Nov. 19, 1968 D. G. FLECK 3,411,563

ELIMINATION OF EQUIAXED GRAIN SUPERIMPOSED ON COLUMNAR STRUCTURES

Filed Aug. 26, 1965

Fig-1

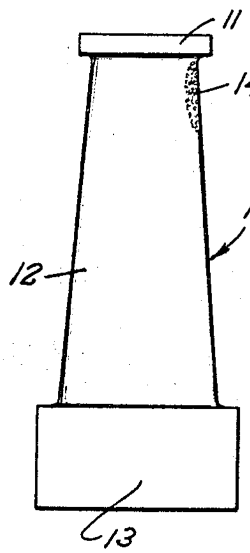


Fig-2

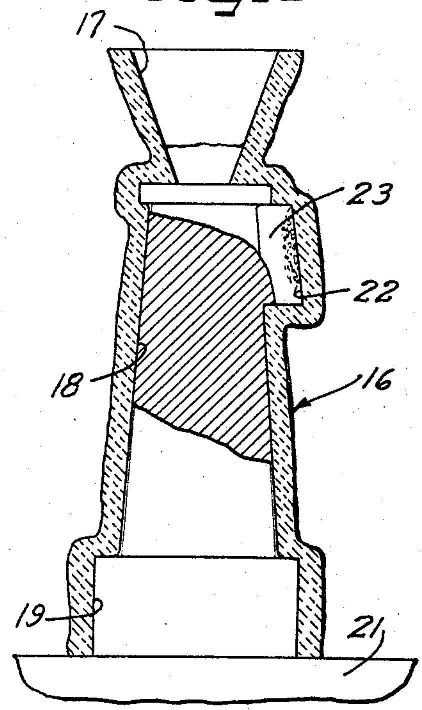


Fig-3

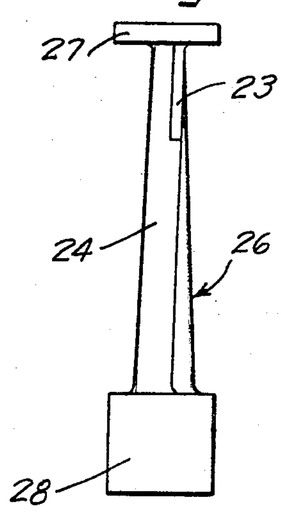
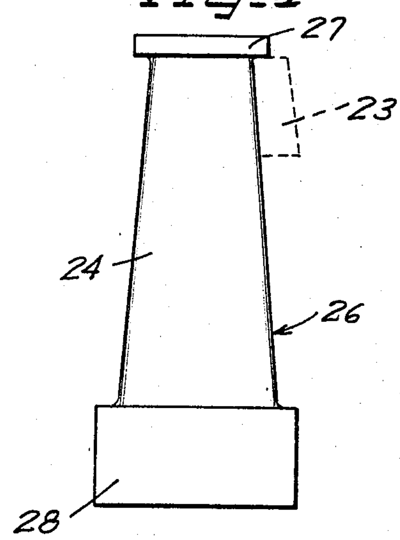


Fig-4



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United States Patent Office 3,411,563 Patented Nov. 19, 1968

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ELIMINATION OF EQUIAXED GRAIN SUPERIMPOSED ON COLUMNAR STRUCTURES
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Filed Aug. 26, 1965, Ser. No. 482,799
1 Claim. (Cl. 164—69)

ABSTRACT OF THE DISCLOSURE

Method and apparatus for eliminating equiaxed grain defects from columnar castings wherein a secondary cavity is provided at the portion of the casting where such defects ordinarily occur, so that upon directional solidification any inclusions are carried into the secondary cavity by the advancing solidification front to form an appendage which can be readily severed from the columnar casting.

The present invention relates to the production of columnar structures from high temperature alloys. The invention is specifically applicable to the manufacture of turbine vanes consisting entirely of columnar grains. Such cast vanes have been found to possess greater fracture resistance and ductility under creep loading conditions than castings having equiaxed grain structures.

Columnar structures are formed by the unidirectional growth of dendrites during solidification. There is no exact relationship between the dendritic structure and the columnar grains, but each columnar grain is usually composed of more than one dendrite and the number may vary from a few to several hundred. The interdendritic spacing is related to the solidification rate only. Columnar grain size, however, may be affected by factors other than the solidification process such as ordinary grain growth. Despite these differences, the most convenient approach for the examination of columnar structure formation is through the study of dendrites formed during solidification.

The primary requirement for the formation of a parallel dendritic structure is the presence of a unidirectional thermal gradient. This gradient is achieved by pre-heating the mold, and using an open ended mold positioned on a chill block composed of a metal of very high thermal conductivity compared to the material of the mold. When the metal first enters the mold, the initial solidification occurs at the chill block, and may result in the formation of many fine dendrites having a random orientation. The initial freezing releases the heat of fusion, resulting in some temperature rise locally, arresting the chill zone formation. At the interface of the chill zone and the melt, the dendrites begin to grow into the melt at a rate dependent upon the amount and depth of the supercooling.

Initially, all dendrites at the chill zone-melt interface grow at equal rates, since equal supercooling is present. However, those oriented parallel to the thermal gradient are growing into an area of continuous supercooling. Those oriented unfavorably cannot advance as rapidly in the direction of the thermal gradient, since only a component of the growth velocity is aligned with this gradient. The dendrites growing parallel to the gradient, since they have already undergone some growth, will give off a latent heat of fusion due to the freezing process. This heat of fusion increases the temperature at the base of the dendrites and decreases the amount of supercooling available for growth of the more unfavorably oriented neighbors. In this manner, the growth of

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the misoriented dendrites is stifled, and only those aligned with the thermal gradient will undergo significant growth.

Comparative tests between equiaxed and columnar castings indicate that the columnar casting has marked advantages for certain applications. The high temperature strength and ductility of the columnar structures is generally superior to the equiaxed structure, and may be attributed to the preferential occurrence of gas porosity at grain boundary locations. In the equiaxed structures the gas porosity is distributed randomly, following a grain boundary pattern. As a result, intergranular fractures occur with low ductility. In the columnar structure the grain boundaries are oriented parallel to the growth direction. Accordingly, the porosity has little or no influence on ductility. The improvement in ductility can be attributed to several factors. The segregation normally associated with equiaxed grains is reduced by the columnar solidification process. The conditions necessary to form columnar structures are identical to those required for proper feeding. Thus, microshrinkage is almost completely eliminated. The primary reason for improved ductility, however, appears to be the elimination of grain boundaries perpendicular to the stress axis. This prevents the normally brittle intergranular type of fracture, permitting a great amount of deformation to occur prior to failure.

While techniques for securing sound columnar castings have been highly developed, there is a recurring defect which exists in such columnar castings and seems to be associated with the slow solidification process. This defect consists in areas of equiaxed grain structure which, because of their physical appearance, have been called "freckles." These defects normally appear on the macroetched casting as a vertical streak of fine equiaxed grains, and usually occur in the portion of the casting which is the last to solidify. In the case of a turbine vane, this may occur on either the leading or trailing edge near the tip of the part, depending upon the configuration of the mold. The equiaxed grain is superficial in nature and stock removal reveals the underlying structure to be the desired columnar grain. Chemical analyses of these areas show them to be highly segregated. Radiographic examination reveals the segregation as well as microporosity associated with it. Consequently, the existence of this condition is undesirable for several reasons, (1) the equiaxed surface grain is a weak spot on the casting, from the standpoint of thermal shock, (2) the segregation of low melting constituents in this area creates a relatively weak area in the casting and (3) the microporosity associated with the defect can act to initiate cracks.

The presence of such equiaxed defects is particularly noticeable when the mold is heated by induction heating and presumably could be due at least in part to inductive stirring of the molten metal by the electromagnetic energy.

One of the objects of the present invention is to provide an improved method for eliminating equiaxed grain defects in columnar castings without interfering with normal columnar grain growth.

Still another object of the invention is to provide an improved method for casting superalloys and other high temperature materials under conditions of directional solidification, and isolating any equiaxed defects so that they can be readily removed upon removal of the solidified metal from the mold.

A further object of the invention is to provide a casting assembly for producing turbine vanes and the like, the casting assembly including a mold having a secondary cavity which forms an appendage on the casting in which any equiaxed defects will occur.

A further description of the present invention will be made in conjunction with the attached sheet of drawings in which:

FIGURE 1 is a view in elevation of a turbine vane produced accordingly to prior techniques and exhibiting the type of defects which the present invention overcomes;

FIGURE 2 is a view partly in elevation and partly in cross-section of a mold assembly which incorporates the improvements of the present invention;

FIGURE 3 is a side elevational view of a cast turbine vane produced according to the present invention; and

FIGURE 4 is a front elevational view of the vane of FIGURE 3 after removal of the appendage.

In FIGURE 1, reference numeral **10** indicates generally a turbine vane composed of a superalloy or the like, and having a shroud portion **11**, an airfoil vane portion **12**, and a relatively massive root portion **13**. When produced by the usual techniques of casting, particularly when involving induction heating, it has been found that a portion of the edge of the vane portion **12**, such as indicated at reference numeral **14**, provides an undesirable area of equiaxed grains which are objectionable for the reasons mentioned previously.

In accordance with the present invention, I make the casting oversized in the portion thereof in which the equiaxed defect tends to occur. The surplus metal is in the form of an appendage which can readily be removed by severing it from the body of the casting after solidification. Thus, any equiaxed defects are eliminated with the severing of the appendage, leaving the casting sound, homogeneous, and completely columnar.

The mold illustrated in FIGURE 2 is of the open ended, thin, relatively porous ceramic shell mold type. The mold is indicated generally at reference numeral **16**, and provides an integral gate portion **17** which feeds a main casting cavity including an airfoil vane defining portion **18** and a root defining portion **19**. The open end of the shell mold **16** is positioned on a chill block **21** consisting of a metal having a high degree of thermal conductivity, such as copper. The mold, in accordance with the present invention, is also provided with a secondary cavity **22** contiguous with the vane defining portion **18**, and located near the tip of the blade where, from experience, it has been found that the "freckle" type defect will most likely occur.

While there are a number of ways of making the ceramic shell mold **16** for the purposes of the present invention, I particularly prefer that method for making refractory molds which is described in Mellen et al. U.S. Patent No. 2,932,864 of Apr. 19, 1960. In accordance with the procedure in describing that patent, a disposable pattern composed of wax, or the like, is dipped in an aqueous ceramic slurry having a temperature about the same as that of the pattern material to form a refractory layer of a few mils in thickness. A typical slurry may contain ceramic materials such as zirconium oxide, a binder such as colloidal silica, and a thickener and low temperature binder such as methyl cellulose. The initial layer while still wet is then dusted with small particles (40 to 200 mesh) of a refractory glass composition such as that known as "Vycor" which is a finely divided high silicon oxide glass containing about 96% silica and a small amount of boric acid together with traces of aluminum, sodium, iron, and arsenic. The dusted wet refractory layer on the pattern can then be suspended on a conveyor and moved through a drying oven having a controlled humidity and temperature, wherein the coated pattern is dried adiabatically.

The steps of dipping, dusting, and adiabatic drying are then repeated using air at progressively lower humidities for succeeding coats. For example, the first two coats can be dried with air having a relative humidity of 45 to 55%. The third and fourth coats can be dried with a relative humidity of 35 to 45%, the fifth and sixth coats with a relative humidity of 25 to 30%, and finally the last coats with a relative humidity of 15 to 25%.

The first layer is preferably applied at a thickness of about 0.005 to 0.020 inch, and the fine refractory particles are dusted onto the wet layer with sufficient force to embed the particles therein. It is preferred that the dusting procedure used provide a dense uniform cloud of fine particles that strike the wet coating with substantial impact force. The force should not be so great, however, as to break or knock off the wet prime layer from the pattern. This process is repeated until a plurality of integrated layers is obtained, the thickness of the layers each being about 0.005 to 0.020 inch.

After the mold is built up on the pattern material, the pattern is removed by placing the flame in a conventional steam autoclave operated at temperatures of about 300 to 350° F. After removal of the pattern material the green mold is ready for firing at temperatures on the order of 1500 to 1900° F. The resulting shell molds are hard, smooth, and relatively permeable, and measure on the order of ⅛ to ¼ inch in thickness.

When the molten metal is poured into the mold **16** through the gate **17**, assuming the mold to have been properly preheated, directional solidification will occur starting at the chill plate **21** and progressing upwardly. The metal also fills the secondary cavity **22** to provide an appendage **23** attached to the vane portion of the casting. The secondary cavity **22** does not feed the casting in the same sense that a conventional riser feeds a part, but rather by virtue of its configuration and location provides a place other than the casting itself for the advancing solidification front to deposit these undesirable defects and constituents.

While the conditions of casting do not form any part of this invention, it should be realized that such casting will normally take place under vacuum conditions.

After solidification of the mold under controlled cooling conditions conducive to the formation of a completely columnar structure, the shell mold is broken away, leaving a casting as shown in FIGURE 3, including the appendage **23** integral with but severable from the airfoil vane portion **24** of the cast turbine vane **26**. The finished casting has a shroud portion **27** and a relatively massive base **28**. It is then relatively a simple matter to cut off the appendage **23** as illustrated by the dotted lines in FIGURE 4, leaving the casting sound, homogeneous, and exhibiting proper columnar structure in the entire area.

A comparison was made between molds embodying the secondary cavity and those not including the cavity. The test was made on a six piece mold in which four of the six castings had the appendage, and two did not. The four which had the appendage were all acceptable upon microetch inspection, and the two castings without the appendage were found to be rejectable for "freckles." All six parts were then X-rayed, and the four castings which had been made with the appendage were all acceptable by X-ray analysis, while the two cast without the appendages were both rejectable for porosity and segregation in the trailing edge of the vane portion.

While I have described a particularly preferred embodiment of the invention, as applied to a cast article of specific geometry, it should be understood that the process and apparatus of the present invention have applicability to other shapes produced by the columnar casting technique.

I claim:

1. The method of producing a columnar grained casting of a turbine blade which has a tendency to form equiaxed grain defects along a portion thereof which comprises providing a mold having a main casting cavity conforming to the shape of the turbine blade and having a vertically disposed gate portion arranged to deliver molten metal into said casting cavity, said cavity having a contiguous secondary cavity axially displaced from the vertical axis of both said gate portion and said main cavity and positioned at one upper edge of the portion of the casting cavity which forms the airfoil portion of the casting, pouring molten metal into the main casting cavity until both the main cavity and said secondary cavity are filled with molten metal, rapidly abstracting heat from the bottom of the main casting cavity upwardly to thereby provide an advancing solidification front leading to directional solidification of the casting, continuing the abstraction of heat until the casting is directionally solidified and any segregating constituents are deposited and solidified in said secondary cavity to form an appendage to the casting, and severing said appendage from said casting.

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