

[54] **METHOD FOR DIRECTIONAL
SOLIDIFICATION**

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Related U.S. Application Data

- [63] Continuation-in-part of Ser. No. 128,273, March 26,
1971, abandoned.
[52] U.S. Cl. **164/60, 164/129, 164/136,**
164/338, 164/350
[51] Int. Cl. **B22d 25/06**
[58] Field of Search 164/60, 122, 125, 129,
164/133, 136, 322, 350, 338; 13/22, 25, 31;
219/388, 390, 406, 407, 535; 249/110

[56] **References Cited**

UNITED STATES PATENTS

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|-----------|---------|-------------------|----------|
| 3,677,324 | 7/1972 | Higginbotham..... | 164/60 |
| 3,532,155 | 10/1970 | Kane et al..... | 164/60 |
| 2,049,950 | 8/1936 | Dixon et al..... | 13/22 X |
| 3,680,625 | 8/1972 | Hein et al..... | 164/60 X |

OTHER PUBLICATIONS

Process Speeds Up Directional Solidification, Erick-
son et al., Metals Progress, pp. 58-60, 3/1971.

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[57]

ABSTRACT

Method and apparatus for improving the production rate of directionally solidified castings employing an annular mold having one or more molding cavities therein and a pair of heat radiating elements disposed concentrically with the mold, one being located inside and the other being located outside the mold, the heat radiating elements being arranged so that no temperature gradient exists across the mold. A pair of heat sinks is provided, the heat sinks being coaxial with the two heat radiating elements. Means are provided for causing relative movement between the annular mold and the heat radiating elements and the coaxially aligned heat sinks. The annular mold is positioned on a highly heat conductive pedestal or chill. The mold is preheated by the heat radiating elements to a temperature above the solidification temperature of the metal to be cast. After casting, the solidification of the metal progresses upwardly from the chill and the relative movement between the annular mold and the heat radiator-heat sink combination causes the solidification interface to occur at or near the boundary between the heat radiators and the heat sinks. A baffle is advantageously positioned at this boundary to prevent heat being radiated from the heat radiators to the heat sinks. The solidified metal in passing through the heat sinks radiates heat uniformly to the heat sinks so as to prevent a lateral or radial thermal gradient across the mold during solidification of the metal therein.

4 Claims, 4 Drawing Figures

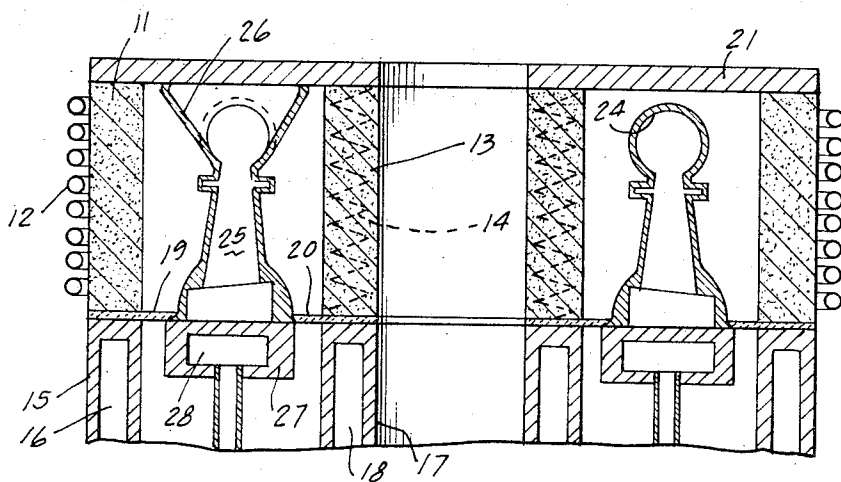


Fig. 1

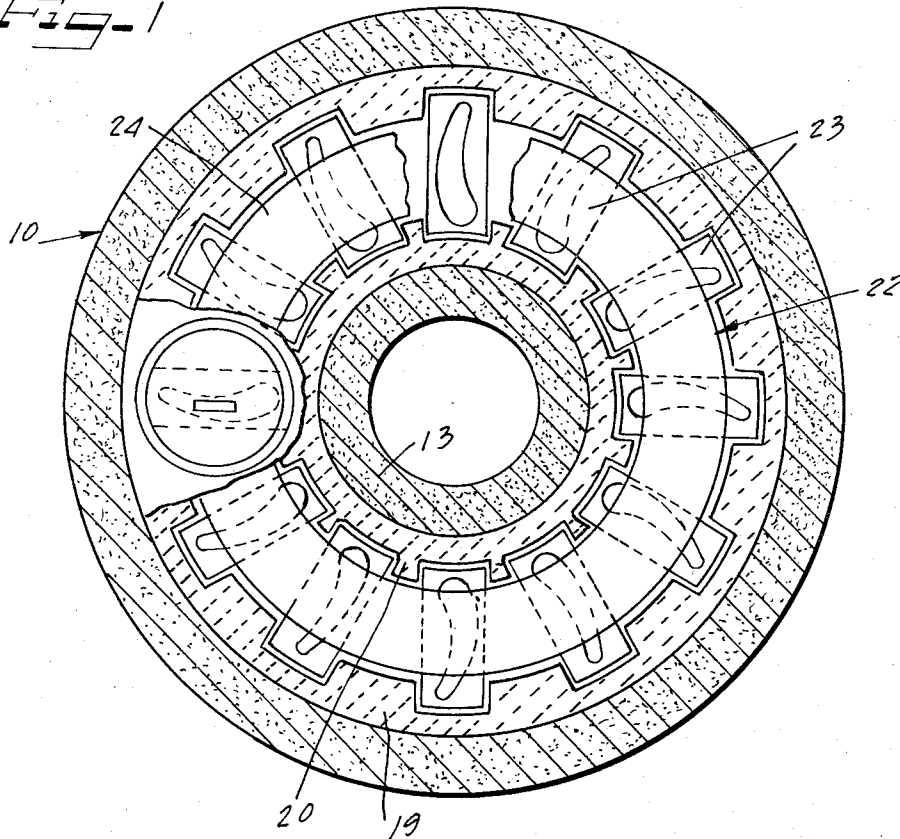
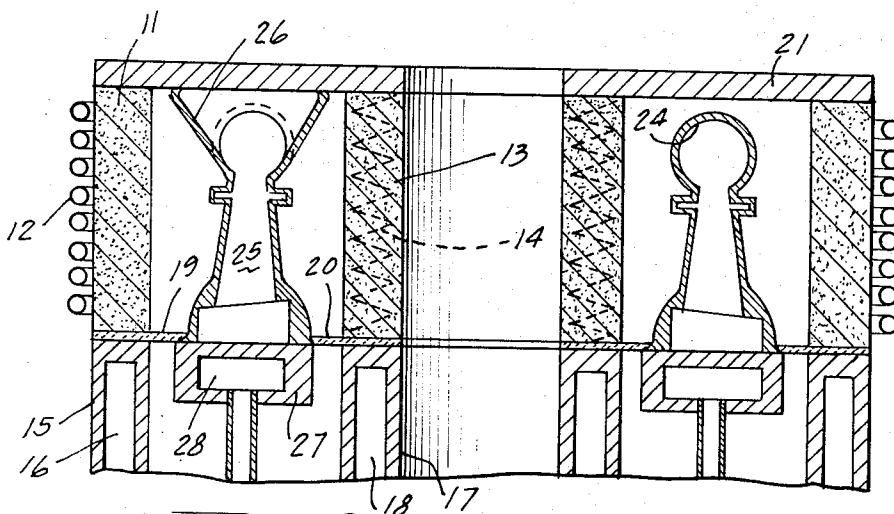


Fig. 2

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Fig. 3

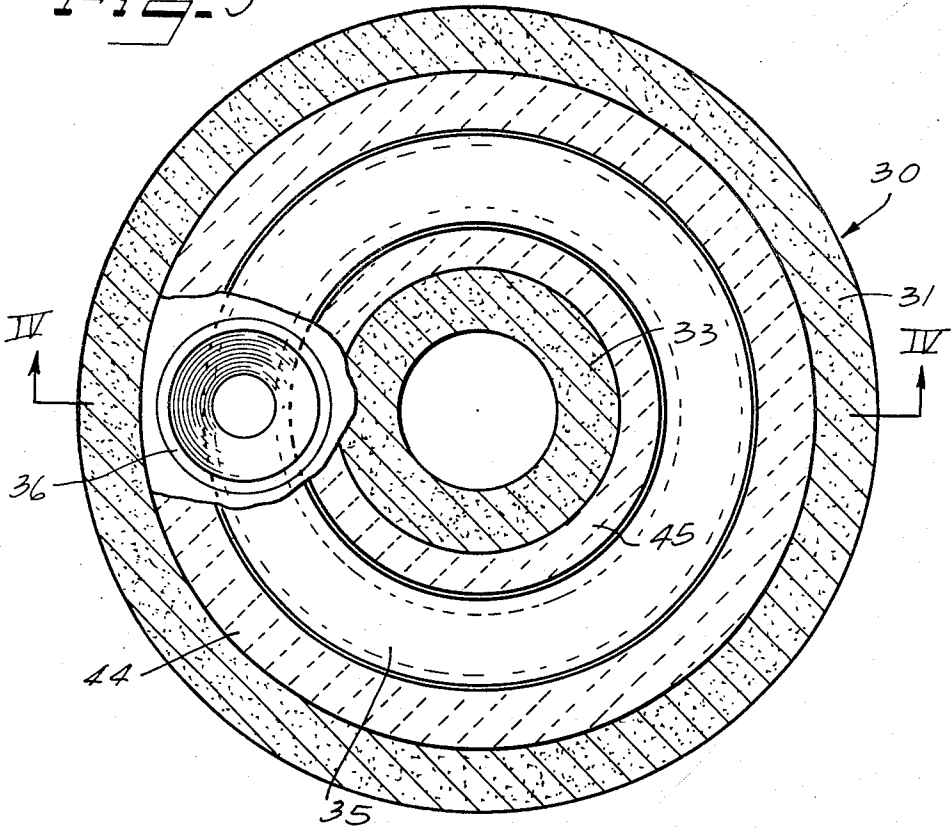
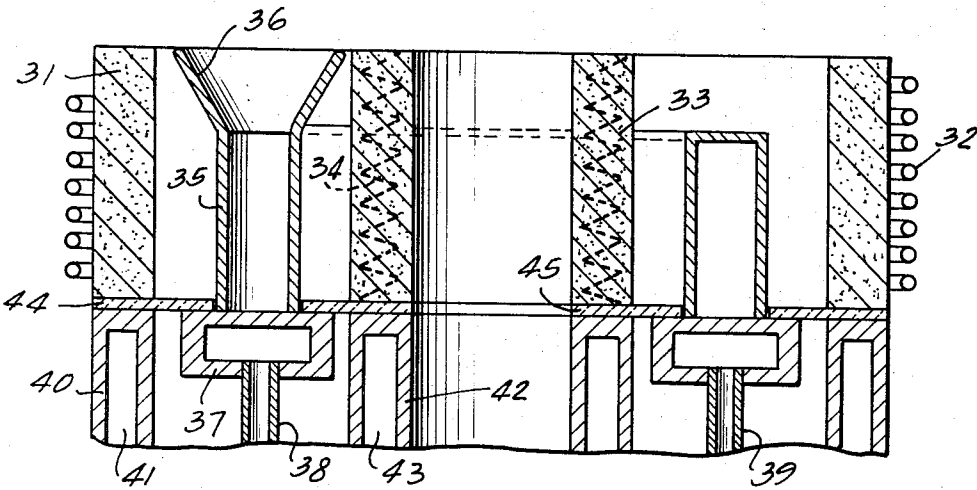


Fig. 4



METHOD FOR DIRECTIONAL SOLIDIFICATION

REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of my co-pending application Ser. No. 128,273 entitled "Method and Apparatus for Unidirectional Solidification of Castings," filed Mar. 26, 1971, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention is in the field of producing castings with columnar grain structures utilizing an annular mold which is moved relative to a pair of heat radiating sources, one inside and the other outside the mold, followed by relative movement between the mold and a pair of heat sinks, one inside and the other outside the mold to maintain a substantially uniform temperature across the mold and thereby minimize the formation of lateral or radial thermal gradients.

2. Description of the Prior Art

There has been a substantial amount of work devoted to the production of columnar structures and cast articles such as jet engine blades and vanes which are subject to extreme heat and thermal cycling. For this type of application, it has been found that the columnar structures are superior to equiaxed structures.

In order to produce a parallel dendritic structure, there must be a directional thermal gradient present in the mold, as this thermal gradient provides a driving force for dendrite growth into the liquid. This is usually accomplished by including a chill block at the base of the mold, assuming that the direction of growth is to extend along the vertical dimension of the casting. When metal is poured into the mold there is copious nucleation of dendrites at the chill surface. However, only those whose preferred growth direction is parallel to the thermal gradient are encouraged to grow and form mature dendrites.

There have been a number of disclosures in the prior art relating to controlling cooling conditions in the mold during solidification of the metal so that a rapidly advancing metal-liquid interface is achieved in the mold under controlled conditions. In U.S. Pat. No. 3,376,915 issued to George D. Chandley and assigned to the same assignee as the present application, there are described several types of methods and apparatus for securing directional grain growth. In one embodiment described in that patent, growth is promoted by progressively reducing the power input to the heating source by turning off the sections of a split induction coil starting with that section nearest the chill block. As the power is cut off, the heat transfer to the mold of the corresponding section of the susceptor is cut off, and the temperature of the metal in the corresponding section of the mold falls below that required for solidification as the result of axial heat loss to the chill. Very little heat is lost radially out the sides of the mold to the susceptor and the rate of solidification is limited by the rate of axial heat flow through previously solidified metal to the chill. This tends to make the process relatively slow. In addition, turning off successive segments of the induction heating coil, results in a discontinuous advance of the liquid-solid interface in the mold, under non-uniform conditions. In some cases, this inherently limits the amount of control which can be exercised over the process and provides the possibility of cooling

a given segment of the casting too rapidly, giving rise to equiaxed grains.

There have been numerous disclosures in the prior art, also, of employing relative movement between the heating source and the metal being solidified to maintain proper temperature differentials. For example, the Snook U.S. Pat. No. 1,961,399 while directed to ingot casting rather than investment casting provides for relative movement between the furnace and the solidifying metal in order to obtain proper cooling conditions. More recently, Kane et al. in U.S. Pat. No. 3,532,155 have described a casting process wherein relative movement is provided between the combination of a radiant heat zone and a lower heat sink zone and a chill plate-mold assembly to accelerate heat loss by radiation from the solidified metal to increase the velocity of the advancing solidification front along the length of the mold.

An article by Erikson et al., appearing in "Metal Progress" for March, 1971 (pages 58 to 60) describes a high rate solidification process used at Pratt & Whitney Aircraft. In this process, a superheated alloy is poured into a mold, and an axial temperature gradient is established in the vicinity of the chill plate so that solidification is initiated from the chill surface. The chill and the attached mold are then lowered out of the susceptor at a predetermined rate, the withdrawal being continued until the casting is completely solidified.

Regardless of the technique employed, it is necessary that the production cycle time for directionally solidified castings be reduced to the point that they are comparable to production times of conventionally made castings. The large difference in production time for directionally solidified castings as compared with castings solidified by more conventional procedures accounts for the wide difference in cost, the directionally solidified hardware commanding a price of several times that of an ordinary casting produced with the same alloy.

Conventional casting is usually done into a cluster of molds produced by the well known precision investment mold-making process. In this type of process, disposable patterns are linked together into a cluster resembling a tree with runners for the molten metal defining the branches of the tree and the individual patterns are disposed at the ends of these runners. With this type of arrangement, particularly where there are a large number of casting cavities, heat cannot escape from each casting to the surrounding heat sink equally in all directions. This is due to the fact that the sides of the casting toward the center of the cluster do not have a direct "line of sight" toward the heat sink, but radiate heat only to other hot castings. The outer sides of the castings, however, located at the outside of the cluster are directly in the line of sight of the heat sink so that they can cool more rapidly than the inner surfaces of the castings which are obstructed from the heat sink. The result is that for any given time after pouring and the onset of relative movement between the combination of heat source and sink, and the casting, the sides of the casting toward the outside of the cluster will be colder than the sides of the casting toward the inside of the cluster and a thermal gradient will exist horizontally or radially across the casting, in addition to the desired vertical thermal gradient which exists in the casting from the chill plate. This horizontal gradient causes

grains to grow at other than right angles to the chill face, destroying the grain orientation that is essential to directional solidification.

SUMMARY OF THE INVENTION

The present invention involves positioning an open-ended annular mold in the space between an inner heat radiating source and an outer heat radiating source. The mold is preheated by means of the two heat sources to a temperature above the melting point of the metal to be cast therein. The open end of the mold is positioned on a chill plate. When molten metal is poured into the mold, heat is abstracted through the open end of the mold to the chill plate, thereby initiating directional solidification of the metal and providing a liquid-solid interface commencing at the open end of the mold and advancing upwardly therein. Relative movement is provided between the mold and the heat sources and the portion of the mold containing the solidified metal is advanced into an area of two heat sinks, one disposed internally and the other externally of the annular mold. Heat is radiated from the mold to this pair of heat sinks during such relative movement to thereby minimize the presence of lateral temperature gradients in the solidifying metal. The presence of an interior heat source and sink, as well as an exterior heat source and sink aids casting production first, by improving the rate at which mold preheating occurs, as the mold surfaces toward the center of the cluster are heated directly rather than by indirect reflection from the outer heat source, as presently occurs, and, second, the horizontal temperature gradient from the outside of the casting to the inside is eliminated, as thermal conditions are the same on the outside as on the inside.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages of the invention will be readily apparent from the following description of certain preferred embodiments thereof, taken in conjunction with the accompanying drawings, although variations and modifications may be effected without departing from the spirit and scope of the novel concepts of the disclosure, and in which:

FIG. 1 is a plan view of a mold assembly which can be used for the purposes of the present invention, with the cover removed, and with portions thereof broken away to better illustrate the structure;

FIG. 2 is a cross-sectional view taken substantially along the line II—II of FIG. 1;

FIG. 3 is a plan view of a mold assembly of modified form, with the cover removed, and portions thereof broken away to better illustrate the structure; and

FIG. 4 is a cross-sectional view taken substantially along the line IV—IV of FIG. 3.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIG. 1, reference numeral 10 indicates generally a casting assembly which can be used for the purposes of the present invention, the casting assembly 10 being positioned within a suitable furnace enclosure (not shown) to permit operation either under inert gas or under vacuum conditions. The mold assembly 10 includes an outer heat source consisting of a cylinder 11 composed of graphite or the like and heated to radiant temperatures by means of heating means such as an induction coil 12 disposed therearound. Concentric with

the outer heating cylinder 11 is an inner cylinder 13 also composed of graphite or the like. The cylinder 13 may be heated by induction heating as in the case of the outer cylinder 12, or it may be heated by a resistance element 14 embedded therein, as illustrated in FIG. 2.

The outer cylinder 12 rests on an outer heat sink 15 having an inner and outer diameter substantially the same as that of the outer heating cylinder 11, as illustrated in FIG. 2.

The outer heat sink 15 has a hollow interior illustrated at reference numeral 16 through which a suitable coolant such as water or air can be circulated.

The inner heat source consisting of the cylinder 13 is disposed on an inner heat sink 17 also composed of a hollow cylinder having a hollow inner space 18 through which a suitable coolant can be circulated. The inner and outer diameters of the cylinder 17 are made substantially the same as the respective dimensions of the inner heat radiating cylinder 13.

The heat radiating elements are separated from the heat sinks by means of thin baffle elements 19 and 20 composed of a heat insulating material to minimize the amount of direct heat transfer which occurs between the heat sources and the underlying sinks. An insulating cap 21 is also provided over the top of the molding assembly to prevent heat losses from the top of the molding assembly.

An annular cluster 22 of individual investment molds 23 is located between the inner heat source 13 and the outer heat source 11. A runner portion 24 directs molten metal between the individual casting cavities 25 of the molds 23. A pour cup 26 is provided for introducing molten metal into the cluster.

The individual molds 23 have open ends thereon which are positioned on a chill block 27 which has a hollow interior 28 through which a suitable coolant can be circulated. In the form of the invention shown in the drawings, the chill block 27 is positioned on a support cylinder 29 to provide for relative movement between the cluster and the combined heat sources-sinks which are positioned on opposite sides of the cluster 22. Alternatively, of course, the mold cluster can be held stationary and the heat source-heat sink combinations moved relative to it.

At the start of the operation, the heat sources 11 and 13 are energized so that the mold cluster is heated uniformly to a temperature in excess of the melting point of the metal to be poured. During preheating, the position of the cluster is as illustrated in FIG. 2, namely, with the bottoms of the casting cavities at substantially the same level as the radiation baffles. The cap is thereupon removed and molten metal is introduced into the pour cup 26. This is followed by relative movement between the heat sources 11 and 13 on the one hand and the cluster 22 to provide a liquid-solid interface which moves uniformly up the solidifying metal in each of the casting cavities 25. Once relative movement is started between the cluster 22 and the heating zones 11 and 13, progressively larger surface areas of the clusters will be exposed to the heat sinks 15 and 17 so that there will be radial or lateral heat transfer between the emerging portions of the mold cluster and those heat sinks. Since the heat sinks are at substantially the same temperature, however, there will not be any significant thermal gradient across the lateral dimension of the mold and therefore no tendency to grow grains at other

than right angles to the chill plate 27, which is in the desired direction of grain orientation.

A modified form of the invention is illustrated in FIG. 3 in which reference numeral 30 has been applied to a mold assembly for producing an annular shaped object, for example, resembling a diffusor case for a jet turbine engine. An outer heat radiating cylinder 31 composed of graphite or the like is inductively heated to radiation temperatures by means of an induction coil 32 (FIG. 4) disposed therearound. An inner heat radiating cylinder 33 is positioned concentrically with the outer heat radiating cylinder 31. The inner heat radiating cylinder 33 can be inductively heated or, as illustrated in FIG. 4, may include an electric resistance element 34 embedded therein. Disposed between the outer cylinder 31 and the inner cylinder 33 is an annular mold 35 comprising a single casting cavity and being provided with a pour cup 36 for introducing molten metal into the casting cavity. The mold 35 is open ended on the bottom and rests upon an annular chill plate 37 having a hollow interior. A coolant such as water or air is circulated into a hollow interior of the chill plate 37 through a supporting cylinder 38 and the coolant may be withdrawn from a supporting cylinder 39 which is diametrically opposed to the supporting cylinder 38. Additional support means may, of course, be provided for raising and lowering the annular chill plate 37 when required.

An outer heat sink consisting of a hollow cylinder 40 is positioned coaxially with the outer heat radiating cylinder 31, as best shown in FIG. 4. The heat sink 40 has a hollow interior 41 through which a coolant may be circulated. An inner heat sink 42 is provided coaxially with the inner heat radiating cylinder 33 and it also has a hollow interior 43 through which a coolant can be circulated. An annular baffle 44 composed of a refractory material is confined between the heat radiating cylinder 31 and the heat sink 40. A second baffle 45 is also confined between the inner heat radiating cylinder 33 and the inner heat sink 42. The spacing between the annular baffles 44 and 45 is just sufficient to permit clearance of the mold 35 as the mold is moved from the heating zone to the cooling zone.

The mold 35 is positioned within the space between the outer heat radiating cylinder 31 and the inner heat radiating cylinder 33, as shown in FIG. 4. Power is applied by means of the induction heating coil 32 to preheat the mold 35 to a temperature above the solidification point of the metal to be poured. Superheated molten metal is then introduced into the molding cavity in the mold 35 through the pour cup 36. Shortly after an equilibrium condition is set up, the molten metal begins to solidify at the chill plate 37 to provide a liquid-solid

interface in the vicinity of the chill plate. The mold 35 is then gradually moved downwardly by means of the support columns 38 and 39 to keep the solid-liquid interface substantially in the plane of the baffles 44 and 45. Continued downward movement of the mold 35 at a controlled rate thereby results in a completely solidified casting which has an axially oriented columnar grain structure.

With the molding assembly of the present invention, it is possible to speed up mold preheating and to secure uniform mold cooling since all of the surfaces of the mold are exposed to direct "line of sight" heating from a radiating heat source. Since the same conditions exist during cooling, no thermal gradients are established to across the horizontal or lateral direction in the mold, and all of the grain growth is upwardly from the chill block in the desired direction. When using multi-cavity annular molds, a significantly larger number of individual molds can be positioned in a cluster and still provide acceptable directionally solidified castings. This capability significantly improves the production rate for a given size furnace.

I claim as my invention:

1. The method of producing directionally solidified castings which comprises providing an open-ended annular mold, preheating said mold with heat sources located at both the interior and exterior thereof to a temperature above the melting point of the metal to be cast therein, the inner periphery of said annular mold being substantially shielded from direct heat radiation from the exterior heat source, pouring molten metal into said mold to form a continuous annulus of metal, abstracting heat through the open end of said mold to thereby initiate directional solidification of the metal and provide a liquid-solid interface commencing at said open end of said mold and advancing upwardly therein, providing relative movement between said mold and the heat sources, and radiating heat from said mold to a pair of heat sinks during such relative movement, one heat sink being positioned internally and the other externally of said mold to thereby minimize the presence of lateral temperature gradients in the solidifying metal.

2. The method of claim 1 in which said heat sources are stationary and said mold is moved relative thereto.

3. The method of claim 1 in which said mold is stationary and said heat sources are moved relative thereto.

4. The method of claim 1 in which said mold includes a plurality of interconnected individual molding cavities.

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