United States Patent [19]
Daigne et al.
[11] 3,838,729
[45] Oct. 1, 1974

[54] METHOD FOR MAKING A CASTING OF A DIRECTIONALLY SOLIDIFIED ALLOY

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[22] Filed: **Oct. 27, 1972**

[21] Appl. No.: **301,638**

[30] **Foreign Application Priority Data**
Nov. 5, 1971 France 71.39703

[52] **U.S. Cl.** **164/50,** 164/127, 164/136
[51] **Int. Cl.** **B22d 27/02,** B22d 37/00
[58] **Field of Search** .... 164/50, 51, 60, 122, 125, 164/133, 136, 250, 338 H, 348, 371, 127

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[57] **ABSTRACT**

A method and device are disclosed for casting parts and ingots of a metallic alloy with an ordered structure obtained by the progressive solidification of a liquid alloy. The device comprises a thin walled mould means for introducing the alloy into the mould having at least one duct and means for maintaining the lower end of the duct at a constant distance from the free surface of the liquid phase, heating means constituted by elements radiating heating energy and facing said free surface, and heat insulating means around the lateral walls of the mould.

12 Claims, 3 Drawing Figures

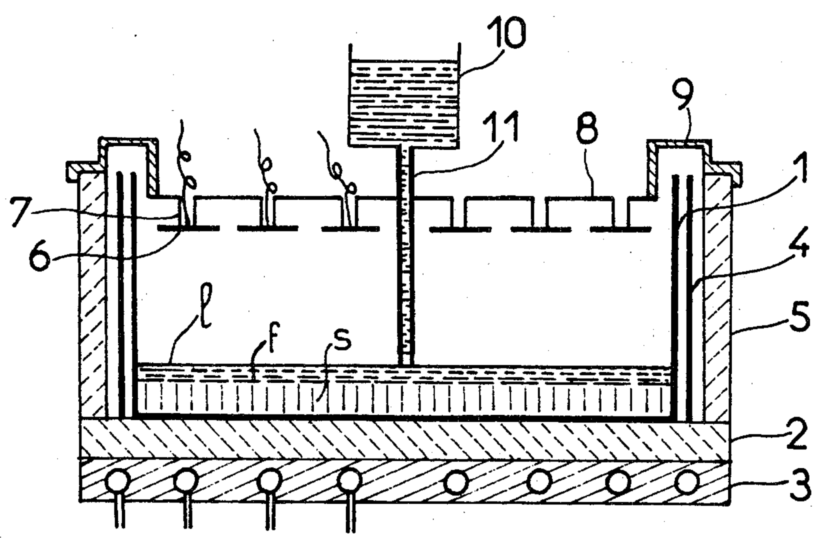


FIG. 1

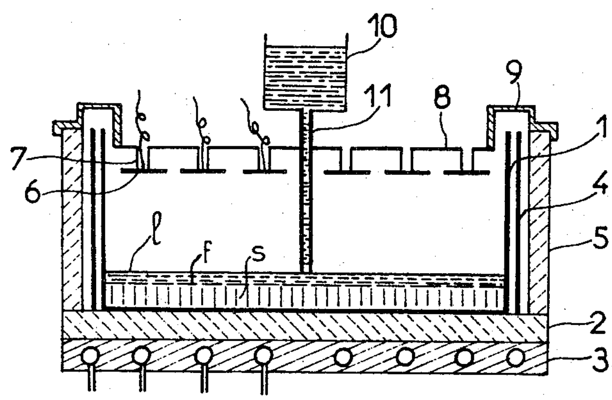


FIG. 2

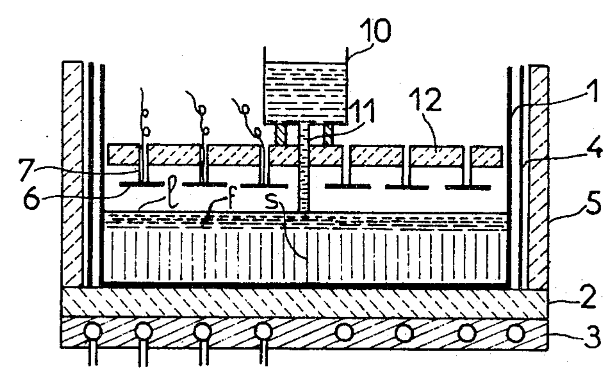
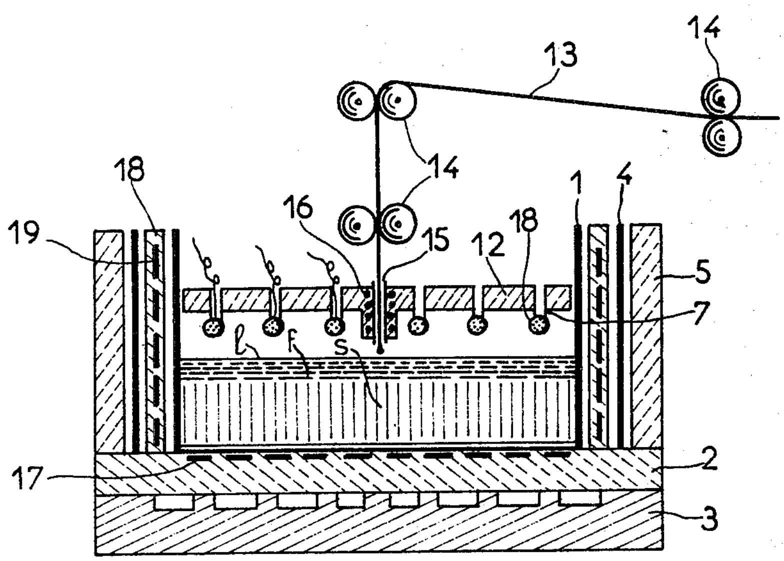


FIG. 3



METHOD FOR MAKING A CASTING OF A DIRECTIONALLY SOLIDIFIED ALLOY

The present invention concerns a process and a device for casting parts and ingots. In particular, it enables the obtention of high strength alloy ingots intended to be cut for machining of parts which structure must be fine, homogeneous and free from micro-flaws such as microscopic voids and micro-scopic shrinkages.

It is particularly suitable for the manufacture of refractory alloy ingots or parts having an ordered or directional structure and eventually comprising a reinforcement phase of metallic compounds fibers.

It is known that, in order to obtain fine ingots or fine castings, care must be taken to ensure that the zones in the process of solidification are supplied with liquid metal as the solidification areas or interfaces are in movement, in order to especially compensate the decreases in volume resulting from the shrinkage accompanying solidification. This precaution consists in making the isotherm and isobar surfaces coincide as much as possible in the zones that are in the process of solidification. It is also known that the solidification structure is all the finer and sounder as the greater the temperature gradients are in the vicinity of the solidification interfaces. The art of the founder-moulder consists in judiciously disposing in the moulds sources of heat (deadheads that are metal reserves as well) and cold sources (coolers in sand moulds, cooled zones in cast iron moulds) in order to control the isotherm distribution and the temperature gradients.

While it is enough for the majority of castings, to approximately observe the above conditions, this is not the case when castings or ingots of refractory alloys with a very fine and compact structure and with an ordered reinforcing phase have to be produced. The reinforcing fibers appear during solidification and their orientation corresponds precisely to that of the temperature gradients and their continuity may be seriously affected if the values of said gradients are not sufficient in certain zones.

We have thus been led to design processes and devices for controlled solidification such as those described in U.S. Pat. No. 3 124 452 and the C.I.P. Application 268,751, having the same assignee as this application, in which are described devices comprising a heat source surrounding the upper portion of the mould and shifting at the same rate as the interface of solidification and a cold source located at the lower portion of the mould. While providing advantageous results, these devices and processes may be industrially exploited on a small scale only.

On the one hand, the isothermal areas, and consequently the interfaces of solidification, remain approximately plane (an essential requirement for obtaining parallel fibers) only if the moulds and parts have small lateral dimensions. On the other hand, in order to obtain sharp temperature gradients without excessive overheating of the liquid metal, care must be taken to maintain within very restricted limits, the rate at which the solidification interface progresses, for example of the order of 5 cm per hour. Consequently, using said processes, it is possible to produce only castings with small transverse dimensions at a very slow rate of production.

By using the method and the device according to the invention, it is possible to obtain ingots or castings made of high strength alloys and, in particular, ingots having an ordered structure, with relatively large lateral dimensions and from which a great number of parts may be cut, thus considerably increasing the production rate.

Reference is now made, to provide non-limitative examples of the embodiment of the invention, to FIGS. **1**, **2** and **3**, each representing a diagrammatic cross-section view of different embodiments.

FIG. **1** illustrates the simplest form of embodiment of the moulding device according to the invention.

The mould **1** is of a refractory material which is a good heat conductor, for example a molybdenum sheet covered by an appropriate potting, or else alumina externally reinforced with a molybdenum ring. It rests on an alumina block **2**, itself disposed on a copper plate **3** which is provided with circular channels through which passes a flow of cooling water supplied by autonomous circuits.

Surrounding the crucible **1**, are found successively a heat shield **4** of polished refractory metal, for example molybdenum, to decrease lateral loss of radiated heat, and an outer heat insulating wall **5** increasing the efficiency of the shield.

Resistances **6** in crown formation for example of tungsten strip, are suspended by means of tubes **7** of refractory insulating material from a plate **8** of polished molybdenum, functioning as a heat shield, itself attached to a molybdenum ring **9** bearing against the wall **5**. The resistances **6** are supplied by independant electrical power sources.

The crucible **10**, which is of molybdenum, is vertically moveable. It is moved by a device not represented in the figure. The bottom of the crucible is connected to a calibrated central nozzle **11**.

The device of FIG. **1** is used as follows:

Crucible **10** is arranged in its lowest position so that the lower end of nozzle **11** is only a few millimeters from the bottom of mould **1**. The resistances **6** and the cooling channels of the cold source **3** are powered. When thermal equilibrium is attained, crucible **10** is filled with liquid metal which flows at a slow, constant rate through calibrated nozzle **11**. As the level of liquid metal rises in the mould, crucible **10** is raised progressively so that the nozzle **11** is always flush with the free surface *l* of the liquid metal within a few millimeters.

It is noteworthy that the combination of the heat source constituted by the resistances **6** and of the cold source constituted by block **2** cooled by plate **3** causes a marked vertical heat flow while the lateral flow is very small owing to the insulating effect of shield **4** and wall **5**. By means of preliminary adjustment trials, the electrical power supplied to resistances **6**, the water flow rate of cold source **3** channels and the raising speed of crucible **10** and nozzle **11** are regulated in such a way that the solidification interface *f* of the casted metal progresses at the same speed as level l of the liquid metal. Since the free surface of the bath is not disturbed by the casting, since the height of fall of the liquid metal is almost zero, the thickness of the liquid phase is a few millimeters, and the temperature gradient across the solidification interface is uniform over its entire surface and is vertically oriented whatever the transverse dimensions of the mould.

There is no disadvantage in the capacity of crucible **10** to be less than that of the mould. Since nozzle **11** regulates the casting rate, it is always possible, during the operation, to add liquid metal to the crucible.

The method device according to the invention thus combine the required conditions for obtaining a casting having a fine, ordered structure free from micro-flaws.

The device in FIG. **1** does not, however, enable a constant temperature gradient to be obtained in the vicinity of the solidification interface throughout the entire duration of the operation, since the distance between the interface and the heat source constituted by the resistances **6** decreases as casting progresses, while the impedance or heat resistance imposed by the solidified metal to the heat flow going towards the cold source increases at the same time.

Now, the production of alloys having a directional reinforcement phase such as those of U.S. C.I.P. Application 268,751 not only requires the solidification interface to progress at a constant speed, but also requires the temperature gradients to remain constantly greater than a critical value below which cristallization degenerates.

The device of FIG. **2** enables the obtention of a sharper and more constant temperature gradient than that of FIG. **1.** It comprises almost all the elements of FIG. **2,** but shield **8** and support **9** are discarded. Crucible **10** and nozzle **11** are integral with a refractory plate **12** which, in addition supports tubes **7** and resistances **6.** This arrangement enables the same distance to be maintained between resistances **6,** the free surface *l* of the liquid metal and the interface *f* of solidification throughout casting by means of the upward movement of plate **12.**

Although the heat impedance opposed by the solid phase *s* to the heat flow travelling between interface *f* and the cold source remains variable, since it increases as casting progresses, the device of FIG. **2** does, however, enable aluminium alloy ingots having an ordered structure and a height of about 10cm to be obtained.

FIG. **3** represents a device according to the invention which enables obtention of ingots of an even greater height and production of refractory alloys with ordered reinforcing phase.

Before going on to describe it, it should be noted that, at this stage of development, the invention enables a constant temperature gradient at the solidification interface to be obtained throughout the entire casting operation, despite the increasing resistance of the solid phase to the heat flow, by providing means to impose to the lower end of said solid phase a variable temperature according to a law of the following kind.

$$\int_{T_1}^{T_S} C(T)dT = GC_LH$$

T_1 being the temperature of the lower end of the ingot,

T_S the alloy solidification temperature,

C (T) the heat conductivity of the solid phase at temperature T,

C_L the heat conductivity of the liquid phase in the vicinity of the solidification interface,

G the temperature gradient in the liquid phase in the vicinity of the interface,

H the height of the solid phase.

According to this equation, the invention thus allows for the fact that the temperature T_1 of the lower end of the solid phase must vary in inverse proportion to the height H to preserve a constant gradient G.

The invention provides different constructive solutions meeting this requirement while ensuring evacuation of the heat flow through this liquid and solid phases, for example:

a. applying an auxiliary, diminishing heat flow to the lower end of the solid phase, using an auxiliary source of heat in contact with the bottom of the mould (solution adopted in FIG. **3**)

b. placing a decreasing thermal resistance under said lower end,

either, for example, by using a material having a heat conductivity varying in inverse proportion to its own temperature to make the support block of the mould (solution adopted in FIG. **3**) or the lower wall of the mould,

or, for example, by inserting into the support a variable heat resistance, for example a liquid layer of variable thickness.

These different arrangements may be employed independantly.

It will be noted that the device in FIG. **3** shows different embodiments in the system supplying the bath, and in the system heating the bath, which is an inductor **18.** The alloy is supplied in the form of a strip or wire **13** driven and guided by rollers **14** integral with plate **12** and it is fed by a storage reel not represented in the figure. It is pushed towards the bath through a nozzle **15** and, on passing through, is progressively heated by resistances **16** which bring it close to the melting point temperature. Melting induced by the radiation of surface *l* of the bath.

The water circulation channels are here made by machining the upper surface of the plate **3** on which block **2** is brazed. Tungsten strip heating resistances **17** are set in the upper face of block **2** and are in contact with mould **1.**

Finally, between the lateral wall of mould **1** and shield **4** is inserted a refractory wall **18** in which are set tungsten strip resistances **19.**

By judiciously dimensioning the different elements, by regulating the heating voltages and the other functional parameters, the device in FIG. **3** allows the obtention of a temperature gradient in the vicinity of the solidification interface that is substantially constant and uniform throughout the entire duration of the casting operation.

In fact,

a. lateral heat losses may be completely eliminated by judiciously adjusting heating of wall **19;**

b. the increased heat resistance of the solid portion s of the alloy may be compensated for by reducing the temperature of resistances **17** as solidification progresses,

c. finally, a very interesting property, in this respect, of certain materials such as alumina, which has a heat conductivity coefficient varying in inverse proportion to the temperature, is exploited in order to compensate even more efficiently for said increase in heat resistance.

The above will now be illustrated using a numerical example.

It is desired to obtain a 90 mm high alloy ingot with an ordered reinforcing phase, in a cobalt nickel-chrome matrix reinforced by tantalum carbide fibers.

The block **2** is 99.5 percent alumina and is 25 mm thick. The cooling water is at a temperature of 20°C. The temperature of the heat source resistances **6** is adjusted so that they are brought to 2,250°C and calculation shows that the heat flow through the bath is about 30 W/cm^2. During solidification, the temperature of resistances **17** will be decreased progressively from 1,350°C to 350°C.

Calculation will show that, under these conditions, the thickness of the liquid bath will be of the order of 15 mm and that, during the entire process of solidification, the thermal gradient in the bath will be of the order of 100°C/cm, a suitable value for the chosen alloy. As a certain thermal gradient fluctuation is admissible in many cases, the device in FIG. **3** enables the production of castings or ingots of refractory alloys, with an ordered reinforcing phase, the size of which may reach 150 mm and the diameter 200 mm or more.

The invention may comprise arrangements other than those illustrated in the given examples. Thus, the alloy may be brought to the surface of the bath not only in a liquid form or in the form of a wire or strip, but also as a powder.

The bath may be heated not only by radiant resistantes, but also by induction or electron flow.

The material with a variable heat transmission coefficient constituting block **2** of FIG. **3** may be made of alumina but also, for example, of beryllium oxide.

The alloy may be supplied to the mould by means of several lines **11** or nozzles **15** judiciously distributed.

I claim:

1. A method for making a casting of a directionally solidified alloy, comprising the steps of mounting a mold on a chill plate, positioning around said mold a lateral heat insulating structure to limit transverse heat transfer, melting an alloy material, supplying the alloy material to the mold through delivering means while continually cooling the chill plate to remove heat from the melted alloy so as to solidify the same from the chill plate upwardly, continuously supplying melted alloy material at a rate substantially equal to its rate of solidification while keeping the outlet of said delivering means at substantially the free level of the liquid alloy in said mold, and continuously heating said liquid in the mold by heat generating means facing said liquid free level and extending over a substantial portion thereof.

2. A method according to claim **1** wherein said heat generating means are electrical resistors.

3. A method according to claim **1** wherein said heat generating means are inductors.

4. A method according to claim **1** wherein said heat generating means are of the electron beam type.

5. A method according to claim **1** further comprising the step of continuously displacing the heat generating means away from the chill plate whereby substantially the same spacing between said heat generating means and said liquid free level is maintained during the entire casting operation.

6. A method according to claim **1** wherein said melting of the alloy material is conducted in the vicinity of said delivering mean outlet by additional heat generating means and by the heat radiating from the liquid alloy in said mold.

7. A method according to claim **1** further comprising the steps of providing adjustable heat transfer means between said chill plate and said mold, and of controlling said adjustable heat transfer means according to a predetermined law.

8. A method according to claim **7** wherein said predetermined law is governed by the formula:

$$\int_{T_1}^{T_S} C(T)dT = GC_LH$$

Wherein:

T_1 is the temperature at the lower part of the casting;

T_S is the temperature of solidification of the alloy;

C(T) is the thermal conductivity of the solid phase at temperature T;

C_L is the thermal conductivity of the liquid phase in the vicinity of the solidification interface;

G is the temperature gradient in the liquid phase in the vicinity interface, and

H is the height of the solid phase.

9. A method according to claim **7** wherein said heat transfer means comprise auxiliary heat generating means.

10. A method according to claim **7** wherein said heat transfer means comprise thermal resistor means the thermal resistance of which decreases as a function of the temperature.

11. A method according to claim **10** wherein said thermal resistor means comprise a block of alumina.

12. A method according to claim **10** wherein said thermal resistor means comprise a block of berylium oxide.

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