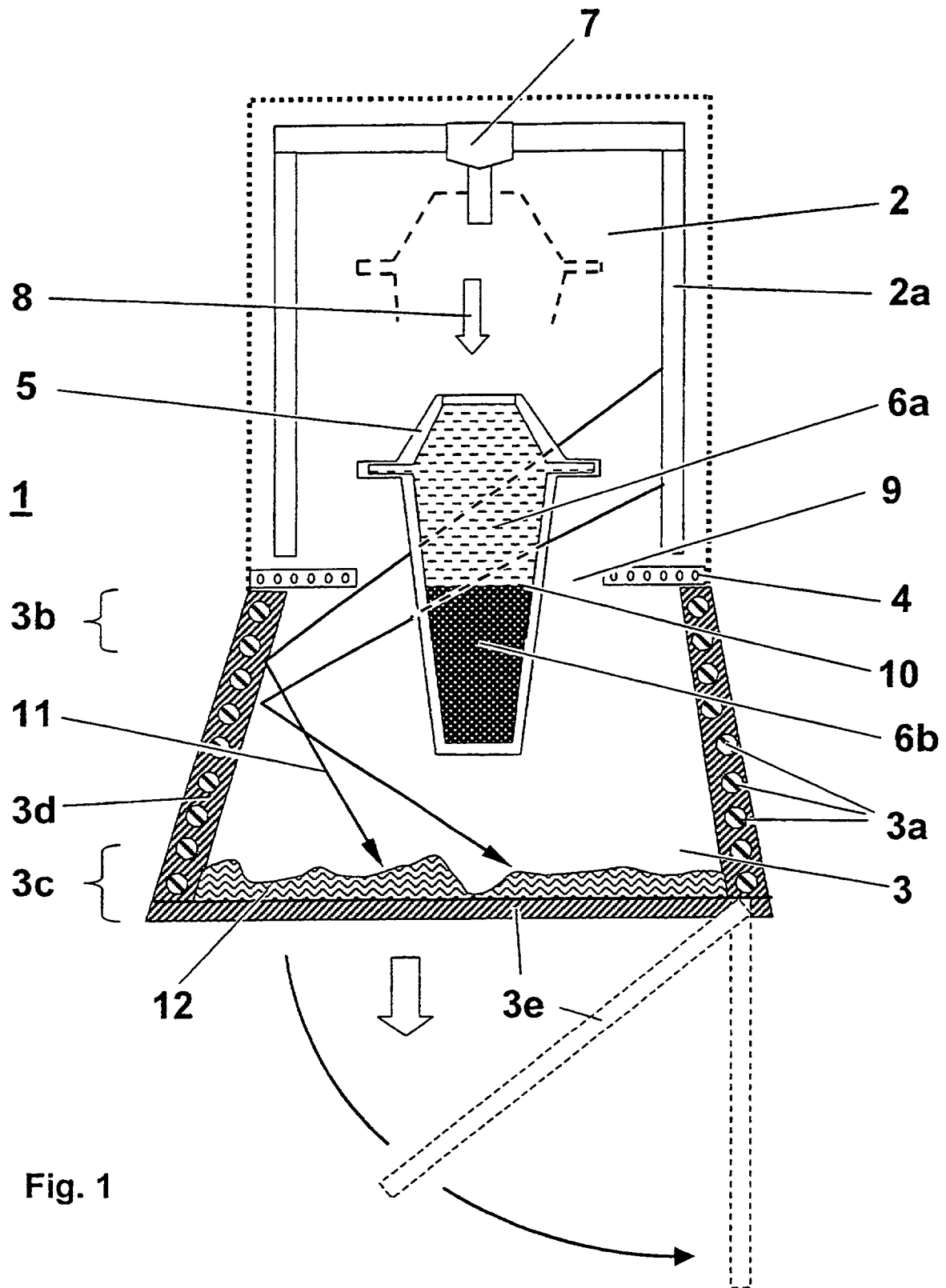
caractérisé en ce que: 45

le moule en coquille (5) comprend une plaque
de base (13) qu'il est possible de refroidir.

11. Four de coulée (1) suivant l'une quelconque des revendications 1 à 4, 50

caractérisé en ce que:

il est prévu un mécanisme d'extraction (14)
connecté à partir du fond du four de coulée (1) 55
au moule en coquille (5) pour extraire le moule
en coquille (5) durant la coulée.



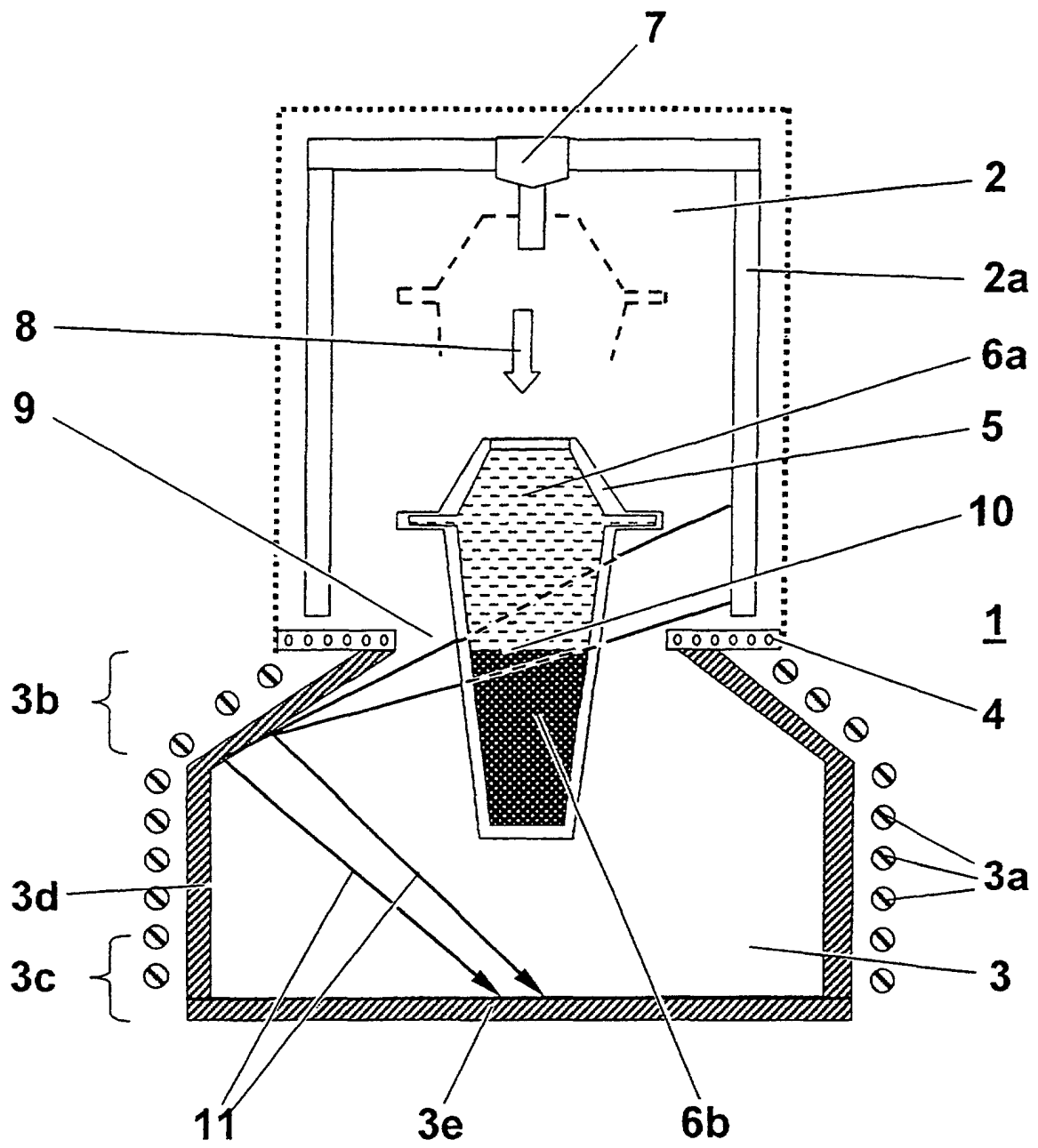


Fig. 2

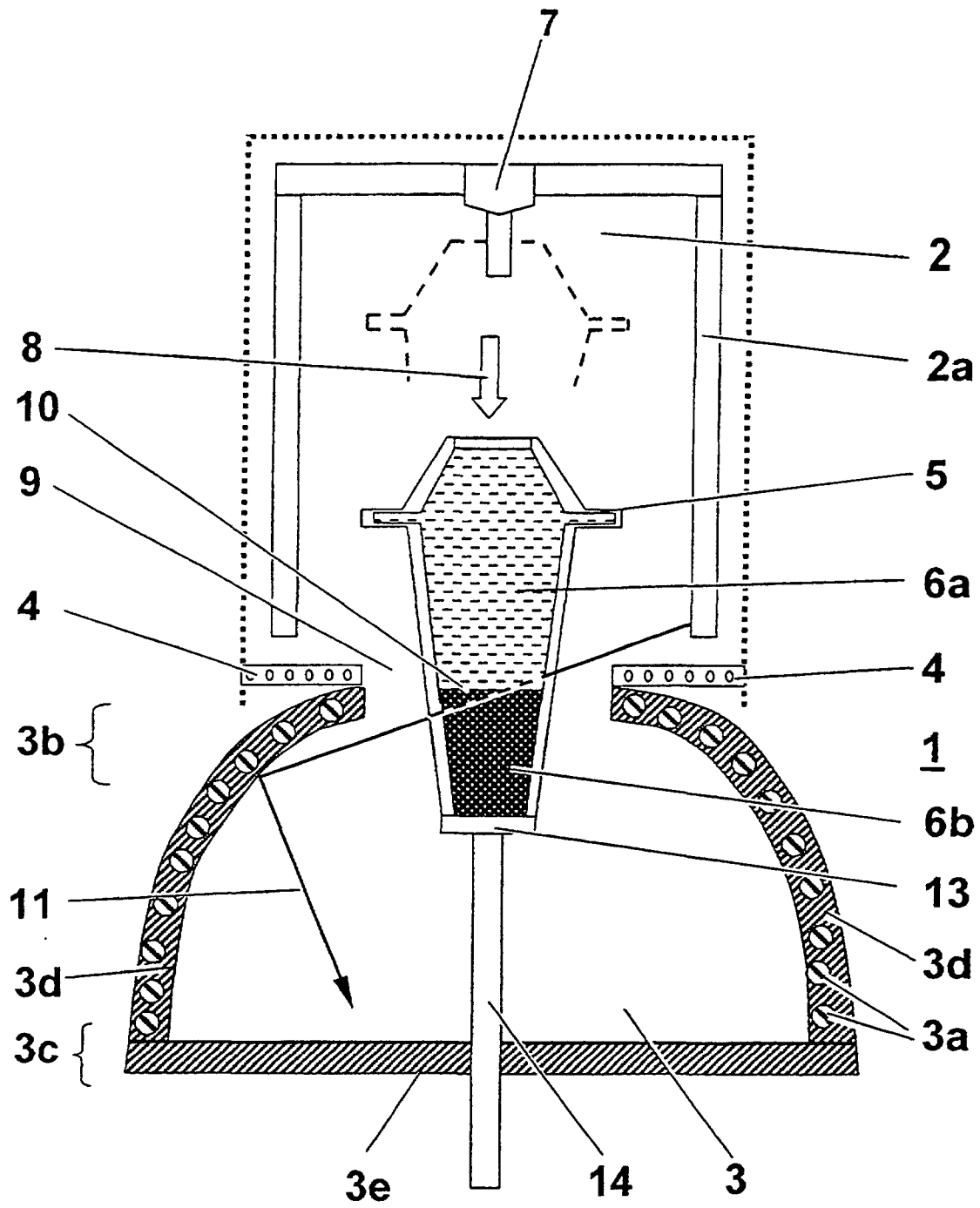


Fig. 3