

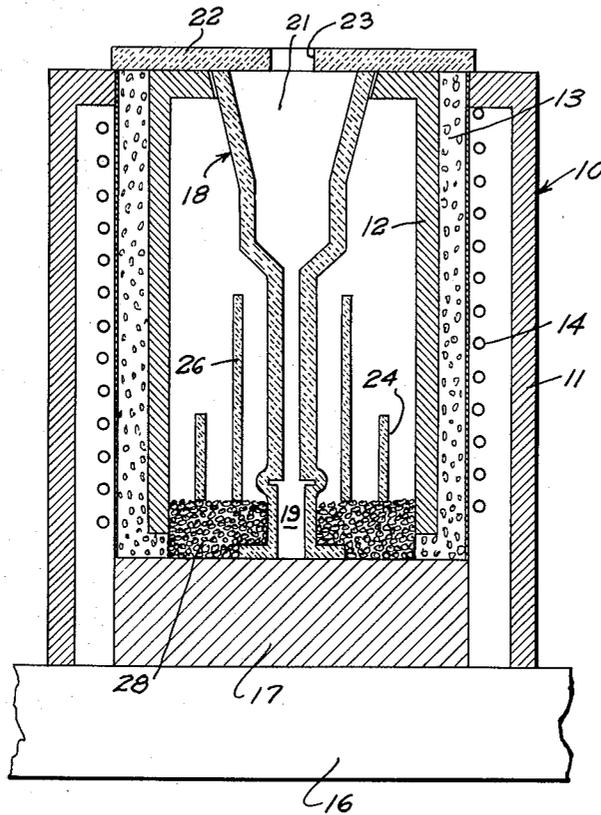
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METHOD FOR IMPROVING GRAIN STRUCTURE AND SOUNDNESS IN CASTINGS

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METHOD FOR IMPROVING GRAIN STRUCTURE AND SOUNDNESS IN CASTINGS

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This application is a continuation-in-part of my application Serial No. 232,733, filed October 24, 1962, and now abandoned.

The present invention relates to improvements in methods and apparatus for producing sound metal castings, and specifically, to the production of metal castings having columnar grain structures.

The presence of columnar zones in castings has been recognized for some time, but until recently, this type of structure was considered a defect and not nearly so desirable as the equiaxed structure. In recent years, however, the properties of columnar structures have undergone reexamination and it has now been determined that in some applications, the columnar structures are markedly superior to equiaxed structures. For example, it has been found that the high temperature properties of columnar structures are superior particularly in fracture resistance and ductility under creep loading conditions.

Columnar structures are formed by the unidirectional growth of dendrites during solidification. The relationship between the dendritic structure and the columnar grains is not exact. 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 the dendrites formed during solidification.

The primary requirement for the formation of a parallel dendritic structure is the presence of a unidirectional thermal gradient. When the metal first enters the mold, the initial solidification occurs at the mold wall due to a chill effect, assuming the mold wall to be below the solidification temperature of the metal. This chill zone consists 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 continued 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 the misoriented dendrites is stifled, and only those aligned with the thermal gradient will undergo significant growth.

The aligned dendrites formed will display a preferred crystallographic orientation, depending on the crystal system, and, in more complex systems, on the particular metal or alloy. This behavior can be rationalized in the

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following way. Crystals growing into a melt are formed with the planes of maximum atomic density forming the faces. In the face centered cubic metals, for example, the faces of the crystals would form an octohedron bounded by the (111) planes. The direction of maximum growth coincides with the maximum dimension of this octohedron, the (100) plane. It would be expected, then, that the (100) would be aligned parallel to the predominating thermal gradient and this has been observed in numerous cases. In the more simple crystal systems, the body centered cubic and the face centered cubic, the direction of preferred orientation, (100) in each case, is generally the same regardless of the metal involved. In systems of non-cubic symmetry the particular metal or alloy will determine the direction. In closed packed hexagonal systems, for example, the c/a ratio is an important factor in determining the direction of preferred orientation.

The solidification of alloys proceeds along the lines mentioned previously, but in a somewhat more complex mechanism since concentration gradients as well as thermal gradients may exist during solidification.

Casting variables affect columnar structure through their influence on the thermal or compositional gradients developed in the molds. These variables include metal superheat, initial mold temperatures, the use of chills or exothermic materials, and the alloy composition. Variation of the thermal gradients within the range of columnar formation also influences the structure of the casting. If a steep thermal gradient exists, the rapid rate of heat extraction requires rapid solidification. At the same time the relatively short supercooled layer restricts the lengths of the dendrites extending into the melts. During solidification mass transport of solute between the dendrites must take place. Since the overall solidification rate is determined by the rate of heat removal, the diffusion distances must be reduced to permit the proper distribution of solute to take place. This is accomplished by increasing the number of dendrites, thus reducing the interdendritic distances. It has been experimentally verified that as the solidification rate increases, the interdendritic spacing decreases at a rate proportional to the square root of the solidification rates.

The consequences of this behavior are evident in extended columnar structures. As the distance from the mold wall increases, the dendritic spacing also increases. This can probably be attributed partially to the elimination of unfavorably oriented dendrites, but the major influence responsible is the decrease in thermal gradients as the dendrite-melt interface moves through the mold.

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 occurred with very 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 greater amount of deformation to occur prior to failure.

While the desirability of producing columnar structures for certain applications has been recognized by workers in the art, the problems of achieving such structures have always been substantial. One technique which has been used to produce columnar structures involves the use of a tapered, relatively thick mold with a heat abstracting means positioned at the bottom of the mold. The high temperature differentials existing in the mold structure, however, have caused severe cracking problems to exist. In some instances where relatively thin walled ceramic shell molds were employed, the molds were constrained against movement, inhibiting their free expansion, and presenting the problems of cracked molds and the introduction of inclusions. The need still remains, therefore, for a method and apparatus for conveniently producing columnar structures in castings. The satisfaction of that need is the principal object of the present invention.

Another object of the invention is to provide a method for establishing unidirectional thermal gradients in a casting so that the gradients exist parallel to the direction of major stress which will exist in the casting during use.

Still another object of the invention is to provide an apparatus for producing castings having columnar grain structures which permits free expansion of the shell molds contained therein.

Another object of the invention is to provide an apparatus for producing columnar grain type castings which enables one to control the location and intensity of the unidirectional thermal gradients existing therein.

In accordance with the present invention, a unidirectional thermal gradient is provided in the casting by positioning a ceramic shell mold having uniformly thin wall thicknesses within the furnace, while permitting free expansion of the shell mold therein. A highly heat conductive material is applied to the mold perpendicular to the direction in which the unidirectional thermal gradient is to exist. Then, radiant heat energy is directed at the mold to preheat the portions of the mold above the melting temperature of the metal to be introduced, followed by pouring the molten metal into the mold and cooling the metal within the mold to produce a casting having an oriented columnar grain structure along the line of the thermal gradient.

A further description of the present invention will be made in conjunction with the attached sheet of drawings in which the single figure illustrates an apparatus which can be employed for the purposes of this invention.

In the figure, reference numeral 10 indicates generally a furnace assembly for the purposes of the present invention including an outer wall 11 composed of a suitable refractory brick material or the like, and an inner radiating enclosure 12 composed of a material such as graphite. Disposed intermediate the outer wall 11 and the radiating wall 12 is a layer 13 of an insulating refractory material. The radiating wall 12 is heated to a high temperature by any suitable means, such as induction coils 14, although other heat sources such as electrical resistance heating, gas, or the like, could also be employed.

The outer wall 11 rests upon a support 16 and on this support there is disposed a block 17 of highly thermally conductive material, such as copper. If desired, additional heat transfer means may be included within the copper block, such as a circulating fluid system.

A ceramic shell mold 18 of generally uniform thin wall structure rests on the block 17. Generally, the mold 18 will have a thickness of from about $\frac{1}{16}$ inch to about $\frac{1}{4}$ inch or so. The mold 18 includes an open ended casting cavity portion 19 and an open ended riser cavity portion 21 into which the molten metal is introduced. A top heat shield 22 having a central aperture 23 is disposed over the furnace assembly to prevent heat loss from the top of the mold.

A pair of radiation shields 24 and 26 is interposed between the mold 18 and the radiating walls of the heat radiator 12. In the form of the invention illustrated, the shields 24 and 26 may take the form of cylindrical bodies which are concentric with the casting cavity 19. The shields may be composed of zirconium silicate or other refractory material which is capable of resisting the high temperatures involved in such furnaces. The purpose of the shields is to control the temperature of various zones within the casting cavity, as desired, since in some instances it is necessary to provide areas of differing thermal gradients within the same casting. The location and the extent of the shields 24 and 26 determines the amount of heat radiation energy which the casting cavity can assimilate from the radiating walls and thereby determines the temperature in preselected areas or zones of the mold.

Also included within the furnace is a relatively loosely packed bed 28 of ceramic particles composed, for example, of zirconium silicate or other material which has a sintering temperature in excess of the operating temperature of the furnace. The bed is sufficiently loosely packed, however, so that it permits relatively free expansion of the ceramic shell mold in that area.

As an example of the technique involved in the present invention, a first stage jet engine turbine blade was cast in an apparatus of the type shown in the drawing. The graphite radiation source was heated by induction to 2800° F. and held for 20 minutes. A nickel base "super-alloy" having an analysis in the range of 15 to 25% chromium, 5 to 30% cobalt, 0.5 to 5% titanium, 2 to 5% aluminum, 1 to 5% niobium, 5 to 11% tungsten, and the balance essentially nickel was poured into the mold at a pouring temperature of 2700° F. and allowed to cool for 25 minutes. The graphite source was then allowed to cool slowly and reached the melting temperature of the alloy about 55 minutes after the original pour was made. The insulation around the base was granular magnesia and the conducting heat sink under the insulation was pure copper. This assembly produced an entirely columnar jet engine blade which had its grain parallel to the axis of major stress.

From the foregoing, it will be seen that the method and apparatus of the present invention provide a carefully controllable means for securing preferred grain orientation in castings, and the production of columnar structures in which the grains are oriented in the direction of maximum stress.

I claim as my invention:

1. The method of providing a casting of controlled directional orientation of grain structure which comprises positioning a thin walled ceramic mold in a furnace in spaced relation to the radiating walls thereof, closing off a portion of said mold with a metal chill, radiantly heating said furnace to a pouring temperature appropriate to the molten metal to be cast into said mold, shielding other portions of said mold selectively against radiated heat in said furnace to thereby cooperate with and augment the chilling effect of said chill to provide a desired thermal gradient between said other portions and the portion in which said chill is located, said thermal gradient being capable of influencing solidification of said molten metal to produce a desired controlled directional orientation of grain structure in the solidifying metal, casting molten metal into said mold while such thermal gradient exists therein, solidifying the cast metal in the mold under the influence of said temperature gradient, and recovering a casting of said structure.

2. The method of claim 1 in which the metal chill is positioned to provide a thermal gradient parallel to the direction of major stress which will exist in the casting during use.

3. The method of claim 1 in which the thermal gradient and cooling conditions are such as to produce a columnar grain structure in the casting.

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4. The method of claim 1 in which the radiant heating is provided by induction heating.

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