ABSTRACT: Unidirectionally solidified articles either columnar grained or single crystal are investment cast by enclosing the mold for the articles in a surrounding mold arranged to make a control casting of two separable parts located on opposite sides of the article cast in the article mold. This permits more precise control of the thermal gradient in the article mold during solidification of the cast material and provides removal of the cast article from the surrounding material.
3,627,015

COCOON CASTING OF DIRECTIONALLY SOLIDIFIED ARTICLES

BACKGROUND OF THE INVENTION

Unidirectionally solidified castings either columnar grained as in the VerSnyder patent, U. S. Pat. No. 3,260,505 or single crystal as in the Pearcey patent, U. S. Pat. No. 3,494,709 are routinely made by casting the alloy in a shell mold resting on a chill plate and with a precise control of the thermal gradient within the mold to maintain a controlled rate of the upward movement of the liquid-solid interface in the solidifying alloy. Surface defects frequently occur in the cast article by reason of the slow rate of heat conduction from the solidifying material into the chill plate. The rate of heat removal has been improved by surrounding the article mold with a secondary mold cavity for a control metal with both article mold and secondary cavity communicating with the chill plate, as in the Kear et al. application, U. S. Ser. No. 806,978 filed March 13, 1969, having the same assignee as this application. This leaves the cast article difficult to remove from the surrounding material.

SUMMARY OF THE INVENTION

One feature of this invention is the enclosure of the article mold by a surrounding cavity with both mold and cavity communicating with the chill plate and with the surrounding cavity made in a plurality of parts so that the article when cast is readily removable from the surrounding cast material by separate removal of the parts.

Another feature is the formation of a shell mold for the articles with a surrounding mold spaced from the article mold except at spaced vertical positions so that the surrounding cast sleeve will be in a plurality of longitudinally separate segments.

Another feature is a process for making a cast article that is readily separable from the surrounding control casting.

According to the invention, a shell mold for the article to be cast having a growth zone extension at the bottom for the start of the directional solidification is encased in an overlay of wax or other disposable pattern material, and this overlay in the region of the shell mold, is in at least two circumferentially separate longitudinally extending parts. A second mold is formed around this overlay with the second mold connected to the first mold at those portions where the parts of the overlay are separated. This outer mold has a depending skirt surrounding and spaced from the growth zone of the first mold and is open at the bottom to rest on the chill plate. When the pattern has been removed from the article mold and the overlay from the surrounding mold alloy is poured into the mold assembly filling both the cavity in the article mold and the surrounding cavity in the second mold. The heat of the alloy in the surrounding cavity assures that the temperature of the article mold is high enough to prevent nucleation on the surface of the article mold.

During solidification the alloy between the first and second molds, that is in the surrounding cavity, loses heat to the chill plate and raises the thermal gradient within the first mold. This body of surrounding metal also serves to cool the material within the first mold such that the liquid-solid interface in the first mold remains substantially flat during the solidification of the alloy within the first mold.

When the growth zone is removed from the rest of the cast article, the plurality of cast parts formed in the space between the first and second molds in surrounding relationship to the article within the first mold are readily removed for access to the cast article. The word "article" refers to the part of the casting that is intended for use and in many cases would be a machine part such as a blade or vane for a gas turbine. In this case, the article is cast from one of the well-known high-temperature super alloys of the type described by way of example in the VerSnyder U. S. Pat. No. 3,260,505.

3 BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a vertical sectional view through a mold adapted for forming a cast turbine blade.

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

FIG. 3 is a view of the mold of FIG. 1 with a surrounding overlay which forms the secondary cavity.

FIG. 4 is a horizontal sectional view along the line 4--4 of FIG. 3.

FIG. 5 is a horizontal sectional view along the line 5--5 of FIG. 3.

FIG. 6 is a vertical sectional view of the mold and pattern of FIG. 3 with a second mold formed thereon.

FIG. 7 is a horizontal sectional view substantially along the line 7--7 of FIG. 6.

FIG. 8 is a horizontal sectional view substantially along the line 8--8 of FIG. 6.

FIG. 9 is a horizontal sectional view substantially along the line 9--9 of FIG. 6.

FIG. 10 is a view similar to FIG. 6 with the patterns removed and with the mold resting on a chill plate.

FIG. 11 is a view similar to FIG. 10 showing a modification.

FIG. 12 is a view similar to FIG. 10 showing a further modification.

FIG. 13 is a sectional view of the cast article removed from the mold material, the section corresponding to the line 7--7 of FIG. 6.

FIG. 14 is a sectional view similar to FIG. 13 along a section corresponding to the line 8--8 of FIG. 6.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring first to FIG. 10 the completed mold assembly 2 after having been heated to remove the wax pattern and wax overlay and to solidify the mold material in readiness for pouring molten alloy into the cavities therein, is mounted on a chill plate 3 by which the solidification of the alloy may be initiated for columnar growth and by which the thermal gradient may be controlled in part. The usual practice is to position this mold assembly within a furnace by which to heat the mold for pouring and by which to maintain a heat input to selected portions of the mold during the solidification process. The control of the heat input and heat removal is described in Pearcey U. S. Pat. No. 3,494,709 and a later type of casting operation and heat control by which to obtain the desired directional solidification is described and claimed in the copending application of the Giamei et al., Ser. No. 63,142 filed Aug. 12, 1970, having the same assignee as this application.

Referring now to FIG. 1, the mold shown is in many respects similar to that shown in the Pearcey U. S. Pat. No. 3,494,709. The mold 4 is formed around a wax pattern 5 essentially of the article to be cast, the pattern having a top extension 6, a blade-forming portion 8 with a platform portion 10 at the bottom and, below the platform a root portion 12. The lower end of the effective portion of the blade root when the article is cast is represented by the dotted line 13. Below this line the root portion of the pattern converges to a helix 14 which has a vertical axis and connects to the bottom wall of the remainder of the pattern. The helix forms a similar shaped passageway in the mold which is utilized in selecting the single-crystal growth from the columnar growth occurring below the helix in the initial growth zone later described. This single crystal grows into and through the blade cavity as the alloy solidifies.

The blade-forming portion 8, platform-forming portion 10 and root portion 12 are represented as the pattern for a turbine blade configuration for use in a gas turbine engine and form the part of the completed casting that becomes the used finished cast article. The remainder of the casting after removal of the cast article or blade therefrom is scrap and may be reused.

The wax article pattern is coated with a ceramic shell 16 made in the conventional form and manner of shell molds to produce the mold configuration shown in FIG. 1. It will be un-
understood that where the article being cast is a turbine blade as shown the configuration of the portion 8 of the pattern is airfoil in section and the surrounding mold 4 is of a similar shape as shown in FIG. 2.

The pattern with its surrounding mold then has a secondary wax overlay or coating 18 positioned therearound from a point above the upper portion of the article-forming portion of the mold to a point below the bottom of the helix. This wax coating extends in substantially completely surrounding relationship to the article mold. The overlay terminates in a downward extension 19 which projects at least an inch below the tip of the helix to space the helix at least this distance from the chill plate when the completed mold assembly is positioned on the chill plate as shown in FIG. 9. The downward extension 19 is preferably formed by pouring wax into a mold 21 while the lower end of mold 4 is supported therein in the position of FIG. 3. This downward extension 19 may be formed before or subsequent to the formation of the remainder of the overlay. The wax used for the overlay generally has a lower melting temperature than the harder wax of the article pattern and a junction between the downward extension and the remainder of the overlay is readily accomplished. This wax overlay as above stated substantially completely surrounds the article mold and is made circumferentially discontinuous by a vertically extending groove 22 near the leading edge of the airfoil portion and another vertical groove 24 near the trailing edge of the airfoil portion so that the overlay, at least from the top thereof to a point somewhat below dotted line 13, is in at least two circumferentially discontinuous and longitudinally extending segments.

The vertical grooves 22 and 24 are extended downwardly around the platform area and meet with groove extensions 25 and 26, FIG. 5, at opposite corners of the root portion of the mold 4. These grooves desirely extend downwardly to a point below the bottom of the root of the finished article (the line 13) but need be continued no further than a line 27. The line represents the preferred location of a saw cut to be made in separating the parts of the casting as will be described later. A wax projection 45 is applied to the overlay near the top to form an opening 29 in the subsequently applied mold for the purpose of filling the mold. The surrounding overlay 18 with the downward extension having been applied to the mold 4 the assemblage is then provided with a surrounding outer shell mold 28, FIG. 6, by the usual shell mold technique. The outer shell mold extends all the way from the top of the primary mold to the bottom of the downward extension 19. In the formation of this outer mold, it will be apparent that the mold material fills in the grooves 22 and 24 and extensions 25 and 26 provided by the discontinuity of the overlay 18 so that the inner and outer molds are interconnected vertically at circumferentially spaced locations as best shown in FIG. 7. These interconnections 30 and 32 extend substantially vertically and are preferably located near the leading edge of the airfoil shape and near the trailing edge of the airfoil shape. Below the platform the interconnections 34 and 36 are at opposite corners of the blade root shape as in FIG. 8. These interconnections between the inner and outer molds continue downward around the platform portion of the inner pattern and to a point below the blade root portion as to the line 27. Below this line the interconnections cease to exist, since the grooves 25 and 26 terminated about at this line. Thus below this line the wax overlay is a continuous annulus as shown in FIG. 9 and the outer shell 28 is not interconnected with the inner shell 4 from this line down to the bottom of the helix. Above the airfoil portion of the mold the portions of both the inner and outer molds surrounding extension 6 are in direct contact as in FIG. 6.

The mold assembly have been completed as shown in FIG. 6, it is placed in a suitable oven for baking the ceramic material of the mold and for melting out the wax pattern and the wax of the overlay in readiness for the casting operation. It will be understood that the connections between the inner and outer molds help to make the entire mold assembly an integral structure such that the inner and outer molds are retained in proper relation to one another. The patterns having been completely removed from the mold and the latter having been baked to a condition ready for use as a mold, the mold assembly 2 is placed on the chill plate 3, FIG. 10 with the skirt portion 39 of the outer mold resting on the plate and supporting the open lower end of the helix above the plate at a distance from 1 to 1 1/4 inches.

The mold and chill plate are located within a device by which the mold can be heated to a temperature above the melting point of the alloy. This heating structure may be a surrounding susceptor and induction coil as described in the above-identified Piercey U. S. Pat. No. 3,494,709. The assembly is also preferably positioned in a vacuum chamber if the alloy being cast is best melted and poured in a vacuum. In any event, the mold is heated to the desired temperature and molten alloy is then poured into the opening 29 of the mold to fill the cavities left therein by the removal of the pattern and overlay. A filling spout 47 is attached to the opening 29 as shown. The central opening at the top of the mold assembly serves as a riser in this mold.

The poured alloy flows downwardly in the secondary cavity and upwardly through the helix passage to fill the main or article forming cavity. This is referred to as "bottom filling" the mold and molten alloy fills all the cavities to a level above the top of the blade cavity of the main mold. After all of the cavities are filled, directional solidification of the alloy begins upwardly from the chill plate into the surrounding control cavity and through the helix into the article cavity. The growth in the space below the helix is columnar grained as described in VerSnyder U. S. Pat. No. 3,260,505 and the columnar grains are vertical by the time grain growth reaches the bottom of the helical passage. The helix selects a single crystal to grow into the article cavity above the helix as described in the Copley application, Ser. No. 806,823 filed March 13, 1969, having the same assignee as this application.

The crystalline formation of the alloy in the second cavity is not critical, since the purpose of the alloy in this cavity is to heat the article mold initially and then to maintain the desired thermal gradient within the article-forming mold. The effect of the surrounding control cavity is to permit a greater conduction of heat into the chill plate since it provides a much greater area of contact with the chill plate than is provided by the small outer limbs of the helix.

The alloy within the entire mold having solidified, the mold may be removed from the chill plate and from the heating means surrounding the mold. When the cast alloy and surrounding mold are cool enough to handle, the outer mold is removed from the casting by making a saw cut through the casting slightly below the base of the root portion, that is to say, slightly below the dotted line 13, and preferably along the line 27 to which the parting lines for the surrounding cavities extend. This saw cut serves to remove the portion of the casting below the saw cut and separates from the base cast segments formed above this line between the inner and outer molds. Since these segments are now disconnected from one another, they can be separately separated from the inner mold and from the cast article within the inner mold thereby providing direct access to the portion of the cast article that is to be used.

The cast article which has filled all the wax cavities in the mold, consists when separated from the mold of the inner cast article 31, FIGS. 13 and 14, the shape of which was defined by the pattern 5, and the outer article consisting of the annular base portion 32, FIG. 14 and the opposed segments 34 extending upwardly therefrom and located on opposite sides of the inner cast article 31. The helix interconnects the inner cast article and the outer cast article as will be apparent but separation of the inner and outer cast articles is accomplished by cutting both articles along a line represented by the dotted line 27.
Although the helix is described as the grain selector by which to obtain single-crystal growth within the article mold other grain selectors may be used such as a constriction at the bottom of the article mold as in the copending application of Sink and Kear, Ser. No. 714,743, filed March 20, 1968 and having the same assignee as the present application. Alternatively, the grain selection may be accomplished by the form of device described in Piercey U. S. Pat. No. 3,494,709.

Instead of a bottom pour mold as in FIG. 10, the mold may be utilized as a top pour mold as in FIG. 11. If the mold is to be a top pour mold, the filling spout 37 of FIG. 10 is omitted and the top of the mold has affixed thereto a suitable pouring spout 36, FIG. 11, by which the melted alloy may be poured directly into the open top end of the article mold. In this event, the alloy flows down through the article mold and downwardly through the helical passage so that the surrounding cavities are filled by an upward flow of alloy. Routinely, the arrangement of FIG. 10 is more satisfactory since in the arrangement of FIG. 10 the alloy being poured flows over the outer surface of the article mold and assures a suitable and proper temperature for the mold before the alloy fills the mold.

The arrangement of FIG. 11 is however a slightly simplified mold structure which is found suitable under many casting conditions. As shown in FIG. 11, the mold assembly 2a is supported by the chill plate 3c and the helical grain selector 14a is positioned with its open end spaced between an inch and an inch and one-half from the surface of the chill plate, again to provide the desired growth zone between the chill plate and the open end of the helical passage. The inner mold 4a is filled first and molten alloy enters the space between inner mold 4a and outer mold 28a through the helix 14a.

Under certain conditions, it may be desirable to pour the article mold of one of the so-called high-temperature super alloys and to use a different less critical alloy within the surrounding cavity. Since the alloy in the surrounding cavity serves primarily as a heat control for the solidification of the alloy in the article mold it is apparent that it need not possess the same alloy. To permit the use of separate alloys, the mold may be made at the bottom end in the manner shown in FIG. 12 where the article mold and its extension at the bottom correspond in general to the article mold of Piercey U. S. Pat. No. 3,494,709.

Referring to FIG. 12, the bottom of the helix of the mold 4b has attached thereto a growth portion 42 the lower edge of which is in the same plane as the lower edge of the surrounding skirt 39b of the outer mold 28b so that the skirt and the lower edge of the growth portion 42 both rest on the chill plate 3b. The mold assembly is otherwise the same as in the preceding mold described in FIG. 10 in which there is the center top opening 44 by which the article mold may be filled with the appropriate super alloy and also the side opening 29b which permits the surrounding cavities to be filled with a suitable control alloy which need not be the same as the super alloy since the two alloys no longer mix at any point in the mold cavities. In producing the mold of this character, it will be understood that the growth zone 42 is produced during the formation of the article mold as described with respect to FIGS. 1 and 2 above and the remainder of the mold manufacture follows the procedure outlined above. When alloys are poured into the cavities in this mold the effect of the chill 36 is to establish columnar grains within the growth portion 42 of the mold and the helix passage 14b thereafter serves to select a single crystal from the columnar grains for growth into the article mold.

Although the invention has been described as being accomplished by the use of a wax pattern and wax overlay on the article mold, it will be understood that other suitable pattern and overlay material may be used instead of wax. Routinely, however, the material selected is a disposable material that will melt or otherwise remove itself from the mold when the latter are placed in a furnace for the purpose of baking the mold to the right hardness for pouring the alloy into the mold.

We claim:
1. A mold assembly for casting directionally solidified articles including an article-forming first mold portion having a cavity the shape of the article to be cast, a second mold portion surrounding said first mold portion in spaced relation thereto and defining between said mold portions a pair of cavities on opposite sides of and substantially surrounding the article-forming mold portion, said first and second mold portions being interconnected longitudinally of the article-forming portion by webs of mold material at two circumferentially spaced locations to define said pair of cavities and to retain first and second mold portions in fixed relationship.

said first mold portion having a crystalline growth portion at the bottom thereof with said second mold portion having a surrounding base portions, both growth portion and surrounding portion being open at the bottom.
2. A mold assembly as in claim 1 in which the open end of the crystalline growth portion is located inwardly of the mold with respect to the open end of said surrounding base portion.
3. A mold assembly as in claim 1 in which the surrounding base portion forms a continuous casting spaced around the crystalline growth portion.

4. A mold assembly as in claim 1 in which the growth portion and the surrounding portion are spaced from each other to form a continuous annular space surrounding the growth portion.

5. In the manufacture of directionally solidified articles the steps of forming a first mold having an article portion with a growth portion at one end thereof, said mold having a longitudinal axis, providing a second mold surrounding and spaced from said first mold, interconnected said molds by webs located at circumferentially spaced points and extending longitudinally of the molds and defining casting cavities on opposite sides of and substantially surrounding the article portion, said second mold also having a skirt portion extending around and spaced from the growth portion, and defining a base cavity extending continuously around the growth portion, said skirt portion having an open end to rest on a chill plate, positioning said molds on a chill plate and pouring a molten alloy into said molds, cooling the alloy to solidification and removing the alloy formed in the casting cavities from the article formed in the article portion.

6. The process of claim 5, in which the two molds are integrally connected by webs of mold material positioned between the ends of and defining the casting cavities.

7. The process of claim 5 in which the cavities extend longitudinally and are circumferentially separate with the two molds interconnected between said cavities.

8. The process of claim 5 in which the cavity surrounding the growth zone is circumferentially continuous and with additional steps of removing the alloy within the skirt portion and in the growth zone from the cast alloy in the article portion and the surrounding casting cavities for separation of the cast alloy in the cavities from the cast article.

9. The process of claim 5 with the additional steps of forming the first mold around a wax pattern, forming a wax overlay around the first mold with the overlay discontinuous at least at two circumferentially spaced points around the article portion and forming a second mold around the overlay.

* * * * *
CERTIFICATE OF CORRECTION

Patent No. 3,627,015 Dated December 14, 1971

Inventor(s) Anthony F. Giamei, et al.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Title page, Assignee - Delete "Hughes" and insert "United"

Signed and sealed this 17th day of October 1972.

(SEAL)
Attest:
EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCALK
Commissioner of Patents