**United States Patent** [19] [11] **3,908,733**

**Brazer et al.** [45] **Sept. 30, 1975**

[54] **METHOD AND APPARATUS FOR CONTROL OF ALLOY IN COLUMNAR GRAIN CASTINGS**

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[21] Appl. No.: **410,146**

[52] **U.S. Cl.** .................................... **164/60;** 164/361
[51] **Int. Cl.**[2] .......................................... **B22D 25/02**
[58] **Field of Search** .............. 164/60, 122, 127, 361

[56] **References Cited**

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| 3,633,648 | 1/1972 | Barrow et al. | 164/60 |
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[57] **ABSTRACT**

A method and a mold for casting high temperature alloys having as an ingredient an element that reacts with the mold and core material and is thereby depleted during alloy solidification. A reservoir which is shaped to minimize depletion of the element is positioned above the article cavity in the mold to supply alloy to the top of the article cavity. As solidification proceeds, the molten alloy in the reservoir serves to enrich the solidifying alloy in the article forming portion of the mold with the depleted reactive ingredient.

**8 Claims, 5 Drawing Figures**

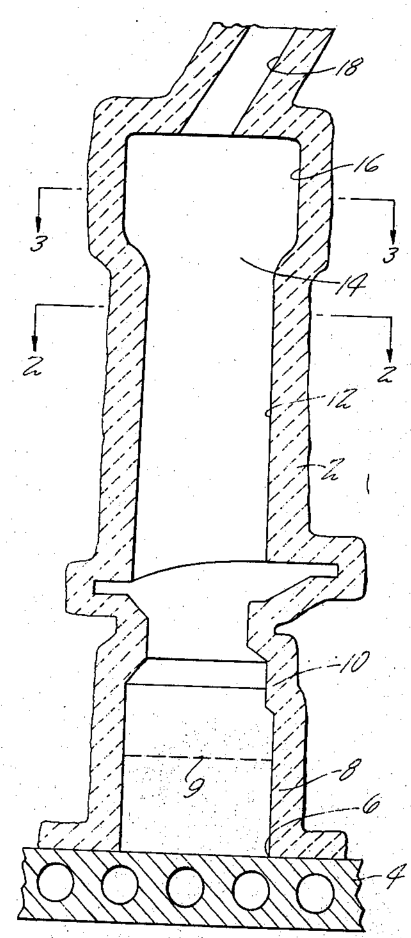


FIG. 1

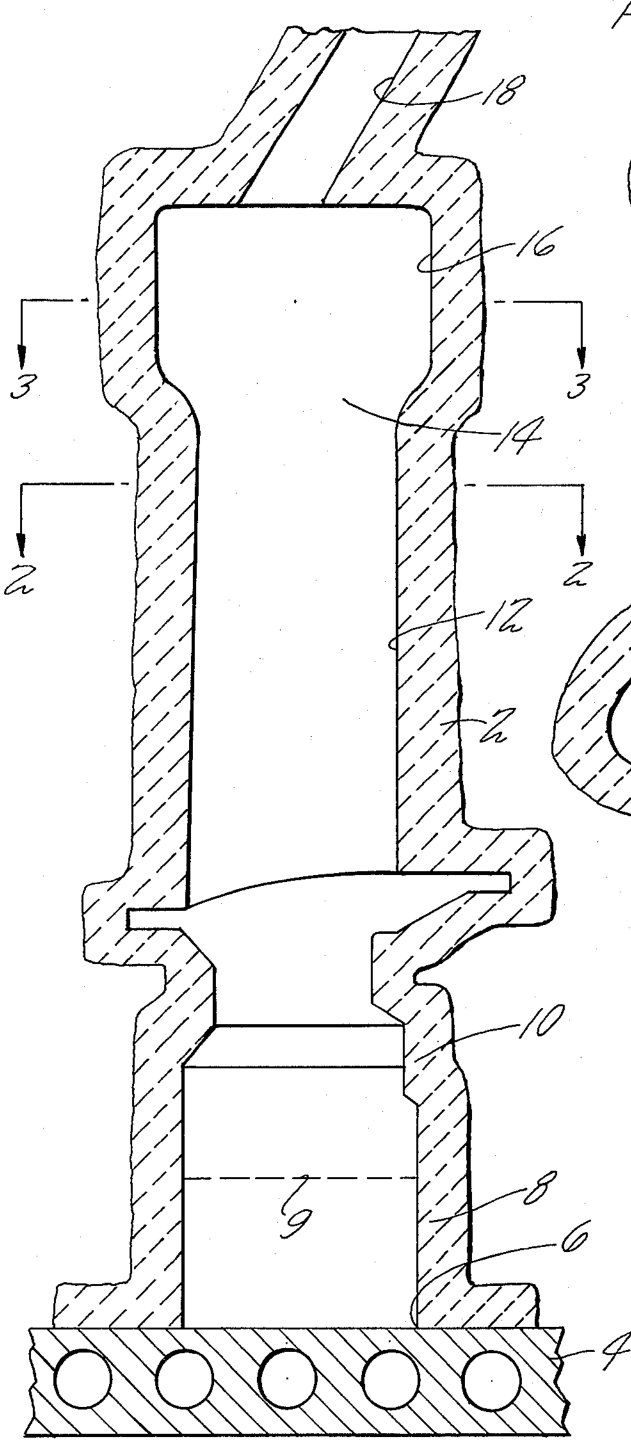



FIG. 2

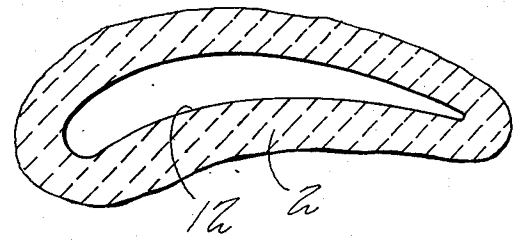



FIG. 3

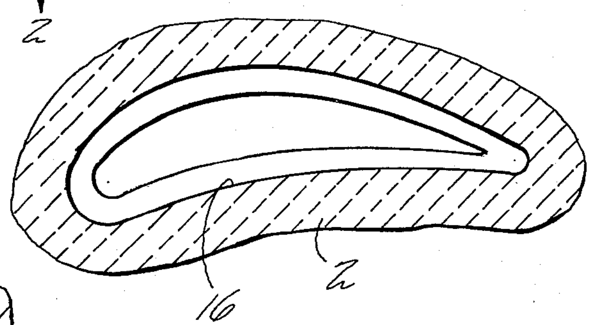


FIG. 4

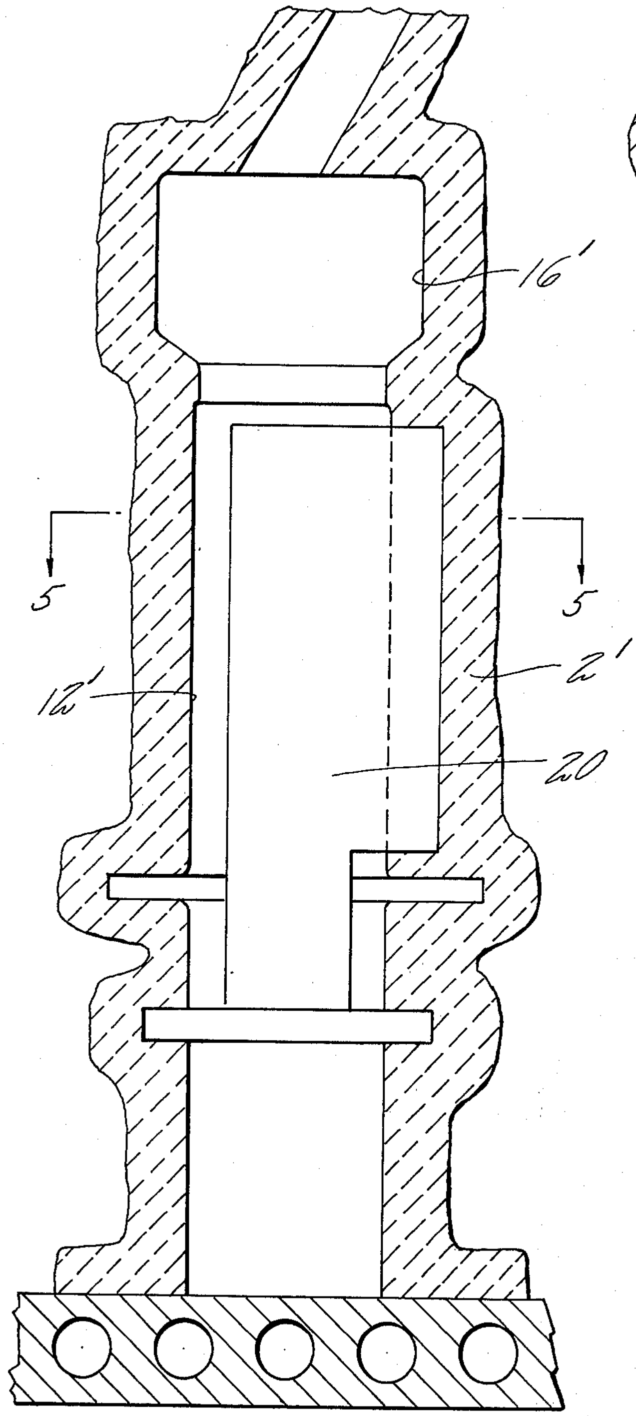
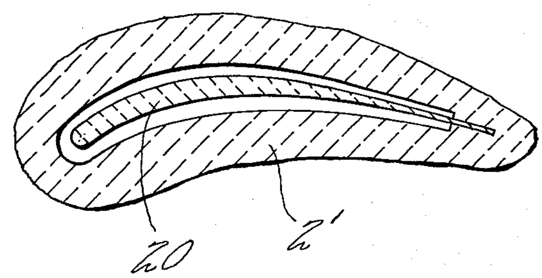



FIG. 5



# METHOD AND APPARATUS FOR CONTROL OF ALLOY IN COLUMNAR GRAIN CASTINGS

## BACKGROUND OF THE INVENTION

Directionally solidified nickel base superalloys are given significantly better mechanical properties especially in ductility by the addition of small portions of certain alloying elements such as hafnium. The importance of such an ingredient is described and claimed in the Sullivan et al. U.S. Pat. No. 3,711,337. It has been found that the addition of hafnium from 1.5 percent to 3.5 percent increases the transverse ductility significantly in turbine blades and vanes with resultant better performance and longer life in use in a gas turbine engine.

However, because hafnium reacts with oxides such as the silicon dioxide contained in the core and the mold materials, the molten alloy is depleted in hafnium during the solidification cycle. This is especially true in casting columnar grained articles as in the VerSnyder U.S. Pat. No. 3,260,505 or the particular type of columnar grain single crystal of the Piearcey U.S. Pat. No. 3,494,709 since such casting necessitates a controlled cooling of the alloy from the bottom to the top of the mold. In such casting procedures it is found that the lower portion of the cast article has the percentage of hafnium that is provided in the alloy as it is poured but that further up in the cast article the hafnium content is found to be lower. For example, in certain turbine blade designs it is desirable to maintain the hafnium content between 1.75 and 2.50 weight percent. However, by reason of depletion of hafnium by reaction during the solidification process, hafnium contents as low as 1.43 percent have been observed at the tip end of the airfoil with hafnium content at the base 2.50 percent. Such a low percentage of hafnium at the tip is undesirable.

## STATEMENT OF THE INVENTION

According to the present invention in casting columnar grained articles from a high temperature superalloy, a reservoir of molten alloy is located in the mold above the article cavity and this reservoir has a large volume to surface ratio so that the hafnium will be depleted to a lesser extent. The invention also includes the process of making castings of high temperature superalloys with an added ingredient such as hafnium which reacts with the mold and cores so that the ingredient is depleted during solidification, the process includes the supplying of the ingredient rich alloy from a reservoir located in the mold above the article cavity, the alloy in the reservoir remaining molten until all the alloy in the article cavity is solidified.

Other features and advantages will be apparent from the specification and claims and from the accompanying drawings which illustrate an embodiment of the invention.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a vertical sectional view through a mold embodying the invention.

FIG. 2 is a sectional view along the line 2—2 of FIG. 1.

FIG. 3 is a sectional view along the line 3—3 of FIG. 1.

FIG. 4 is a vertical sectional view of a modification for making hollow blades.

FIG. 5 is a sectional view along line 5—5 of FIG. 4.

## DETAILED DESCRIPTION OF THE INVENTION

Referring to FIG. 1 the mold 2 when ready for use is positioned on the chill plate 4 and has an open lower end 6 so that when molten alloy is poured into the mold, it will be in direct contact with the chill plate. The mold is used in making castings from a high temperature superalloy of the nickel base types described in the VerSnyder and Piearcey patents that have been enriched by an added ingredient that improved the mechanical properties of the cast alloy but which ingredient reacts with the mold or core so that the amount of ingredient is reduced during the solidification process. One such ingredient is the element hafnium and a nominal composition of one of the superalloys to which hafnium is added is as follows:

| | | | |
|---|---|---|---|
| Carbon | 0.14 | Tungsten | 12.5 |
| Chromium | 9.0 | Columbium | 1.0 |
| Cobalt | 10.0 | Boron | 0.015 |
| Aluminum | 5.0 | Zirconium | 0.05 |
| Titanium | 2.0 | Hafnium | 2.5 |
| | | Nickel Balance | |

The molds used in the casting process contain oxide materials such as silicon dioxide that react with the hafnium in the molten alloy. It has been found for example that if the casting is made even by the so-called high-rate solidification process as described in the copending application of Barrow et al. Ser. No. 327,917 filed Jan. 30, 1973 having a common assignee with this application, the percentage of hafnium in the molten alloy is depleted in a conventional mold during the solidification process. Although the percentage of hafnium at the base of the casting is the same as the percentage of hafnium in a molten alloy as poured, for example, 2.5 percent, the percentage of hafnium at the upper end of the cast article, the tip of the blade, may be as low as 1.40 percent and this is too low to produce the desired ductility in a cast article. The purpose for which the hafnium is added is to increase ductility as described in the Sullivan et al. U.S. Pat. No. 3,711,337 above mentioned.

As it is undesirable for the cast alloy to contain more than a predetermined percentage of hafnium, for example 2.5 percent as above described, the amount of hafnium in the master alloy as poured cannot be above this value. Thus, the net loss of the hafnium from the upper portion of the casting must be reduced.

To minimize the net loss of the hafnium during the casting process, the mold is constructed with a reservoir which is sized to reduce the amount of depletion. As shown in FIG. 1, the mold has a growth zone 8 at the bottom in which the crystalline growth is converted into columnar grains, this growth zone being removed after the casting is solid substantially along the dotted line 9 in the drawing. Above the growth zone in FIG. 1 is the root zone 10 of the cast article and above this is the shroud or platform cavity for the turbine blade being cast. Above the platform cavity is the cavity 12 for the airfoil or gas contacting portion of the blade, this portion being relatively thin as shown in FIG. 2 and airfoil shaped in cross section. Being thin with a high surface to volume ratio, a substantial surface area is exposed to the oxide surface area of the mold and permits reaction of the hafnium in the molten alloy with the material in the mold with resultant depletion of the hafnium. At the top of the airfoil forming cavity **12** is a riser portion **14** relatively short in height and then a reservoir **16** providing a significant volume for a supply of the molten alloy.

The reservoir **16** communicates through the riser **14** over the entire area of the tip of the blade or airfoil portion **12** of the article portion of the mold. Thus, the riser **14** is shown as increasing in area from the top of the blade portion **14** to the base of the reservoir and the latter is broader at all points than the thickness of the tip of the blade and is slightly larger than the chord of the blade portion and extends beyond both the leading and trailing edges of the blade cross section at the tip. This is emphasized by showing the tip opening of the blade in the showing of FIG. **3**, the section through the reservoir. This reservoir will supply molten alloy to the top portion of the article cavity as the alloy is depleted in hafnium during solidification thereby supplying an alloy with an adequate quantity of hafnium to the upper portion of the cast article.

This reservoir **16** is preferably somewhat similar in cross sectional shape to the cavity **12** but larger as shown in FIG. **3** preferably at least twice as large in horizontal cross section. This reservoir is of significant height, for example, from 1 to 1½ inches in height for a blade that may have an airfoil portion from 2 to 3 inches tall. The riser portion provides a location at which the blade when cast may be cut off from the cast alloy in the reservoir. Above the reservoir **16** is a gate **18** through which the mold cavity is filled the latter communicating with a filling sprue, not shown.

In use the mold is positioned on the chill plate and in the furnace having means for heating the mold to a temperature above the melting point of the alloy. After the mold is so heated, the alloy with about 300°F of superheat is poured into the mold to fill it at least to the top of the reservoir **16**. Solidification starts at the chill plate and continues upwardly with columnar grains or a single crystal columnar grain formed in the growth zone. By controlling the temperature gradient in the mold as described in the VerSnyder or the Piearcey patent, the columnar growth continues through the mold into the reservoir so that the entire blade structure is columnar grained or single crystal.

As the upward solidification proceeds, the hafnium in the molten alloy reacts with the mold and thus the hafnium content is depleted to a greater degree toward the top of the article cavity **12** thereby reducing the percentage of hafnium. However, because of the low surface to volume ratio of the reservoir the depletion is reduced in the alloy in the reservoir thus as the alloy solidifies within the blade cavity it is enriched from the still hafnium-rich alloy in the reservoir. As a result the percentage of hafnium in the airfoil portion of the blade is not reduced below the desired minimum and the ductility required in the blade particularly near the tip is obtained.

The transfer of the reactive ingredient in the alloy from the reservoir into the alloy in the blade portion of the cast article is caused by the convective currents above the liquid solid interface in the solidifying alloy and by diffusion of the hafnium downwardly in the molten alloy. Such convective currents and diffusion are enhanced by the arrangement of the reservoir to communicate with the entire area of the blade tip.

With this reservoir above described, it has been found that if the percentage of hafnium in the poured alloy is 2.50 percent, the hafnium is not so depleted in the alloy in the solidified blade as to reduce the hafnium below the desired 1.75 percent minimum even at the tip of the blade.

The invention is equally effective in making hollow blades as shown in the cross section in FIGS. **4** and **5**. In these figures the mold **2'** has a core portion **20** which is also high in oxides such as silicon dioxide which reacts with the hafnium in the molten alloy. Since this core does not extend upward into the reservoir **16'** at the top of the article cavity **12'** in the mold as shown in FIG. **4**, the same results are obtained in the finished article with the resultant satisfactory percentage of hafnium in the finished cast blade even at the top thereof. The term mold is intended to include the core as an essential part of the mold.

Although the description is directed to a mold for making a turbine blade and to the use of such a mold it is equally adapted to making other articles such as stationary turbine vanes and other geometries having high surface area to volume ratios. The significant feature is that the reservoir be of such a size that the hafnium therein is not depleted below the desired minimum during the solidification cycle. In this way there is an adequate supply of hafnium rich alloy to enrich the top of the article cavity during solidification.

Although the invention has been shown and described with respect to a preferred embodiment thereof, it should be understood by those skilled in the art that various changes and omissions in the form and detail thereof may be made therein without departing from the spirit and the scope of the invention.

Having thus described typical embodiments of our invention, that which we claim as new and desire to secure by Letters Patent of the United States is:

**1.** In the manufacture of columnar grained cast articles from a high temperature alloy having as an ingredient an element that reacts with the mold material the steps of:

- making a mold having an article cavity and a large secondary cavity directly above the article cavity and directly communicating therewith with the second cavity acting as a reservoir and having a large volume-to-surface ratio to minimize depletion of the ingredient by the reaction between the alloy in the reservoir and the mold material the connection from the article cavity to the secondary cavity increasing in dimension in all directions from the maximum area of the article cavity at the top to the larger in-area secondary cavity, the connection providing a gradual blending from the top of the article cavity to the secondary cavity;
- positioning the mold on a chill plate;
- filling the mold including both cavities with a molten high temperature alloy;
- solidifying the alloy from the chill plate upward to form one or more columnar grains therein; and
- causing a convective flow in the molten alloy such that the molten alloy in the secondary cavity replenishes the depleted ingredient in the alloy in the article cavity during solidification.

**2.** The process of claim **1** in which the ingredient is hafnium.

**3.** The process of claim **1** in which the temperature of the mold is reduced from bottom to top of the mold as the alloy solidifies to produce the columnar grained structure.

**4.** The process of claim **1** in which the cast article is a turbine blade so that the article cavity of the mold has an airfoil shaped portion and the secondary cavity communicates with the upper end of the airfoil portion and is also airfoil shape and larger in cross section than the upper end of the article cavity.

**5.** The mold for casting gas turbine blades from high temperature alloys having as an ingredient an element that reacts with the mold material and is thereby depleted during solidification, said mold including:

a base portion having a growth zone cavity therein;

a root cavity above and communicating with the growth zone cavity;

an airfoil shaped cavity above and communicating with the root cavity; and

a large reservoir cavity directly above and communicating directly with the airfoil shaped cavity, the communication gradually increasing in dimension in all lateral directions from bottom to top, said reservoir cavity being shaped to have a large volume-to-surface area ratio, and being large enough to prevent depletion of the reactive element therein below the required amount during solidification of the alloy, said reservoir cavity being greater in all lateral directions from the maximum area of the top of the airfoil cavity and the communication providing a gradual blending of dimension from the top of the airfoil cavity to the reservoir cavity.

**6.** A mold as in claim **5** in which the reservoir cavity is also an airfoil shape and larger in cross sectional area than the end of the blade cavity communicating therewith said secondary cavity extending laterally in all directions beyond the top of the airfoil shaped cavity.

**7.** A mold as in claim **5** in which the bottom of the mold is open to rest on a chill plate.

**8.** A mold as in claim **5** in which the reservoir is similar in cross section to and communicates with the entire cross section of the tip of the airfoil shaped cavity.

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