[54] METHOD AND APPARATUS FOR MELTING AND CASING METAL

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[56] References Cited

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ABSTRACT

A system for producing metal castings wherein molten metal is introduced into a preheated mold and then directionally solidified by withdrawing heat from the bottom of the mold. The system involves the location of a crucible containing solid metal on top of a mold and positioning the arrangement in a furnace. The heating mechanisms of the furnace are utilized for melting the metal and also for preheating the mold. By providing for discharge of the metal from the bottom of the crucible, the molten metal is maintained in the crucible until such time as casting is desired at which time the crucible is either tilted or lifted to permit the metal to flow through an opening in the bottom of the crucible and into the mold passages communicating with the top surface of the mold.

16 Claims, 3 Drawing Figures
METHOD AND APPARATUS FOR MELTING AND CASING METAL

This invention relates to improvements in metal casting techniques. In particular, the invention is directed to a method and apparatus for accomplishing melting and casting of metal with the metal being directionally solidified to produce castings having desired directional properties.

The production of directionally solidified castings is well-known. Thus, many techniques have been developed for controlling the grain structure and orientation of cast metal whereby the properties of a casting can be maintained at the most desirable levels in a direction which will undergo the greatest stress during use. In a typical application, directionally solidified casting techniques are employed in the production of jet engine blades and vanes from high temperature alloys. Directionally solidified or so-called columnar structures have been found to be superior for high temperature operation, particularly with respect to fracture resistance and ductility under creep loading conditions. High temperature nickel base and cobalt base alloys are typically cast in this manner in the production of jet engine blades and vanes.

The production of directionally solidified castings generally involves the pouring of molten metal into a mold which is supported on a chill plate or other heat conductive means. Heat is extracted unidirectionally from the mold whereby the crystal structure of the casting will be perpendicular to the mold support.

In practice, the molds may be preheated in a susceptor heating chamber. After pouring, the unidirectional withdrawal of heat is often controlled by controlling the application of heat to the mold in the heating chamber. For example, the mold may be gradually withdrawn from the heating chamber thereby gradually eliminating application of heat to the mold walls.

Vacuum or inert atmosphere casting equipment is usually employed, and to improve the efficiency of the operation, the melting of the metal is conducted in the same furnace. In order to provide space for melting, pouring and casting, a relatively large furnace, and accordingly, a relatively great investment is involved. The need for two power supplies for melting and casting is one item which leads to the high cost.

The prior art techniques typically involve induction melting operations which means that the metal is being continuously stirred. This makes it difficult to separate any dross formation from the metal prior to casting. In view of these and other considerations, it is clearly desirable to simplify casting operations of this type while also improving the quality of the cast products.

It is a general object of this invention to provide an improved process for the melting and casting of metals.

It is a more specific object of this invention to provide an improved process for the melting of metals such as nickel and cobalt base alloys designed for high temperature applications, the process also including the casting of the metals to achieve directional solidification thereof.

It is a still further object of this invention to provide an improved apparatus for achieving melting and casting as set forth in the foregoing objects.

These and other objects of this invention will appear hereinafter and for purposes of illustration, but not of limitation, specific embodiments of the invention are shown in the accompanying drawings in which:

FIG. 1 is a schematic illustration in vertical section of a furnace construction adapted for the practice of this invention;

FIG. 2 is a schematic vertical sectional view illustrating a mold and crucible arrangement associated with a furnace construction in accordance with the concepts of this invention; and,

FIG. 3 is a schematic vertical sectional view illustrating a mold and crucible construction in the pouring stage of an arrangement incorporating features of the invention.

The system of the invention generally relates to a method and apparatus designed for the melting of metal and the casting of the metal in a mold. The invention is particularly concerned with the melting and casting of alloys such as high temperature nickel and cobalt base alloys which are advantageously cast by means of directionally solidification techniques.

The apparatus of the invention involves means for supporting a mold, the supporting means preferably comprising a chill plate or the like for achieving the withdrawal of heat from the bottom of the mold. The mold defines an upper surface, and a passage leading to a mold cavity communicates with this upper surface whereby molten metal can be poured onto the upper surface and then passed into the mold cavity.

The procedure of the invention involves the location of a melting crucible directly on the top surface of the mold. This crucible defines a bottom wall which has at least one opening for communication with the interior of the crucible. By providing a flat upper surface for the mold and a flat bottom wall for the crucible, the engagement of the flat walls of the crucible and mold will have the effect of sealing this opening so that molten metal in the crucible will not normally flow through this opening.

A spherical or conical shaped insert or projection in the mold could also be utilized to stopper the metal until casting is desired. Other methods of stoppering the metal for bottom pour could also be incorporated as part of the invention.

The invention involves locating the mold and crucible combination in a furnace whereby metal contained in the crucible can be heated above its melting point. Once the metal is in a molten state, the sealing or stoppering engagement referred to may be broken by tilting the crucible. This allows the metal to flow out of the crucible onto the mold surface and then into the mold cavity. In accordance with accepted practice, the mold is preheated, and heat is withdrawn from the metal, at least in the initial stages of metal solidification, only from the bottom of the mold. The furnace heating means or other structure may be utilized for insuring the desired directional solidification. Discharge of the molten metal could also be accomplished by raising the crucible or withdrawing the mold away from the crucible.

The accompanying drawings provide an illustration of a system adapted for use in accordance with the concepts of the invention. FIG. 1 illustrates a housing arrangement including an upper housing 10 and a lower housing 12. The alloys which are most advantageously employed in the practice of the invention are melted and cast in a vacuum or in an inert atmosphere, and
conduits 14 are provided for achieving these conditions.

The upper housing 10 encloses an induction furnace 16 including induction coil 18. The coil is located in surrounding relationship with refractory wall 20, and a radiation liner 22 is provided. The furnace construction is thus of the susceptor type with the coil 18 generating heat in the liner 22, this heat in turn being radiated inwardly. A furnace cover 24 defines a hole 26 which permits visual access to the furnace interior through the viewing window 28 formed in the top wall of the upper housing 10. This arrangement may be utilized, for example, for taking temperature readings with an optical pyrometer. It will be appreciated that a resistance heated furnace or other means for generating heat may also be utilized.

A chill plate 30 is provided for supporting a mold 32 relative to the furnace. This chill plate is provided with water cooling coils 34 to enhance the withdrawal of heat during operation of the system. A shield 36 surrounded by water cooling coils 38 is adapted to be positioned around the mold 32 upon lowering of the mold again to provide a means for controlling the direction of heat withdrawal from the mold. The chill plate is supported on rod 40 which is received within cylinder 42, and this rod is thereby reciprocally driven for gradually raising and lowering the chill plate and associated mold.

A flapper valve 44 is provided to permit isolation of the melt chamber from the loading chamber to permit a vacuum or inert atmosphere around the furnace while molds are being transferred. This provides for better efficiency of operation by eliminating the necessity of cooling the furnace between cycles.

FIG. 2 illustrates a mold 32 supported on chill plate 30, this mold comprising a shell mold produced by building up layers of molding material around a disposable pattern. Mold cavities 46 are defined within the mold, and these cavities communicate with the top of the mold through passages 48. It will be noted that the cavities 46 extend directly to the upper surface 50 of the chill plate 30 whereby solidification of metal poured into the mold will be initiated at the bottom of the mold. In accordance with standard techniques, the continued withdrawal of heat in this direction will result in the formation of columnar grains in a direction perpendicular to the surface 50.

The upper portion of the mold 32 defines a flat centrally located surface 52 surrounded by upstanding walls 54. This combination comprises a bowl or dish-shaped area which is dimensioned to receive a melting crucible 56.

The crucible 56 defines a flat bottom wall 58 adapted to engage the surface 52 of the mold. An outlet opening 60 is defined by the bottom wall of the crucible whereby molten metal is adapted to be poured through the bottom of the crucible. The crucible receives a solid charge 62 of metal alloy to be cast whereby parts can be obtained in accordance with the configurations defined by the mold cavities 46.

In the arrangement shown in FIG. 2, the crucible 56 is initially located opposite the lower section of coils 18. With full power applied to the coils, the crucible is brought to a temperature sufficient to melt the metal. The platform 36 is then raised to bring the mold 32 into the heated zone whereby the mold can be brought to temperature. This additional heating period serves to raise or at least maintain the metal temperature while stabilizing the mold temperature in preparation for casting.

To provide an alternative operating technique, the furnace induction coils 18 are divided into an upper section 64 and a lower section 66. With the crucible 56 and mold 32 located as shown in FIG. 3, full power is applied to the upper section 64 for purposes of melting the metal 62 within the crucible 56. At or near the completion of the melting operation, power is applied to both sections 64 and 66. This arrangement permits preheating of the mold while maintaining the metal in the molten state.

As indicated, the engagement of the respective flat surfaces of the crucible and mold effectively prevents passage of molten metal through the opening 60 whereby the melting and preheating operations can be completed without passage of metal into the mold. This provides a simple and efficient technique but, as explained, other stoppering methods are available.

When the mold has been preheated to the proper level, a crucible tilting construction is brought into operation. The tilting construction consists of a pivotally mounted arm 68 which is attached to an operating rod 70, the latter being accessible on the exterior of the upper housing 10. By pulling on the rod 70, the end of the arm 68 will move into engagement with crucible 56 thereby tilting the crucible as illustrated in FIG. 3. When this tilting occurs, the molten metal will flow through the opening 60 and into the mold cavity 46. The dish-shaped arrangement provided by the upstanding walls 54 of the mold serves to avoid spilling of molten metal. A baffle 72 may be attached to the top of the mold, this baffle serving as a splash plate while also tending to insulate the interior of the furnace relative to the upper housing, particularly with the mold 32 in the lower position shown in FIG. 2. The baffle may be of flexible material to facilitate raising and lowering of the mold.

The structures illustrated are completely suitable for achieving directional solidification in accordance with accepted practice. The chill plate 30 provides for withdrawal of heat from the bottom of the mold, and the induction coils serve to maintain the mold in a heated state to inhibit withdrawal of heat laterally. As the initial solidification takes place, the plate 30 may be gradually lowered thereby gradually withdrawing the mold from the influence of the furnace coils. The withdrawal of heat may be further accelerated due to the influence of the water cooled shield 36 which is encountered as the mold is lowered.

In preparing molds for use in the practice of the invention, it is important to provide a very flat surface in the area 52, and this can be most readily accomplished by utilizing a metal disc in the wax pattern employed for producing the shell mold. Thus, the wax pattern is formed around the disc whereby the disc will be located in the area of the mold dish portions. The shell mold surface which forms over the metal disc has the desired flatness for mating with the flat bottom of the crucible.

In a typical operation involving the casting of vanes and blades from the nickel base alloy PWA-1422, an alloy manufactured by Pratt and Whitney, 20 pounds of metal charge were located in a crucible. The crucible was heated for approximately 45 minutes to achieve a temperature of 2900°F. and melting of the charge. A
2-zone 14-inch ID susceptor furnace having a 50 kw power supply was employed. With full power applied to the entire furnace coil, the metal temperature was raised and the mold brought to temperature. Upon tilting of the crucible, the metal entered the mold by passing through a three-fourth inch diameter hole formed in the bottom of the crucible and controlled solidification follows. The total time cycle for these operations is typically about three hours.

In the practice of the invention, a furnace chamber approximately one-third the volume conventionally required for a directional solidification casting furnace is required. This, of course, reduces initial cost of the furnace, high frequency power supplies therefor, pumps, controls, etc., and maintenance costs are also significantly reduced. It has been found that castings formed have been totally satisfactory from the standpoint of grain structure and physical properties.

The melting and casting procedures involved in the practice of the invention are advantageous since the static melting results in fewer reaction products while most non-metals formed have an opportunity of rising to the top of the melt. Since the techniques involve bottom pouring, fewer non-metals will be carried into the mold cavity. The procedures permit the utilization of a clean crucible with each melt which also minimizes contamination of the cast parts. The techniques are also quite adaptable to automation in view of the simplicity of the operation, and since the operation lends itself to cycle controls.

It will be understood that various changes and modifications may be made in the above described system which provide the characteristics of the invention without departing from the spirit thereof particularly as defined in the following claims.

That which is claimed is:

1. In an apparatus for producing castings wherein molten metal is introduced into a preheated mold and the metal is directionally solidified by withdrawing heat from the bottom of the mold, the improvement wherein said mold defines a flat upper surface, a crucible having a flat bottom wall supported on said surface with said metal being contained in said crucible for melting of the metal while the crucible is supported on said surface, an opening defined by the bottom wall of said crucible, the engagement of said flat upper surface and flat bottom wall normally preventing passage of metal through said opening, at least one passage defined by said mold and communicating with said surface of the mold for the passage of molten metal into the mold, and means for tipping said crucible whereby molten metal therein passes through said crucible opening into said top surface for passage into said mold.

2. An apparatus in accordance with claim 1 wherein said mold is provided with upstanding side walls in surrounding relationship relative to said flat surface for containing molten metal on said flat surface.

3. An apparatus in accordance with claim 1 including a furnace for receiving said mold and associated crucible, said furnace including heating means for melting metal in said crucible and for preheating said mold.

4. An apparatus in accordance with claim 3 wherein said heating means comprise first and second heating means with the first heating means operating to melt said metal and with the second heating means operating to preheat said mold.

5. An apparatus in accordance with claim 4 wherein said heating means comprise induction coils divided into an upper and lower section, said crucible being located within the confines of the upper coil section and means for operating the upper coil section independently of the lower coil section for melting the metal in said crucible, and means for thereafter operating the lower coil section for preheating the mold while maintaining the metal in said crucible in a molten state.

6. An apparatus in accordance with claim 3 including a support for said mold, means for raising and lowering said support, means for positioning said support in a lower position for locating said crucible in said furnace for melting of the metal within the crucible, and means for thereafter operating said support to raise the mold and crucible into the furnace for preheating of the mold while maintaining the metal in a molten state.

7. An apparatus in accordance with claim 3 wherein said means for tilting said crucible comprise a rod extending through the wall of said furnace for engagement with the crucible.

8. An apparatus in accordance with claim 7 including a housing surrounding said furnace, and a rod extension extending outwardly from the housing for operating said rod.

9. An apparatus in accordance with claim 8 including means for creating a vacuum within said housing whereby said metal is melted and cast under vacuum conditions.

10. An apparatus in accordance with claim 3 wherein said furnace comprises a susceptor-type furnace, said heating means including induction coils, and said furnace including an inner liner in which heat is generated by said induction coils, the melting and preheating occurring by radiation from said liner.

11. In a method for the production of castings wherein molten metal is introduced into a preheated mold and the metal is thereafter directionally solidified by withdrawing heat from the bottom of the mold, the improvement comprising the steps of locating the metal in a crucible, positioning the crucible on top of said mold, providing a passage at the bottom of said crucible for providing communication between the crucible and mold, normally sealing said passage, locating the crucible and mold in a furnace, heating the crucible to melt the metal therein while the crucible remains positioned on said mold, heating the mold to preheat the mold, tipping said crucible after the melting of the metal to break the sealing of said passage for thereby delivering metal from said crucible into said mold, and directionally solidifying the metal within said mold.

12. In a method for the production of castings wherein molten metal is introduced into a preheated mold and the metal is thereafter directionally solidified by withdrawing heat from the bottom of the mold, the improvement comprising the steps of locating the metal in a crucible, positioning the crucible on top of said mold, said crucible defining a flat bottom wall and said mold defining a flat top surface, said crucible being supported by the mold by disposing said bottom wall on said top surface, locating the crucible and mold in a furnace, heating the crucible to melt the metal therein, heating the mold to preheat the mold, said crucible defining an opening in said bottom wall for the discharge of molten metal therethrough and said mold defining a passage communicating with said top surface for the movement of molten metal into said mold, the engage-
ment of said bottom wall with said top surface normally preventing passage of molten metal through said opening in said bottom wall, and including the step of tilting said crucible upon completion of the melting for delivering metal from said crucible into said mold, and directionally solidifying the metal within said mold.

13. A method in accordance with claim 12 including heating means associated with said furnace, operating the heating means for melting the metal in said crucible, and thereafter operating the heating means for pre-heating said mold while maintaining said metal in a molten state.

14. A method in accordance with claim 13 including the step of locating said mold and crucible on a movable platform, positioning the crucible within said furnace by means of said platform for melting of metal within the crucible, and thereafter raising said platform to position beyond the mold and crucible within the furnace.

15. A method in accordance with claim 13 wherein said heating means comprise independently operable first and second sections, operating the first section for melting metal within the crucible, and thereafter operating the second section and preheating said mold.

16. A method in accordance with claim 11 wherein said furnace comprises a suscepto- furnace, said melting and preheating being accomplished by radiating heat to said crucible and mold.

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