June 2 1970 C. M. WICKSTRAND, JR 3,515,205

MOLD CONSTRUCTION FORMING SINGLE CRYSTAL PIECES

Filed March 20, 1968

FIG. 1

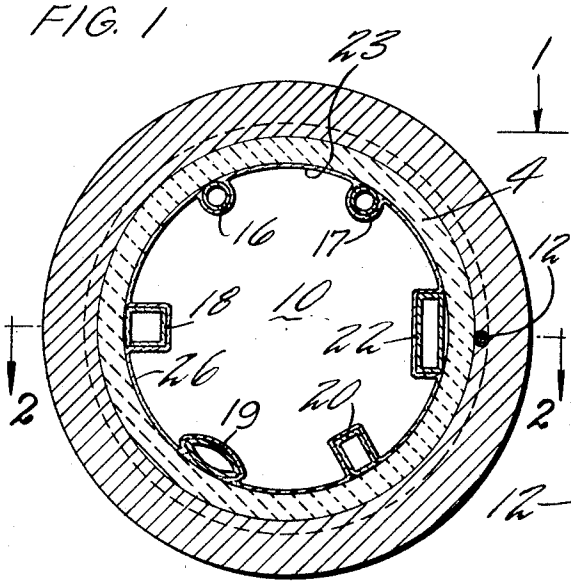


FIG. 2

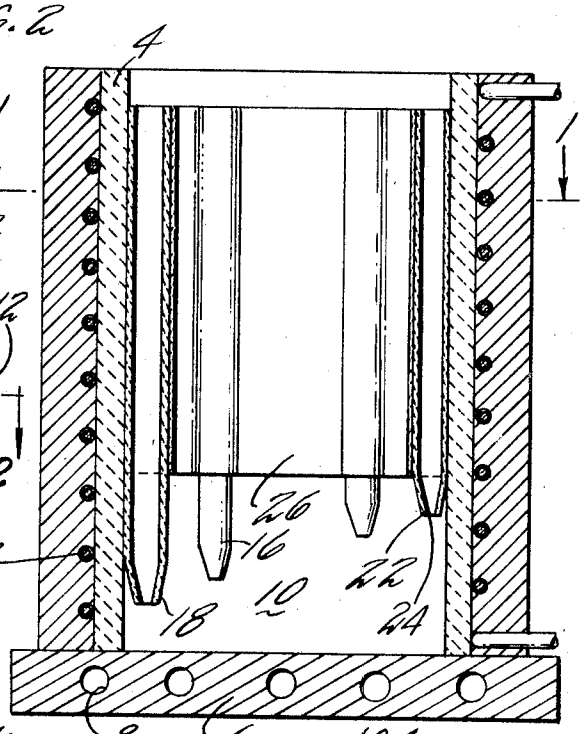


FIG. 3

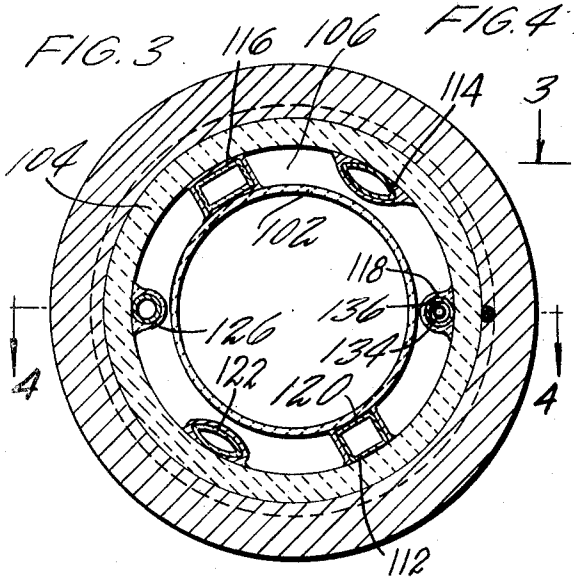


FIG. 4

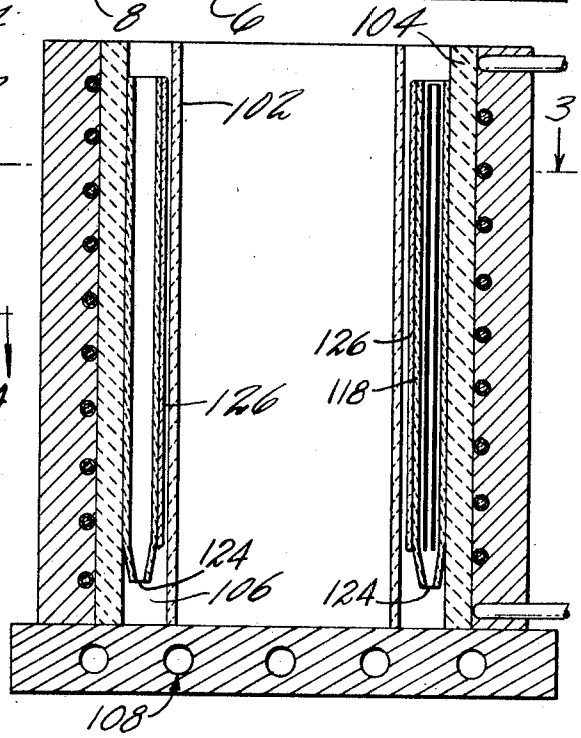
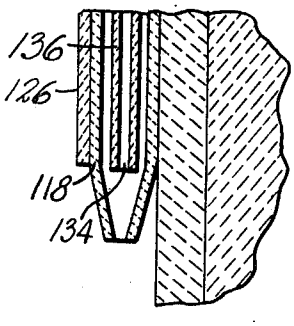


FIG. 5



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3,515,205

MOLD CONSTRUCTION FORMING SINGLE CRYSTAL PIECES

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Int. Cl. B22c 9/02; B22d 25/06
U.S. Cl. 164—353 7 Claims

ABSTRACT OF THE DISCLOSURE

A mold construction for use in the formation of single crystal pieces of relatively long lengths or of complex shapes and wherein the mold geometry provides a means for increasing the rate of solidification within a plurality of individual molds by providing an efficient method of heat extraction from the mold.

BACKGROUND OF THE INVENTION

This invention relates to a mold construction for the formation of single crystal pieces or stock.

In casting single crystal stock it becomes extremely desirable if the single crystal stock or pieces can be cast in relatively large or wide pieces. A problem heretofore which prevents producing relatively large or wide single crystal stock is that the geometry of conventional molds, for producing single crystal stock has caused the heat extraction rate from the mold to be less than desirable. The problem with current single crystal molds is that these molds in promoting single crystal growth use a double bend, or pigtail shape restriction at the lower end of the mold As a result of this restriction, heat from the mold does not have a ready path to the chill plate. Consequently, the heat extraction rate is lower than required for the production of large or wide single crystal stock. It therefore becomes clear that to produce relatively large or wide single crystal stock it is necessary to provide a mold construction, the geometry of which will provide a more efficient heat extraction rate than current molds while simultaneously promoting the fastest growth rate consistent with single crystal growth.

Additionally, as a result of the geometry of current molds, the lower portions of the molds are susceptible to damage or contamination by explosions that occur when the molten metal first contacts the contaminated surface of the water cooled chill plate. The present invention avoids this problem and further provides a mold construction the geometry of which facilitates removal of the single crystal molds.

SUMMARY OF THE INVENTION

It is a primary object of this invention to provide a novel mold construction wherein the rate of solidification within a plurality of individual molds is increased by virtue of a more efficient means of heat extraction therefrom. Additionally, this rate is compatible with a rate which promotes the fastest growth consistent with single crystal growth.

To accomplish the foregoing, the present invention uses the well-known process of unidirectional solidification in conjunction with a novel mold geometry. In this construction, a ceramic tube is placed on a chill plate and around the inner periphery or in an annular chamber formed by two ceramic tubes is placed a plurality of individual molds. The individual molds may be of either a complex shape such as a vane or blade or of a single shape such as a wire, bar or rod. Each of these individual molds contains a small opening, normally positioned at the bottom of each mold. The bottoms of these molds

are positioned above the chill plate, a preferred distance being one-half inch. When the directional solidification process begins, and the liquid-metal interface moves away from the chill plate, it has a particular columnar oriented structure. Therefore, when the liquid metal interface reaches the small openings of the individual molds, single crystal growth will be promoted therein, the axis of orientation of the single crystal growth being a function of the axis of orientation of the directionally solidified metal, the orientation of the opening with each mold and/or the orientation of the mold itself.

By employing the type of mold geometry herein described, it becomes obvious that the only restriction to heat transfer from the molten metal exists in the individual molds. More specifically, the small opening in each mold is a restriction to heat transfer from the metal in the mold to the chill plate. It is pointed out that the restriction as described herein is a significant improvement over current mold designs that use a double or pigtail opening in the mold and this alone would provide a more efficient or increased extraction of heat from the mold. However, the mold geometry of the present invention provides a further increase in the extraction of heat from the individual molds. Since the aforementioned opening is a restriction to the transfer of heat from the mold to the chill plate, the liquid metal interface within the individual molds moves at a slower rate than the liquid metal interface within the ceramic tube. Significantly, the volume within this tube and hence the mass of the molten metal therewithin is substantially greater than the mass within the individual molds. Since the liquid metal interface of this mass moves more quickly than that within the individual molds. it is consequently at a lower temperature. Therefore, heat from the individual molds is transferred to the mass within the tube. Since this mass is substantial with respect to the mass within the individual molds, a more efficient rate of heat extraction is possible. In summary, it is pointed out that the mold geometry of the present invention provides a more efficient means for extracting heat from a single crystal mold by providing a minimum of restriction to heat transfer from the mold to the chill plate and by providing an additional heat path for the transfer of heat from the individual mold to the substantial mass surrounding the individual molds.

Additionally, the mold geometry herein described permits easy removal of the individual molds while preserving the ceramic tube. This removability feature is enhanced by placing a layer of ceramic around each of the individual molds.

Further, it should be understood that the individual molds of the present invention can be arranged in any configuration within and around the tube. Similarly, the individual molds can be of any shape desired, such as a simple shape, a complex shape, or a combination of both.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic top sectional view of the mold and mold geometry of the present invention.

FIG. 2 is a vertical section of a mold in accordance with the present invention.

FIG. 3 is a schematic top sectional view showing a modified embodiment of a mold geometry in accordance with the present invention.

FIG. 4 is a vertical section of the modified mold in accordance with the present invention.

FIG. 5 is an enlarged view of the circled area of FIG. 4.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now in detail to the present preferred embodiments of the present invention, a novel form of mold

geometry is shown in FIGS. 1 and 2. The mold construction described herein is particularly suited for use with any of the so-called super alloys as described for example in the Ver Snyder Pat. U.S. No. 3,260,505, and having the same assignee as this application. As therein noted, these alloys are generally adapted for the process known as directional solidification. The mold construction herein described, in addition to the disclosure contained in the Ver Snyder patent, employs the technique of forming Monocrystaloys$_{TM}$— as described in an application to Piearcey, U.S. Ser. No. 540,114 filed Feb. 17, 1966, and assigned to the same assignee as this application.

As herein illustrated, one end of tubular mold **4**, compatible for use with the procedure described in the Ver Snyder patent, is placed on a relatively cool, heat conductive and preferably water cooled plate **6**. Tubular mold is preferably made from a ceramic material from a conventional slurry of alumina or other high melting point refractory material in accordance with standard shell-molding techniques; and, water for the chill plate **6** is carried through conduits **8**. As illustrated, one end of tube **4** rests on chill plate **6** and cooperates to form an enclosed cavity **10**. The end of tube **4** opposite chill plate **6** is open to receive molten metal.

Surrounding cavity **10** are the means for heating the mold to the desired temperature for casting. Preferably, the cavity is surrounded by a graphite susceptor, not shown, and this in turn is surrounded by an induction coil **12** supplied with high frequency electric current as is usual in a high frequency induction furnace. Prior to casting, the mold is heated to a desired temperature by supplying current to coil **12** and when the desired temperature has been attained, molten metal, heated to the proper temperature for casting, is poured into cavity **10**. The chill plate **6** is maintained at a relatively cool temperature by means of water circulating through conduits **8** so as to establish a temperature gradient within the molten metal filling cavity **10** as the metal solidifies.

In the present embodiment, a plurality of individual molds **16, 17, 18, 19, 20, 22** are positioned around the inner periphery or surface **23** of tube **4**. Each of these molds has a small opening **24**, herein illustrated to be at the bottom of each mold, and is spaced above chill plate **6**. Now as the metal begins to solidify it has a controlled columnar structure and by providing a small opening such as **24** in each of the individual molds **16, 17, 18, 19, 20** and **22**, growth of a single crystal is promoted therein. Therefore, what is produced is in effect a large mass of controlled columnar structure surrounding relatively smaller masses of single crystal. A significant feature about the construction of the individual molds is that the small opening **24** in each of the molds is the only restriction to heat transfer from each of the molds to chill plate **6**. As a result of this, this type mold geometry would permit the heat within the mold to be extracted at a faster rate than the current mold constructions which use a double restriction or pigtail shape as illustrated in the Piearcey application Ser. No. 540,114 filed Feb. 17, 1966.

As hereinbefore noted, the volume of tube **4** is substantially greater than the volume within each of molds **16, 17, 18, 19, 20,** and **22**. Therefore, a relatively greater mass surrounds molds **16, 17, 18, 19, 20** and **22** than is interior thereof. Now as the directional solidification proceeds, the liquid-to-solid interface moves away from chill plate **6**. As a result of the restriction to heat transfer from the individual molds **16, 17, 18, 19, 20** and **22** to chill plate **6** caused by opening **24**, the liquid solid interface interior of molds **16, 17, 18, 19, 20** and **22** is slower moving than that of the mass surrounding the molds. In other words, any distance from the chill plate, the solidification of the substantial mass within the tube will be higher than the solidification within molds **16, 17, 18, 19, 20** and **22**. This also means that the mass surrounding the molds is at a lower temperature, and heat will be extracted laterally from molds **16, 17, 18, 19, 20** and **22**. By removing heat from molds **16, 17, 18, 19, 20** and **22** at this increased or more efficient rate faster single crystal growth is promoted within the molds and relatively larger and more complex shapes can be produced.

To assist in removing individual molds **16, 17, 18, 20** and **22**, each of the molds is surrounded by a layer of ceramic material **26**. It should be understood that layer **26** performs other functions, such as assisting heat extraction from the mold.

The mold construction illustrated in FIGS. 3 and 4, and 5 is another embodiment of the present invention and it has as an advantage the fact that it does not waste a significant amount of molten metal. As shown therein, the mold consists of an inner tube **102** and an outer tube **104** forming an annular chamber **106** therebetween. The tubes **102** and **104** are of the same construction as tube **4** of FIG. 1 and are similarly placed on chill plate **108**. The individual molds **112, 114, 118, 120** and **122** in this embodiment are placed in annular chamber **106** and molten metal is poured only in annular chamber **106**. The single crystal pieces are formed in individual molds **112, 114, 116, 118, 120** and **122** in the same manner as FIGS. 1 and 2, the single crystal entering the molds through opening **124**.

It is pointed out that this type configuration can be employed in the individual molds. More specifically, once the single crystal growth is promoted within the mold, the metal can be caused to grow through a central core **134** and around core **134** to the desired shape **136**. This type individual mold configuration further increases the rate of heat extraction. Also as in FIGS. 1 and 2, the individual molds are surrounded by a layer of ceramic material **126**.

In each of FIGS. 1, 2 and 3 the individual molds are shown positioned above the chill plate. This is of importance in that it has been found that during the directional solidification process, the solidified metal adjacent the chill plate has a random crystal orientation. Accordingly, to get a single crystal with a preferred orientation, the individual molds should be positioned above the chill plate a distance sufficient to avoid this growth zone. It is clear that individual molds may be positioned at the same height above the chill plate or they may be placed in a stepped arrangement thereabove. However, it has been found that an optimum spacing from the chill plate to the lowest individual mold should be about one-half inch.

It is to be understood that the invention is not limited to the embodiments herein illustrated and described but may be used in other ways without departure from its spirit as defined by the following claims.

What is claimed is:

1. A mold construction for producing single crystal pieces comprising:

a ceramic tube having an open end;

a chill plate, said open end resting on the chill plate plate and the remainder of the tube being open to receive molten metal; and

a plurality of individual elongated molds arranged around the inner periphery of the tube and spaced from the end of the tube resting on the chill plate, each of said molds having bottom means forming a relatively small opening to permit the entrance of a single grain of the molten metal, said means being the only restriction in each of the molds to the transfer of heat from the molds to the chill plate and the volume within each of said molds being substantially less than the volume within the tube so that when molten metal is poured into the tube the mass therein is substantially greater than the mass interior of each mold.

2. A mold construction as in claim **1** wherein:

the opening in each mold is at least one-half inch from the end of the tube resting on the chill plate.

3. A construction as in claim 1 wherein:
the openings in the individual mold are spaced in six stepped relationship above the end of the tube resting on the chill plate, the least spacing being at least one-half inch.

4. A mold construction for producing single crystal pieces, comprising:
a first ceramic tube having an open end;
a second ceramic tube having an open end, the first and second tubes being positioned to form an annular chamber therebetween;
a chill plate, the open end of the first tube and the open end of the second tube resting thereon, the remainder of the first and second tubes being open to receive molten metal; and
a plurality of individual elongated molds positioned within said annular chamber and spaced from the end of the tubes resting on the chill plate, each of said molds having bottom means forming a relatively small opening to permit the entrance of a single grain of the molten metal, the means being the only restriction to the transfer of heat from each mold to the chill plate and the volume within the individual molds being substantially less than the volume within the annuar chamber so that when molten metal is poured into the annular chamber, the mass therein

is substantially greater than the mass interior of each mold.

5. A mold construction as in claim 4 wherein:
the molds have a central core into which molten metal enters so that the outer surface and the inner surface of the core is surrounded by molten metal.

6. A mold construction as in claim 4 wherein:
the opening in each mold is at least one-half inch above the end of the tubes resting on the chill plate.

7. A mold construction as in claim 4 wherein:
the individual molds are surrounded by a layer of ceramic material.

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ROBERT D. BALDWIN, Primary Examiner

U.S. Cl. X.R.

164—60, 361, 363