(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 059 549**
B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication of patent specification: **16.06.87**

(51) Int. Cl.[4]: **B 22 D 27/04**

(21) Application number: **82300766.1**

(22) Date of filing: **16.02.82**

(54) Method of casting an article.

(30) Priority: **02.03.81 US 239640**

(43) Date of publication of application:
08.09.82 Bulletin 82/36

(45) Publication of the grant of the patent:
16.06.87 Bulletin 87/25

(84) Designated Contracting States:
BE CH DE FR GB IT LI SE

(56) References cited:
DE-A-2 031 844
FR-A-2 184 610
FR-A-2 444 092
GB-A- 870 213
GB-A-1 256 348
GB-A-1 426 805
GB-A-2 037 200

(73) Proprietor: **PCC Airfoils, Inc**
23555 Euclid Avenue,
Cleveland, Ohio 44117 (US)

(72) Inventor: **Vishnevsky, Constantine**
5940 Buckboard Lane
Solon Ohio 44139 (US)
Inventor: **Kolakowski, Thomas Alan**
34900 Jackson Road
Moreland Hills Ohio 44022 (US)

(74) Representative: **Allden, Thomas Stanley et al**
A.A. THORNTON & CO. Northumberland House
303-306 High Holborn
London WC1V 7LE (GB)

Courier Press, Leamington Spa, England.

EP 0 059 549 B1

Description

The present invention relates to a method of casting an article and more specifically to a method of casting a metal article formed of a plurality of elongated crystals having a desired orientation.

The concept of casting an article, such as a turbine blade, with elongated crystals having a [001] direction parallel to the longitudinal axis of the article is disclosed in U.S.—A—3,485,291. The method disclosed in this US-specification is characterized by initial solidification of the molten metal occurring in a competitive growth zone adjacent to a chill with the longitudinal direction of the article's mold cavity being aligned perpendicular to the chill surface.

This competitive growth zone occurs because when a face-centered cubic metal is cast against a chill, the initial crystals which are formed will not all have the desired [001] orientation, but rather will be substantially randomly aligned. Since solidifying dentrites in the molten metal grow most favorably in the [001] direction, as solidification proceeds from the chill, those dentrites having an [001] orientation perpendicular to the chill will grow preferentially along the longitudinal axis of the article. Eventually, the preferred dentrites will emerge from the competitive growth zone and result in a series of columnar grains or crystals having a [001] direction oriented in the growth direction. The function of the growth zone from which the preferred or [001] aligned columnar grains emerge is to eliminate from the cast article crystals or grains having an off axis orientation.

After casting, the growth zone is cut off the article and is either discarded or reused to make a new lot of melt stock or so-called master metal, for subsequent casting. The growth zone contributes to casting costs through the use of additional metal, wax material used in producing the pattern for mold making, and additional ceramic material for the mold.

Although the [001] direction of crystallographic orientation which results from directional solidification in the manner disclosed in the aforementioned US specification has certain desirable characteristics, such as improved thermal fatigue resistance, it is well known that other crystallographic directions of orientations can yield higher creep strength and Young's modulus values. For certain applications, higher creep strength and Young's modulus values can be important. However, the obtaining of the crystallographic directions of orientation which yield the higher strength and Young's modulus values cannot be done with conventional directional solidification techniques.

In the past, crystal orientation during the casting of a single crystal article has been controlled through the use of seeds or solid pieces of single crystal material. During casting, metal solidification proceeds from the single crystal seed and causes propagation of a single crystal in an entire casting cavity. Control of the seed temperature and suitable means of cooling the molds are needed to achieve the desired effect in a manner which is further described in US—A—1,793,672; 3,139,653; 3,759,310; 3,857,436; and 4,015,657. However, the methods disclosed in these specifications have used single crystal seeds to cause the formation of single crystal articles rather than directionally solidified articles having a plurality of elongated crystals with the desired crystallographic orientation.

GB—A—1256348 and 1426805 drawn to our attention in the examination of the present application disclose the casting of directionally solidified articles formed of elongated metal crystals utilizing a chill and the casting of single crystal articles using a single crystal seed located on a chill.

GB—A—2037200 also drawn to our attention in the examination of the present application, discloses the use of a single crystal seed in the formation of a single article wherein the seed crystal and mold are orientated in fixed orientation to the chill in order to obtain a desired polar orientation of the single crystal of the cast article about its longitudinal axis.

In an effort to obtain an article having an elongated crystal structure with oriented grains or crystals, GB—A—870,213 teaches the use of a seed slab or starter in the manufacture of ingots having preferred crystallographic properties. The seed slab or starter element has elongated grains oriented so that the (100) crystallographic planes, which correspond to the sides of body-centered unit cells, are substantially perpendicular to the longitudinal axes of elongated grains or crystals of the seed slab. The other sides of the unit cells, that is the sides which extended parallel to the longitudinal axes of the grains or crystals, are randomly oriented and are only occasionally parallel to similar crystal planes in other elongated grains or crystals.

During a casting operation, the seed slab or starter element of GB—A—870213 is placed at the bottom of a mold with the longitudinal axes of the crystals extending horizontally, that is perpendicular to the longitudinal axis of the mold. Molten metal is then poured into the mold cavity against the seed slab. The resulting directionally solidified article is formed of elongated crystals or grains having unit cells oriented so as to have a pair of side surfaces extending perpendicular to the longitudinal axes of the crystals or grains and other side surfaces extending parallel to the longitudinal axis of the crystals or grains. The crystallographic orientation along the longitudinal axis is [001], the same as produced through directional solidification in the making of aforementioned gas turbine articles by competitive crystal growth from a chill surface. Hence, this art does not teach how directions other than (001) could be achieved along the longitudinal axis of the article, cast perpendicular to the chill surface, in order to obtain desired changes in strength or Young's modulus.

An object of the present invention is to provide a method of casting a directionally solidified article formed of elongated metal crystal having generally parallel longitudinal axes utilising a starter element in which the formation of a competitive growth zone is avoided and which is suitable for forming articles with any desired unit cell orientation.

In accordance with the invention such a method comprises the steps of providing a one-piece starter element which has a plurality of elongated metal crystals disposed in a side-by-side relationship with longitudinal axes which are substantially perpendicular to first and second sides of the starter element and with the second side of the starter element being formed by ends of the elongated metal crystals, providing a chill, providing a mold having an open end portion and a cavity in which the article is to be cast, positioning the starter element in the open end portion of the mold with the first side of the starter element exposed to the chill and the second side of the starter element exposed to the mold cavity, pouring molten metal into the mold cavity, and initiating the formation in the mold cavity of a plurality of elongated metal crystals having longitudinal axes extending substantially parallel to the longitudinal axes of the elongated metal crystals in the starter element, said step of initiating the formation of metal crystals in the mold cavity including the step of engaging the ends of the elongated metal crystals at the second side of the starter element with the molten metal while the first side of the starter element is exposed to the chill.

By having the elongated crystals in the starter element oriented with their longitudinal axes extending parallel to the direction of crystal growth in the mold cavity, molten metal which is poured into the mold cavity comes into contact with the ends of the longitudinally extending grains or crystals in the starter element. This results in the nucleation of a multiplicity of crystals having the same orientation as the crystals in the starter element. The nucleation of directionally oriented crystals at the starter element eliminates the competitive growth zone which characterizes most prior directional solidification casting processes.

The longitudinally extending crystals which are nucleated at the ends of the crystals in the starter element have unit cells which are disposed in the same orientation as the unit cells of the starter element. By providing a starter element having elongated crystals with unit cells having their side surfaces skewed or extending at an acute angle to the longitudinal axes of the crystals of the starter element, longitudinally extending crystals with unit cells having a similar orientation will be formed in the cast article. It is preferred to orient the unit cells in the starter element in various preselected longitudinal directions to effect the solidification of a cast article having an elongated crystal structure with the unit cells oriented in the same direction. The choice of orientation depends on the specific performance characteristics desired in the article.

As an example of how change in crystal direction can be used to change Young's modulus in the case of a nickel-base superalloy, a casting directionally solidified with elongated crystals having a (001) direction parallel to the longitudinal axis of the crystals will have an ambient temperature Young's modulus of approximately 18,000,000 pounds per square inch (124,000,000 kPa). The same nickel-base superalloy casting would have an ambient temperature Young's modulus in a direction along the casting axis of about 44,000,000 pounds per square inch (303,000,000 kPa) if the longitudinal orientation of elongated crystals were to lie in the (111) direction. Although the method of the present invention can be used in casting many different types of products, the method is advantageously used to cast airfoils with the elongated crystals or grains having longitudinal axes extending substantially parallel to a longitudinal direction of the airfoil.

In order that the invention may be well understood, an embodiment thereof, which is given by way of example only, will now be described, reference being had to the accompanying drawings, in which:

Fig. 1 is a schematic illustration depicting the manner in which a mold is supported on a chill with starter elements exposed to the chill and to mold cavities prior to pouring of molten metal into the mold;

Fig. 2 is an enlarged fragmentary sectional view illustrating the relationship between a starter element, a mold cavity, and chill of Fig. 1;

Fig. 3 is an enlarged, somewhat schematicized, illustration of the starter element of Fig. 2;

Fig. 4 is an illustration of an airfoil cast with the starter element of Fig. 3 and schematically illustrating the orientation of a unit cell of an elongated grain or crystal in the airfoil; and

Fig. 5 is an enlarged schematic illustration further illustrating the orientation of a unit cell of one of the elongated grains or crystals of the airfoil of Fig. 4, the structure of the unit cell being simplified in Fig. 5 for purposes of clarity of illustration.

A mold 10 (Fig. 1) is preheated in a known furnace assembly 12 prior to pouring of molten metal into the mold. The known furnace assembly 12 is provided with a refractory outer wall 16 which is surrounded by an induction heating coil 18. A graphite susceptor wall 20 is enclosed by the outer wall 16 and is heated by the induction effect of the coil 18. The furnace assembly 12 has a top plate 22 with an opening which may be provided with a funnel 24 through which molten metal is poured into the mold 10. It is contemplated that the entire furnace assembly 12 will be disposed within a vacuum furnace.

The mold 10 has a pouring basin 32 through which molten metal enters a plurality of runners or passages 34 which are connected with a plurality of mold cavities 38 which are disposed in a circular array around the pouring basin 32. A cylindrical heat shield 40 may be provided on the inside of the circular array of mold cavities 38.

The mold 10 is disposed on a copper chill plate 42. The chill plate 42 promotes the directional solidification of molten metal in the mold cavities to provide a casting having a columnar grain structure with a grain orientation extending generally parallel to the longitudinal central axes (vertical axes) of the mold cavities 38. It should be noted that although the furnace 12 and mold 10 could have many different constructions, they have the same general construction as the furnace and mold disclosed in US—A—3,680,625.

A starter element 50 (see Fig. 2) is positioned in the lower end portion of the mold cavity 38. The cylindrical starter element 50 is exposed both to the chill 42 and to the mold cavity 38. Thus, a lower or bottom side surface 54 of the starter element 50 is disposed in abutting engagement with an upper or top side surface 56 of the chill 42. The opposite side surface 58 of the starter element 50 is directly exposed to the mold cavity 38.

When molten metal is poured into the funnel 24 and basin 32 to the runners 34 and mold cavity 38, the molten metal flows downwardly against the upper side surface 58 of the starter element 50. Due to the rapid conduction of heat from the starter element 50 to the chill 42, solidification of the molten metal in the mold cavity 38 is initiated at the upper side surface 58 of the starter element 50. As solidification of the molten metal proceeds upwardly in the mold cavity 38, the chill 42 and mold 10 are advantageously lowered to withdraw the mold from the furnace 12 in a known manner.

The starter element 50 is formed of a plurality of elongated metal crystals or grains 62 (see Fig. 3) disposed in a side-by-side relationship with longitudinal axes which are substantially perpendicular to the opposite side surfaces 54 and 58 of the starter element which are formed by ends of crystals 62. The large majority of the crystal 62 extend completely through the starter element 50.

Generally in the embodiments, the elongated grains 62 have one transverse end disposed in the circular side surface 54 and the opposite transverse end disposed in the circular side surface 58. A few of the longitudinally extending grains 62 may terminate between the two side surfaces 54 and 58. However, all of the grains which end at the side surface 58 have an opposite end at the side surface 54. The elongated grains or crystals 62 have longitudinal axes which extend perpendicular to the side surfaces 54 and 58 and which are disposed in a parallel relationship with a longitudinal central axis 66 (Fig. 2) of the mold cavity 38.

Since the elongated crystals 62 (Fig. 3) have ends disposed in the upper surface 58 of the starter element 50, each of the starter element crystals can effect nucleation of a corresponding longitudinally extending crystal or grain in the molten metal in the mold cavity 38 upon initiation of solidification of the molten metal. This results in the molten metal in the cavity 38 solidifying in a multiplicity of longitudinally extending crystals or grains having their origin at the surface 58 of the starter element 50 and extending parallel to a longitudinal central axis 66 of the mold cavity 38. The elongated crystals which are solidified in the mold cavity 38 have longitudinal axes which extend parallel to the mold axis 66 (Fig. 2) and the longitudinal axes of the grains 62 in the starter element 50. Due to nucleation of the grains in the cast product in the desired orientation at the end surface 58 of the starter element, the competitive growth zone which characterizes many known directional solidification processes where the desired longitudinal direction is [001] can be eliminated.

In the event it is desired to provide the cast article being formed in the mold cavity 38 with a fine grained structure, the starter element 50 has a fine grain structure so that an array of closely packed and relatively small crystal end portions are provided in the surface 58. This results in the formation of a corresponding number of longitudinally extending crystals or grains in the mold cavity 38. Since these grains nucleate at the end surface 58 of the starter element 50, the molten metal solidifies in the mold cavity 38 with a fine grained structure extending substantially throughout the entire length of the mold cavity and with the grains or elongated crystals extending parallel to the axis 66.

Although it is contemplated that the mold 10 could be constructed with the cavities 38 to form different types of articles, the mold 10 is advantageously used to form a directionally solidified airfoil 70 (see Fig. 4). The airfoil 70 has a leading edge portion 74 and a trailing edge portion 76 which extend between a root end portion 78 and a tip end portion 80 of the airfoil. It should be understood that the configuration of the airfoil 70 has been indicated schematically in Fig. 4 and is merely representative of many known airfoil configurations.

When the airfoil 70 is to be cast, molten metal is poured into the mold cavity 38. Although many different types of metal could be utilized, it is contemplated that the molten metal may be a nickel-base superalloy. When the molten metal engages the upper side surface 58 of the starter element 50, elongated columnar crystals or grains 86 (see Fig. 4) are nucleated at the end surfaces of the elongated crystals or grains 62 in the starter element 50. This results in the airfoil 70 having a multi-grained elongated crystal structure which corresponds to the multi-grained elongated crystal structure of the starter element 50.

The elongated grains or crystals 86 in the directionally solidified airfoil 70 have longitudinal axes which extend parallel to the longitudinal axes of the grains 62 in the starter element 50 and to a longitudinal central axis 88 of the airfoil 70 (see Fig. 4). Although a few of the grains or crystals 86 which are nucleated at the upper face 58 of the starter element 50 may terminate part way through the airfoil 70, the vast majority of the grains 86 extend completely through the airfoil 70 from the root end 78 to the tip end 80 of the airfoil. This results in the airfoil 70 having a multi-grained structure throughout its axial length. Although the airfoil 70 may have a leading edge 74 with a twisted and/or bowed configuration, the elongated crystals 86 extend substantially parallel to the leading edge 74 of the airfoil 70 to enhance the operating characteristics of the airfoil 70 in a known manner.

Each of the elongated crystals or grains 86 in the airfoil 70 is formed of a plurality of cubic unit cells 94 (Figs. 4 and 5) having the same orientation relative to the longitudinal axis of the crystal. In addition, the unit cells 94 in each elongated crystal 86 have the same longitudinal orientation relative to the unit cells in adjacent crystals. Thus, adjacent longitudinally extending crystals 86 have unit cells which have the same longitudinal orientation relative to the longitudinal central axis 88 of the airfoil 70.

The unit cell, the fundamental building block of the crystal, has an atomic arrangement which, when repeated in three dimensions, gives the total structure of the crystal. The configuration of the unit cell will vary depending upon the material from which the crystal is formed. For the nickel-base superalloy forming the airfoil 70, the unit cell 94 has a face-centered cubic configuration which consists of an atom at each cube corner and one at the center of each face, as depicted in Fig. 4. The orientations within each unit cell is specified in terms of its coordinates relative to orthogonal X, Y and Z axes. When specifying directions in a crystal the notation [XYZ] is used to indicate the direction of a line from the origin to a point the coordinates are X, Y and Z. By custom, brackets are utilized and fractional coordinates are avoided.

Thus, a direction along one of the edges of the cubic cell would also be parallel to one of the three axes and would be denoted as [100], [$\bar{1}$00], [010], [0$\bar{1}$0], [001], or [00$\bar{1}$]. In each case, the minus notation above the numeral denotes a negative direction from the origin. Each of these directions is said to be equivalent and of the <100> family. Crystals whose longitudinal axes are vertically aligned and which one of the unit cell axes is also vertically aligned are said to have a [001] orientation, reflecting the convention of denoting the vertical axis as Z. The spatial position of the unit cell may be simply visualized as that of a cube lying flat on one of its faces with the longitudinal central axis 88 being perpendicular to the horizontal plane on which the cube rests.

An extreme form of unit cell orientation occurs in a direction joining the diagonally opposite corners of the cube. This may be visualized as a cube so positioned that one corner makes point contact with a horizontal surface and the other, diagonally opposite, corner falls on a line that both joins the two corners and is perpendicular to the supporting horizontal surface. There are several such equivalent directions in a cubic unit cell, all part of the <111> family. A crystal in which a direction of this family is parallel to the longitudinal central axis 88 is said to have a [111] orientation. Intermediate between these two extreme orientations of [001] and [111], numerous others are possible. The notation accorded these is well known in the field of crystallography and is not essential to delineating the features of this invention.

Turbine engine blades and vanes produced by the process of directional solidification wherein metal is solidified in contact with a horizontally disposed copper chill typically involve the use of nickel-base superalloys having a face-centered cubic crystal structure. The resulting orientation of elongated crystals in this process [001]. The side surfaces or faces of the unit cells lie either perpendicular or parallel to the longitudinal central axis 88 of the airfoil 70. This orientation is recognized as superior from the standpoint of thermal fatigue resistance. However, other orientations, particularly the [111], offer the possibility of greatly improved Young's modulus without sacrifice in creep strength. Such a combination of properties may be attractive in applications where particular vibrational and high temperature strength characteristics are desired and thermal fatigue resistance is not a pacing concern.

The airfoil 70 is cast with each cubic unit cell 94 in the same orientation with respect to the longitudinal axis 88 and with each side surface of a unit cell extending at an acute angle relative to the longitudinal axis of the crystals 86. In one extreme case, this results in a cube diagonal corner to corner orientation of the unit cells denoted above as [111]. Thus, each of the side surfaces of the unit cells 94 extends at an acute angle to the longitudinal axes of the crystals 86 and corresponding longitudinal central axis 88 of the airfoil 70. Although the side surfaces of the unit cells 94 are skewed relative to the longitudinal axes, each cell within an individual crystal has the same orientation.

The skewed relationship of the side surfaces of the unit cell 94 relative to the central axis of a crystal 86 has been illustrated schematically in Fig. 4. Thus, the face centered cubic unit cell 94 has side surfaces 96, 98 and 100 all of which extend at acute angles relative to the longitudinal central axis of the crystal 86. Although only three of the six side surfaces of the cubic cell 94 have been identified in Fig. 4, it should be understood that the other three side surfaces of the cubic cell also extend at acute angles to the longitudinal axis of the crystal 86.

Although the unit cells 94 of the crystals 86 could be oriented with the side surfaces of the cubic cells skewed in many different angles relative to the longitudinal axes of the crystals, in one specific preferred embodiment the [111] direction of the unit cells is parallel to the longitudinal axis of the crystals 86 and corresponding longitudinal central axis 88 of the airfoil 70.

A unit cell 94 having this orientation has been illustrated schematically in Fig. 5. It should be noted that, although the unit cell 94 is of the face-centered cubic construction, only the lattice points at the corners of the unit cell 94 have been illustrated in Fig. 5, the lattice points at the center of each face being omitted for purposes of clarity of illustration. In Fig. 5, the [111] direction, parallel to the longitudinal axis of the crystals 86 and longitudinal central axis 88 of the airfoil 70, is denoted by the arrow 106.

When the unit cell has the [111] orientation shown in Fig. 5, each of the side surfaces of the unit cell 94 extends at an acute angle relative to the longitudinal central axis 88 and a line extending between one pair of diagonally opposite corners of the unit cell is parallel to the axis 88. Although only a single unit cell 94 has been shown in Figs. 4 and 5, it should be understood that other unit cells of the elongated crystals 86 have the same longitudinal orientation. Within an individual crystal 86 all unit cells also share a common rotational orientation about the longitudinal central axis 88 such that the corresponding side surfaces of all unit cells are parallel. Although other crystals 86 need not share the same rotational orientation, a common longitudinal orientation of [111] exists, imparting within the airfoil 70 a common set of Young's modulus and other mechanical behavior characteristics along the longitudinal central axis 88.

The extreme cornerwise or skewed, cube diagonal, [111], orientation of the unit cell 94 provides the highest value of Young's modulus. At ambient temperature this value is approximately 44,000,000 psi (724,000,000 kPa) versus approximately 18,000,000 psi (303,000,000 kPa) for an [001] orientation. High creep strength has also been reported for the [111] orientation as measured by creep rates and stress rupture lives at elevated temperatures on tests performed using individual crystals of nickel-base superalloys. Depending on the alloy and specific test conditions of stress and temperature, the [111] orientation has been found to provide considerably less primary creep versus that of an [001] orientation and stress rupture lives that are comparable to and, in some cases, superior to those seen with an [001] orientation. Using available data for two nickel-base superalloys, one published study postulates that the [111] orientation provides the highest creep resistance and rupture lives in comparison with [001] or other orientations.

In order to form the airfoil 70 with elongated crystals or grains 86 in which the unit cells 94 are oriented with their side surfaces extending at an acute angle relative to the central axis of the crystal, the crystals 62 in the starter element 50 have unit cells which are disposed in the same orientation as the unit cells in the crystals 86 of the airfoil 70. Thus, the unit cells of each crystal 62 in the starter element 50 has a face-centered cubic construction. Each of the side surfaces of the cubic unit cells of the starter crystals 62 extends at an acute angle relative to the longitudinal axes of the crystals 62 and relative to the mold axis 66. Since the airfoil 70 is formed of elongated crystals or grains 86 in which each of the unit cells has a [111] orientation, the longitudinally extending starter crystals 62 have unit cells which also have a [111] orientation.

During a casting operation molten metal is poured into the mold 10. The molten metal engages the upper side surface 58 of the starter element 50. The starter crystals 62 having unit cells located in the [111] orientation then nucleate airfoil crystals 86 in which the unit cells have a corresponding [111] orientation. As the crystals 86 continue to grow from the upper side surface 58 of the starter element 50 to the tip end 80 of the airfoil 70, the orientation of the unit cells 94 in the crystals 86 remains constant. Therefore, all of the unit cells in each of the airfoil crystals 86 have the same [111] orientation.

In view of the foregoing description, it is apparent that the described embodiment of the present invention utilizes a directionally solidified seed or starter element 50 having elongated crystals or grains 62. The starter element or seed 50 is oriented in a mold 10 with the longitudinal axes of the crystals 62 in the starter element 50 extending parallel to the preferred direction of grain growth in the mold cavity 38. This results in the initiation or formation of elongated metal crystals or grains 86 in the mold cavity 38 at the starter element 50 with the longitudinal axes of these grains 86 extending parallel to the longitudinal axes of the elongated metal crystals 62 in the starter element.

By having the elongated crystals 62 in the seed or starter element 50 oriented with a longitudinal axis extending parallel to the direction of grain or crystal growth in the mold cavity 38, molten metal which is poured into the mold cavity comes into contact with the ends of the longitudinally extending grains or crystals 62 in the starter element. This results in the nucleation of a multiplicity of crystals or grains 86 having the same orientation as the grains or crystals 62 in the starter element 50. The nucleation of directionally oriented crystals 86 at the starter element 50 eliminates the competitive growth zone which characterizes most prior directional solidification casting processes in which the [001] orientation is a natural outgrowth of the early stages of the solidification near the chill surface.

The longitudinally extending crystals or grains 86 which are nucleated at the ends of the grains 62 in the starter element have unit cells 94 which are disposed in the same orientation as the unit cells of the starter element. By providing a starter element 50 having elongated grains or crystals 62 with unit cells having their side surfaces skewed or extending at an acute angle to the longitudinal axes of the crystals or grains of the starter element, longitudinally extending crystals or grains 86 with unit cells having a similar orientation will be formed in the cast article. In one specific preferred embodiment it is advantageous for the unit cells in the starter element to have a [111] orientation to effect the solidification of a cast article 70 having an elongated crystal structure with the unit cells 94 having the same [111] orientation. When the unit cells 94 are oriented with all of their side surfaces extending at an acute angle relative to the longitudinal central axis of the grains of the cast product 70, the Young's modulus and creep resistance of the cast product is improved.

Although the method the present invention can be used in casting many different types of products, the method is advantageously used to cast airfoils 70 with the elongated crystals or grains 86 having longitudinal axes extending substantially parallel to a leading edge 74 of the airfoil.

Claims

1. A method of casting a directionally solidified article (70) formed of elongated metal crystals (86) having generally parallel longitudinal axes, said method comprising the steps of providing a one-piece starter element (50) which has a plurality of elongated metal crystals (62) disposed in a side-by-side relationship with longitudinal axes which are substantially perpendicular to first and second sides (54, 58) of the starter element and with the second side (58) of the starter element being formed by ends of the elongated metal crystals (62), providing a chill (42), providing a mold (10) having an open end portion and a cavity (38) in which the article is to be cast, positioning the starter element (50) in the open end portion of the mold with the first side (54) of the starter element exposed to the chill and the second side (58) of the starter element exposed to the mold cavity, pouring molten metal into the mold cavity, and initiating the formation in the mold cavity of a plurality of elongated metal crystals having longitudinal axes extending substantially parallel to the longitudinal axes of the elongated metal crystals (62) in the starter element, said step of initiating the formation of metal crystals in the mold cavity including the step of engaging the ends of the elongated metal crystals at the second side (58) of the starter element with the molten metal whilst the first side (54) of the starter element is exposed to the chill (42).

2. A method as set forth in claim 1, wherein said step of providing a directionally solidified starter element includes the step of providing a starter element in which elongated metal crystals (62) extend between the first and second sides (54, 58) of the starter element (50).

3. A method as set forth in claim 1 or 2, wherein the elongated crystals (62) in the starter element (50) have unit cells oriented with a (111) direction in each unit cell extending substantially perpendicular to the first and second sides (54, 58) of the starter element.

Patentansprüche

1. Verfahren zum Gießen von gerichtet erstarrten Gegenständen (70) aus langgestreckten Metall-Kristallen (86) mit im wesentlichen parallelen Längsachsen, gekennzeichnet durch die Verfahrensschritte: ein einteiliges Starterelement (50) wird vorgesehen, in welchem sich eine Anzahl von langgestreckten Metallkristallen (62) — Seite an Seite zu den Längsachsen, die im wesentlichen senkrecht zu der ersten und zweiten Fläche (54 bzw. 58) des Starterelements sind, — befindet und die zweite Fläche (58) des Starterelements von den Enden der langgestreckten Metallkristalle (62) gebildet ist; eine Kühlplatte (42) und eine Form (10) wird vorgesehen, welche letztere ein offenes Endteil und einen Formhohlraum (38) aufweist, in welchem der Gegenstand abgegossen werden soll; das Starterelement (50) wird in den offenen Endteil der Form mit der ersten Fläche (54) des Starterelements gegen die Kühlplatte und der zweiten Fläche (58) des Starterelements gegen den Formhohlraum angeordnet; Metallschmelze wird in den Formhohlraum gegossen und die Bildung einer Anzahl von langgestreckten Metallkristallen mit Längsachsen im wesentlichen parallel zu den Längsachsen der langgestreckten Metallkristalle (62) des Starterelements wird eingeleitet, wobei die Verfahrensstufe des Einleitens der Bildung von Metallkristallen im Formhohlraum auch die Verfahrensstufe umschließt, bei der die Enden der langgestreckten Metallkristalle an der zweiten Fläche (58) des Starterelements mit der Metallschmelze in Berührung kommen, während die erste Fläche (54) des Starterelements der Einwirkung der Kühlplatte (42) ausgesetzt ist.

3. Verfahren nach Anspruch 1, wobei die Verfahrensstufe der Anwendung eines gerichtet erstarrten Starterelements die Verfahrensstufe umfaßt, ein Starterelement vorzusehen, bei dem sich langgestreckte Metallkristalle (62) zwischen der ersten und der zweiten Fläche (54 bzw. 58) des Starterelements (50) befinden.

3. Verfahren nach Anspruch 1 oder 2, wobei die langgestreckten Kristalle (62) des Starterelements (50) Elementarzellen der Klasse (111) haben, die sich im wesentlichen senkrecht zu der ersten und zweiten Fläche (54 bzw. 58) des Starterelements erstrecken.

Revendications

1. Procédé de coulée d'un objet (70), solidifié de façon orientée, formé de cristaux métalliques (86) allongés comportant des axes longitudinaux parallèles de façon générale, ledit procédé comprenant les étapes consistant à fournir un élément d'amorce (50) d'une seule pièce, lequel présente une pluralité de cristaux métalliques (62) allongés, disposés côte-à-côte avec des axes longitudinaux qui sont sensiblement perpendiculaires aux premier et second côté (54, 58) de l'élément d'amorce, le second côté (58) de l'élément d'amorce étant formé par les extrémités des cristaux métalliques (62) allongés, à fournir une coquille (42), à fournir un moule (10) ayant une portion d'extrémité ouverte et un creux (38) dans lequel l'objet doit être coulé, à positionner l'élément d'amorce (50) dans la portion d'extrémité ouverte du moule en ayant le premier côté (54) de l'élé-

ment d'amorce exposé à la coquille et le second côté (58) de l'élément d'amorce exposé au creux du moule, à couler le métal fondu dans le creux du moule, et à amorcer dans le creux du moule la formation d'une pluralité de cristaux métalliques allongés présentant des axes longitudinaux se prolongeant de façon sensiblement parallèle aux axes longitudinaux des cristaux métalliques (62) allongés dans l'élément d'amorce, ladite étape d'amorçage de la formation de cristaux métalliques dans le creux du moule comprenant l'étape consistant à engager les extrémités des cristaux métalliques allongés sur le second côté (58) de l'élément d'amorce avec le métal fondu tandis que le premier côté (54) de l'élément d'amorce est exposé à la coquille (42).

2. Procédez tel que défini dans la revendication 1, dans lequel ladite étape consistant à fournir un élément d'amorce solidifié de façon orientée comprend l'étape consistant à fournir un élément d'amorce dans lequel des cristaux métalliques (62) allongés se prolongent entre les premier et second côtés (54, 58) de l'élément d'amorce (50).

3. Procédé tel que défini dans la revendication 1 ou 2, dans lequel les cristaux allongés (62) dans l'élément d'amorce (50) présentent des cellules unitaires orientées selon une direction (111) dans chaque cellule unitaire qui se prolonge de façon sensiblement perpendiculaire aux premier et second côtés (54, 58) de l'élément d'amorce.

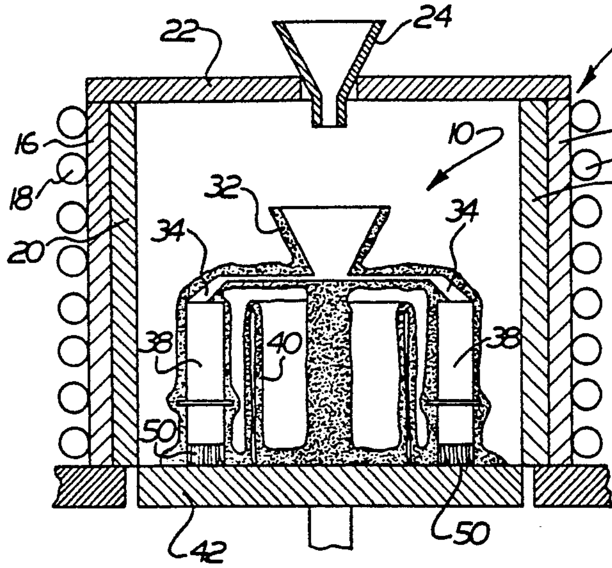

FIG. 1

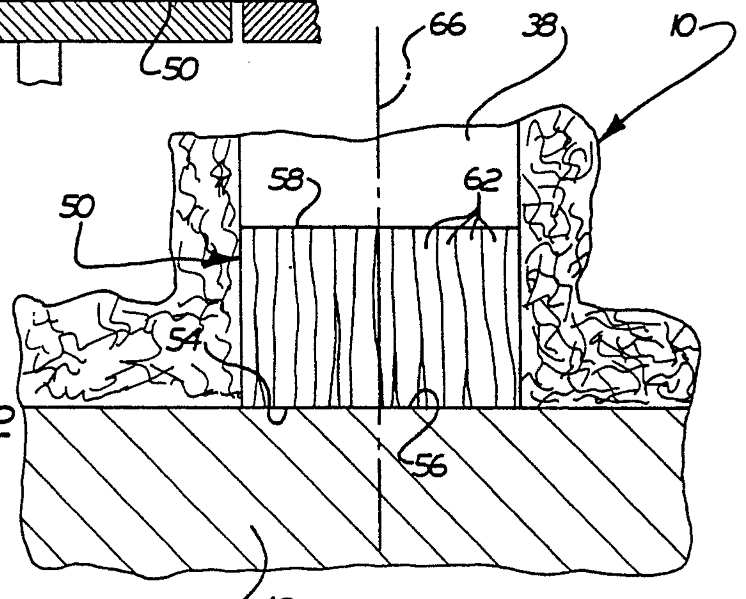

FIG. 2

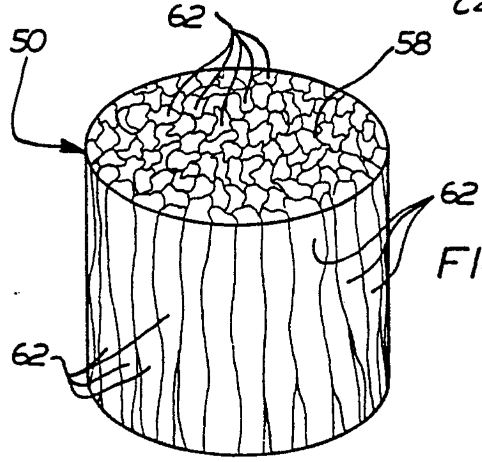

FIG. 3

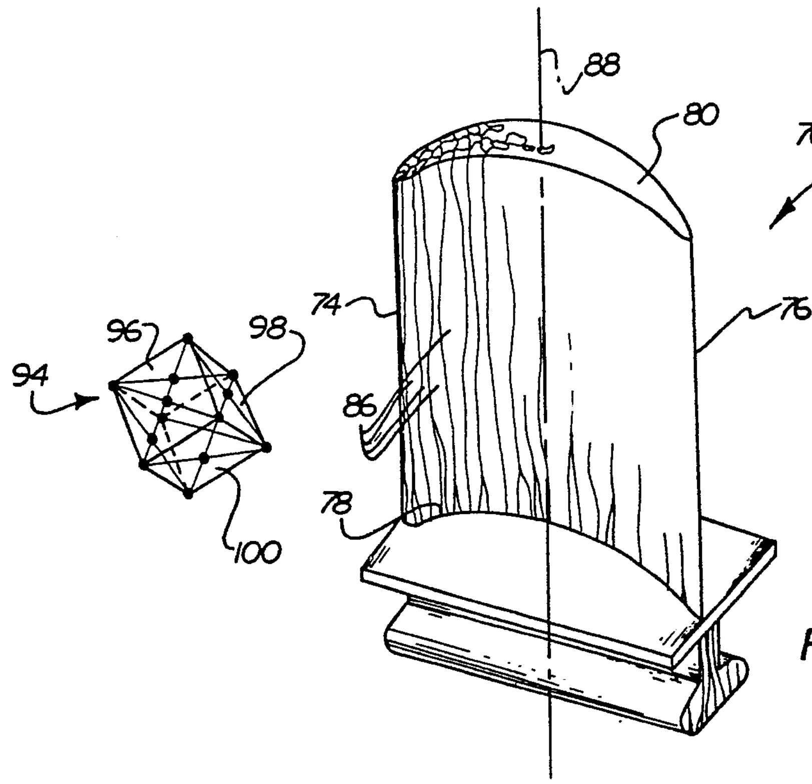

FIG.4

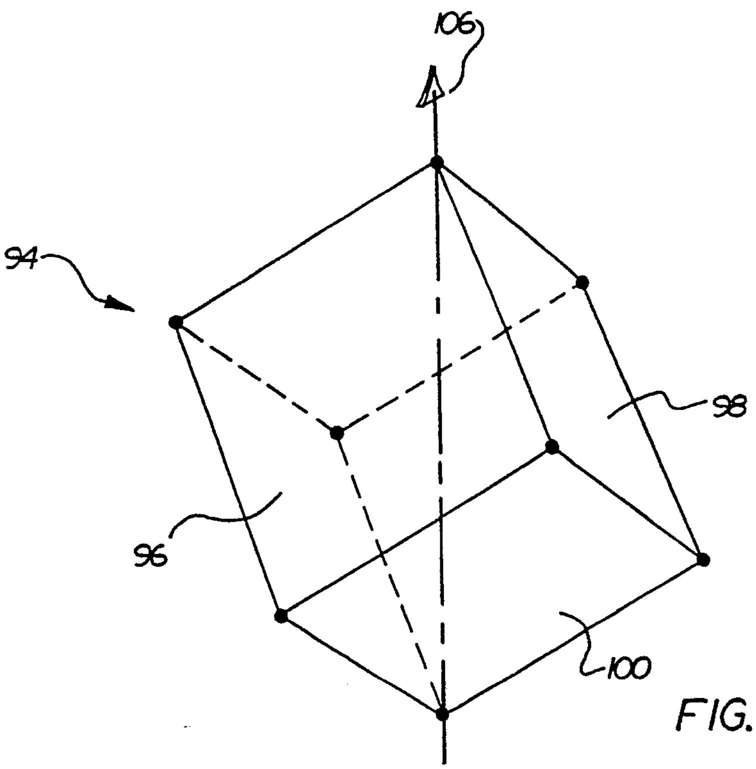

FIG. 5