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[54] **METHOD AND APPARATUS FOR PROVIDING SINGLE CRYSTAL CASTINGS USING A CONSUMABLE ELECTRODE**

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[21] Appl. No.: **176,215**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 803,539, March 3, 1969, abandoned.

[52] **U.S. Cl.** **164/52**, 164/60, 164/252

[51] **Int. Cl.** **B22d 27/02**, B22d 25/06

[58] **Field of Search** 164/52, 60, 252

[56] **References Cited**

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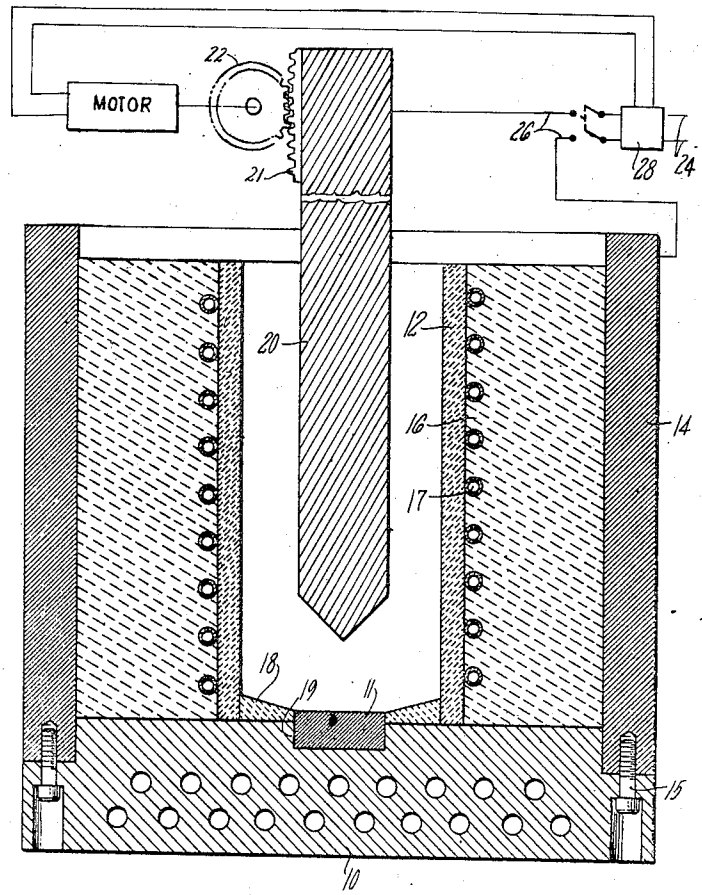
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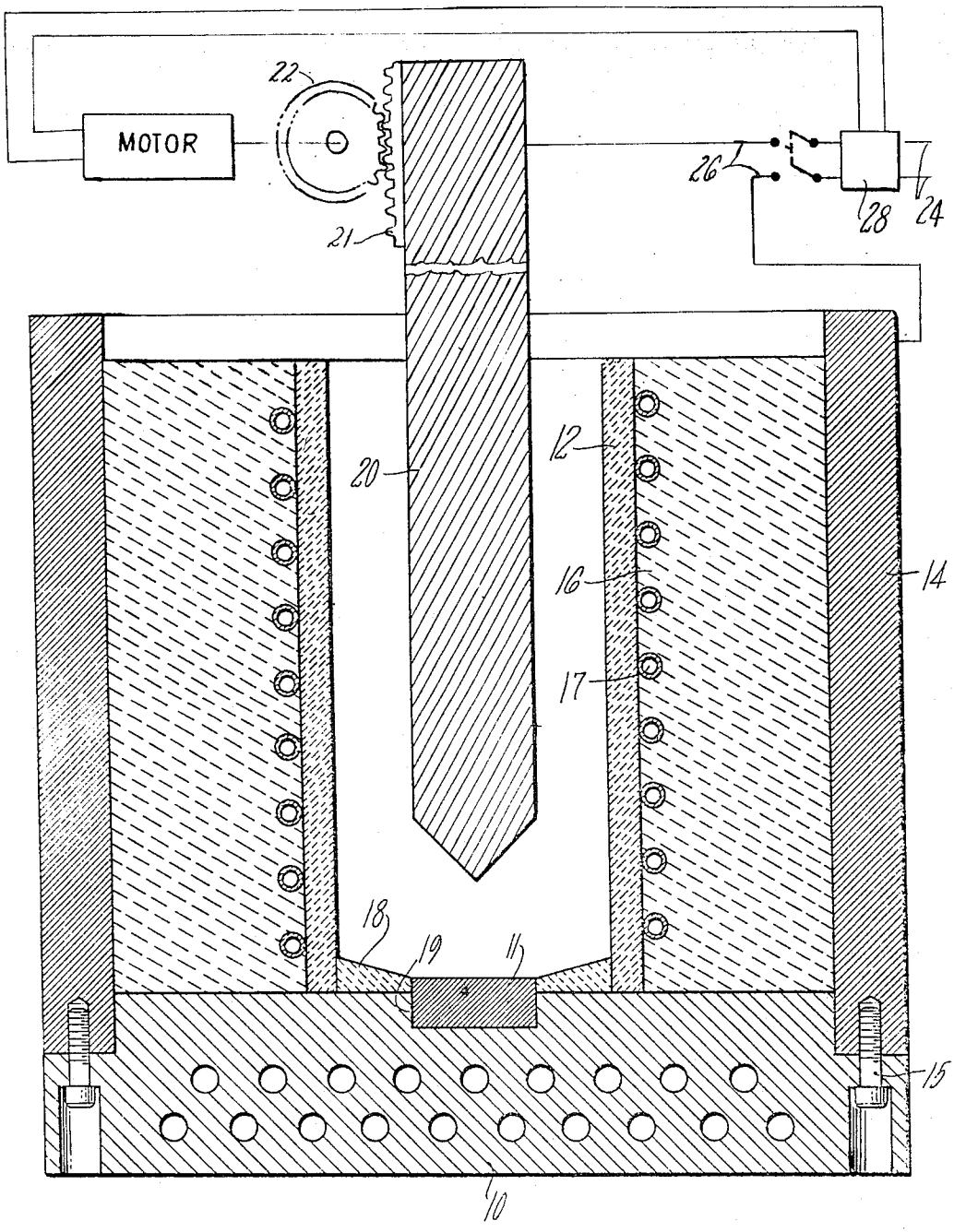
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[57] **ABSTRACT**

Apparatus and method by which to produce single crystal articles using a ceramic mold and consumable arc melting technique with cooling from a chill plate at the base of the apparatus and with the ceramic mold limiting the heat loss laterally from the molten metal.

7 Claims, 1 Drawing Figure




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METHOD AND APPARATUS FOR PROVIDING SINGLE CRYSTAL CASTINGS USING A CONSUMABLE ELECTRODE

This is a continuation-in-part application of Ser. No. 803,539 filed Mar. 3, 1969 now abandoned for SINGLE CRYSTAL CASTINGS.

BACKGROUND OF THE INVENTION

Single crystal articles made of high temperature alloys have been found to be particularly useful in gas turbines especially where the crystalline orientation may be controlled. Such articles and a method of making them is described in the Piearcey U.S. Pat. No. 3,494,709. Articles having close dendrite spacing are most desirable and it has been found that the fine textured dendritic structure desired is obtainable by a relatively fast cooling rate once the crystalline solidification has begun. It is desired to control the crystalline orientation as also described in Piearcey.

SUMMARY OF THE INVENTION

One feature of this invention is the formation of single crystal articles by a consumable arc melting technique combined with a procedure for controlling the solidification rate thereby to produce a fine-grained dendritic structure. Another feature is an apparatus by which to produce such a dendritic microstructure. Another feature is an apparatus and process by which to obtain both the desired dendritic structure and also a desired orientation of the dendritic structure such, for example, as an [001] orientation along the longitudinal axis of the article.

According to the invention the apparatus includes a chill plate by which to start and continue the cooling of the melt at the desired rate on which is positioned a crystalline seed with the dendritic orientation the same as that desired in the cast article. Extending upwardly from the chill plate is a relatively thick mold or shell of ceramic material in which the article is cast and the effective thickness of the mold may be increased by an annulus of granular ceramic material. This annulus is supported by a metallic crucible sleeve or cylinder which surrounds the mold and may, if necessary, have cooling means associated with it to prevent melting of the sleeve during the casting operation. A consumable electrode of the alloy to form the casting is supported above the mold and projects downwardly into the mold to contact the seed. Electrical energy supplied to the electrode and seed form an arc which melts the electrode to form a molten body of alloy which crystallizes upward from the seed as a single crystal to form the cast article by the downward removal of heat through the seed into the chill plate. Insulating material around the seed protects the chill plate from the heat of the arc.

BRIEF DESCRIPTION OF THE DRAWING

The single FIGURE is a vertical cross-sectional view through an apparatus embodying the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawing, the method may be carried out by the apparatus shown which includes a chill plate **10** or crucible bottom to the center of which is secured a single-crystal seed crystal **11** having the desired orientation of the dendritic growth to produce the selected crystalline orientation in the completed cast article. The mold for the cast article is a relatively thick ceramic sleeve **12** on the order of as much as one-fourth inch and having its lower end resting on the chill plate **10** and surrounding the seed crystal. This ceramic sleeve is surrounded in spaced relation by a crucible sleeve **14** solidly secured at its base to the chill plate as by bolts **15**.

The space between sleeve **12** and the crucible sleeve is filled with a ceramic grog or a granular ceramic **16** and the thickness of this space may be as much as from three-fourths to nearly 3 inches, thereby giving an effective heat resistant thickness within the crucible sleeve of from 1 to 3 inches preferably approaching the greater thickness. A heating coil **17** is embedded in the granular ceramic in close relation to or in engagement with the ceramic sleeve **12** and this coil serves to assist in raising the temperature of this sleeve to a temperature slightly above the melting temperature of the alloy being cast. The radiation from the arc and from the surface of the molten alloy supplements the action of the heating coil in this respect as will be described. This crucible sleeve **14** may in turn be surrounded by a cooling jacket not shown although this is not essential and serves to keep the sleeve **14** from overheating. The space between the seed crystal and the walls of the ceramic sleeve **12** may be filled with an insulating ceramic material **18** to prevent damage to the face of the chill plate in operating the device.

The seed crystal is preferably as large as possible in a horizontal dimension to cover as much area of the chill plate surface enclosed within the end of the sleeve **12** as the heat conduction from the melt to the chill plates is through this crystal and the greater the area of the crystal the greater the amount of heat that can be conducted away for each interval of time. This seed crystal will, however, have the desired dendritic orientation such that it will fit readily and securely in a recess **19** in the chill plate. The crystal is also preferably relatively thin but of such a thickness as will be described later, that the arc melting of the surface at the start of the casting operation will not melt to an extent to involve the chill plate.

A consumable bar **20** of the alloy to be cast is positioned within the sleeve **12** and is carried by any of the conventional electrode feeding devices by which an arc may be struck and maintained in the melting of the electrode within the sleeve. One type of well known consumable arc melting furnace having this type of feed equipment is the Heraeus L200 H furnace. For the purpose of the present invention, it is sufficient to note that the bar **20** is mounted on a feed rack **21** that is moved by a gear **22** to advance the electrode into or out of the sleeve **12** at the appropriate rate to maintain the desired melting of the ingot. It will be understood that the arc is formed by an electrical arc, the energy being supplied from a suitable source **24** with power leads **26**, as shown, to the electrode and to the crucible. Obviously, a suitable control **28** of conventional construction maintains the necessary power supply to the arc and also serves to control the electrode feed rate.

The sleeve **12** being ceramic acts as a heat barrier to the molten alloy in the sleeve so that, as the electrode melts to form a pool within the sleeve, the effective heat removal by which to cause solidification of the molten material occurs axially downwardly into and through the chill plate at the base. The solidification

front thus advances upwardly from the crystal so that the solidifying metal becomes a single crystal extension of the crystalline lattice of the seed crystal and this crystalline orientation is the same as that of the seed crystal. Superheated molten metal is continually supplied to the pool of molten alloy above the liquid-solid interface and a very steep temperature gradient is maintained in the solidification zone. With the vertically downwardly removal of heat through the solidified metal and into the chill plate the necessary upwardly moving solidification front for single crystal formation is maintained. This arrangement produces a very fast solidification rate producing a fine single crystal dendritic structure.

When the arc for melting the bar is originally struck between the electrode and the seed crystal, the latter is melted back to some extent but a substantial portion remains solid being in direct contact with the chill plate. The sleeve **12** is preferably heated to a temperature above the melting temperature of the alloy being cast prior to or at the beginning of the casting operation. Thus, the heating coil **17** is energized for the purpose of heating this sleeve **12** and the radiation from the arc and from the molten pool of alloy in conjunction serves to heat the wall surface of the sleeve to the desired temperature. Preferably the heating coil will have been energized in advance of striking the arc in order to have the mold nearly up to the required temperature prior to the start of the melting and casting operation so that shortly after the arc is struck, the portion of the exposed wall adjacent therto will reach the appropriate temperature. It is important that the exposed wall surface of the mold at and above the solidification zone be at this temperature to avoid spurious nucleation on this wall surface which would cause the continued growth of extraneous grains along the surface of the single crystal casting.

The portion of the sleeve immediately above the level of the pool is exposed directly to the arc and with no significant heat loss through the sleeves, this portion of the wall surface of the sleeve is quickly raised to a temperature above the melting temperature of the alloy and this arc-heated area of the wall moves upwardly as the arc is caused to move up with an increase in height of the pool surface during the casting operation.

Being ceramic, the sleeve acts as a heat barrier and no removal of heat from the solidifying alloy occurs in a lateral direction into the sleeve. Thus, the desired heat removal in a vertical downward direction from the solidifying alloy is assured by this arc heating of the sleeve as the bar **19** of alloy is being arc melted. The arc is always above the surface of the molten material within the sleeve and the latter is thus directly exposed to the radiant heat of the arc. It will be understood that the rate of melting and thus of solidification of the single crystal is a function of the power input and the effectiveness of the chill with the preheating of the sleeve by the arc assisting in producing a high thermal gradient. The production of single crystal parts by the use of a chill and a steep thermal gradient in the mold is described and claimed in Piearcey U.S. Pat. 3,494,709.

For example, in producing a single-crystal ingot of 1 ⅛ inches in diameter, the chill plate was a copper plate with cooling passages therein and the cooling flow of water was set at 8 gallons per minute. The electrical input for the arc was 220 amps at 21 volts and the electrode feed rate was substantially ⅛ inch per minute, the electrode being 0.75 square inch in cross section. This ingot was cast from Mar M 200 alloy and the seed crystal was of the same alloy. The seed crystal was produced by vacuum induction casting.

The resulting ingot was found to have the desired microstructure and a reduced microporosity. The high solidification rate obtainable by consumable arc melting produces closer dendritic arm spacing, a small eutectic phase and a finer distribution of smaller MC carbides all of which provide a better casting.

We claim:

1. In the manufacture of a single crystal article, the steps of

mounting an oriented single crystal seed on a chill block,

providing a ceramic shell extending upwardly from the chill plate to serve as a mold and as a heat barrier,

striking an arc between said seed and a consumable electrode of the material for the article to cause partial melting of the seed and melting of the electrode,

heating the ceramic shell at least in part by radiant heat from the arc to minimize heat loss through the mold walls,

solidifying the seed and the molten metal of the electrode upwardly from the seed by heat conduction from the seed and molten metal into the chill plate,

continuing to melt the electrode ahead of the liquid-solid interface of the solidifying material, and

maintaining by heat from the arc a high temperature in the inner surface of the shell at and above the level of the liquid-solid interface thereby to prevent nucleation on the shell.

2. The process of claim **1** in which the shell is exposed directly to the radiant heat of the arc and the wall surface of the shell is heated to a temperature above the melting temperature of the alloy.

3. Apparatus for casting oriented single crystal articles by consumable arc melting, including

a cooled chill plate,

a cylinder above and resting on the chill plate,

an oriented single crystal seed crystal on the chill plate,

a ceramic mold within the cylinder of sufficient thickness to form a heat barrier to the heat from the arc in which the article is formed, said seed crystal being in the base of said mold,

means positioned close to the mold between the mold and cylinder for heating the mold, and

a consumable electrode positionable within the mold.

4. The apparatus of claim **3** in which the chill plate is protected from the arc by a ceramic material surrounding the seed crystal and covering the chill plate.

5. The apparatus of claim **3** including

means for supplying electrical energy from the electrode to the seed crystal to cause arc melting of the electrode and for heating of the wall of the mold.

6. Apparatus for casting an oriented single crystal ingot including

a chill plate,

an oriented single crystal seed secured to the plate,

a crucible surrounding the seed and projecting upwardly from the chill plate,

a thick ceramic mold within and spaced from the crucible,

means externally of the mold and between the mold and crucible for heating the crucible,

a consumable electrode movable into the crucible to contact with the seed, and

means for supplying electrical energy between said electrode and seed for causing melting of the electrode within the mold and for heating the inner wall of the mold.

7. Apparatus as in claim 6 including a granular ceramic filling the space between the crucible and the mold.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,759,310 Dated September 18, 1973

Inventor(s) ROBERT B. BARROW ET AL

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

In the Title the word "Providing" should read

--Producing--

Signed and sealed this 26th day of March 1974.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

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