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METAL PROGRESS, vol. 99, no. 3, March 1971, pages 58-60, J.S. ERICKSON et al.: "Process speeds up directional solidification"

(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)

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Description

The present invention relates to a method of making directionally solidified (DS) castings and more specifically to a method which reduces the time required to cast a directionally solidified article without reducing the quality of the cast product.

In casting directionally solidified articles from nickel-base superalloys, a mold is commonly positioned on a chill plate which is slowly withdrawn from a furnace to provide for controlled solidification of molten metal in the mold in a manner similar to that disclosed in US—A—3,700,023 and 3,714,977. During various DS casting operations, it has been observed that the mold can be withdrawn from the furnace at speeds of up to about 20 in/hr (50.8 cm/h) to generate acceptable columnar grain structures. The specific speeds at which a particular article is withdrawn from the furnace are governed by the geometry of the article. If it is attempted to use higher speeds, such as 30 in/h (76.2 cm/h), it has previously been determined that a substantial and very objectionable coarsening of the columnar grains occurs. Attempts to change the temperatures and temperature distribution in the furnace hot zone have proven to be ineffective in permitting the use of faster withdrawal speeds for the production of gas turbine articles such as blades and vanes.

In an effort to increase withdrawal speeds to a rate of 25 in/hr (63.5 cm/hr) or faster, US—A—3,532,155 discloses an apparatus in which the mold and cooling plate are moved through a heat sink which is disposed immediately beneath the furnace. As a still further effort to reduce the time required to form a casting, US—A—4,190,094 suggests varying the rate of withdrawal of the mold from a furnace as a function of the geometry of the article to be cast and other factors.

An article entitled 'Process Speeds up Directional Solidification in Metal Progress, 1971, Pages 58—60' discloses a method of increasing the solidification rate during casting in order to reduce the casting cycle time which relies on increasing the temperature gradient in the solidified metal during withdrawal of the mold from the furnace by locating at the base of the suscept or of the furnace a radiation baffle through which the mold passes during withdrawal from the furnace at a preset speed.

US—A—3714977 discloses the use of a radiation baffle which is supported on the chill plate during initial withdrawal of the chill plate and mold thereon from the furnace and thereafter is supported by stop means at the base of the furnace such that on further withdrawal of the chill plate and mold from the furnace the mold passes through the radiation baffle. This US specification also discloses increasing the mold withdrawal speed from a first rate to a second rate and subsequently to the maximum rate permitted by the apparatus. However, no explanation of why the withdrawal rate is increased in this manner nor any indication of the factors which determine when the increases should occur are given.

An object of the present invention is to decrease the time required to form a directionally solidified (DS) casting without substantial coarsening of the columnar grains of the casting.

The invention relates to a method of casting a directionally solidified article in a mold cavity, said method comprising the steps of heating at least a portion of a mold in a furnace, pouring molten metal into a cavity in the mold, withdrawing the mold from the furnace at a first rate after having performed said step of pouring molten metal into the mold cavity, solidifying the molten metal in the mold cavity while performing said step of withdrawing the mold from the furnace at the first rate, said step of solidifying the metal in the mold cavity including the steps of forming a dendritic structure having molten metal in its interstices, solidifying portions of the molten metal in the interstices and continuing the formation of the dendritic structure until the dendritic structure reaches an upper end of the mold cavity while performing said step of solidifying portions of the molten metal in the interstices, and increasing the rate of solidification of the molten metal in the interstices of the dendritic structure when the dendritic structure reaches the upper end of the mold cavity, said step of increasing the rate of solidification of the molten metal includes the step of increasing the rate at which the mold is withdrawn from the furnace from the first rate to a second rate when the dendritic structure reaches the upper end of the mold cavity.

Thus in a method according to the invention a mold is initially withdrawn from a furnace relatively slowly and a dendritic structure grows upwardly toward the upper end of the mold cavity. The uppermost interstices of this dendritic structure are filled with molten metal. In the art this region of the casting in which a skeleton of solid dendrite and liquid metal coexist is called the mushy zone. When the dendritic structure reaches the upper end of the mold cavity, the rate of withdrawal of the mold from the furnace is increased to increase the rate of solidification of the molten metal in the interstices of the dendritic structure, that is, to complete solidification of the mushy zone.

In carrying out the method the rate at which the mold is withdrawn from the furnace may be maintained substantially constant at the first rate until the dendritic structure reaches the upper end of the mold cavity. The second rate of withdrawal may be greater than 30 in/hr (76.2 cm/hr).

Although it is contemplated that a method in accordance with the present invention may be used to cast many different types of articles, an advantageous application of the invention is to the casting of airfoils having relatively thick bases and thin airfoils. In this connection, the invention includes a method of casting an article having a relatively thick base and a relatively thin airfoil, said method comprising the steps of heating in a furnace at least a portion of a mold having a cavity having a configuration corresponding to the configuration of the article, an upper end portion of the cavity having a configuration corresponding to the configuration of the relatively thin airfoil of the article, pouring molten metal into the mold cavity, withdrawing the mold from the furnace at a first rate after having performed said step of pouring molten metal into the mold cavity, solidifying the molten metal in the mold cavity to form the relatively thick base of the blade while performing said step of withdrawing the mold from the furnace at the first rate, solidifying part of the molten metal in the upper end portion of the mold cavity to form a portion of the relatively thin airfoil of the article while continuing to perform said step of withdrawing the mold from the furnace, said step of solidifying the molten metal to form a portion of the relatively thin airfoil including the step of extending a dendritic structure with molten metal in its interstices upwardly from the solidified metal forming part of the relatively thin airfoil while performing said step of withdrawing the mold from the furnace, increasing the rate at which the mold is withdrawn from the furnace to a second rate which is greater than the first rate when the dendritic structure extends to the upper end of the mold cavity, and solidifying the molten metal in the interstices of the dendritic structure to complete the formation of the relatively thin airfoil while withdrawing the mold from the furnace at the second rate. Thus during the solidification of the metal in the relatively thick base and a lower portion of the airfoil, the mold is slowly withdrawn from the furnace. However, as soon as the dendritic structure in the relatively thin airfoil reaches the upper end of the mold cavity, that is the tip of the airfoil, the rate of withdrawal of the mold from the furnace is increased to increase the speed of solidification of the molten metal remaining in the dendritic structure.

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

Fig. 1 is a schematic illustration depicting the relationship between a mold containing molten metal and a furnace immediately after pouring of the molten metal into the mold;

Fig. 2 is a schematic illustration depicting the relationship between the mold and the furnace after the mold has been partially withdrawn from the furnace at a relatively slow speed and the molten metal in the mold cavity has partially solidified;

Fig. 3 is an enlarged fragmentary schematic illustration depicting the relationship between a portion of the mold of Fig. 2, the solidified metal at a lower end of the mold cavity, and a schematically illustrated dendritic structure extending upwardly from the solidified metal to an upper end of the mold cavity;

Fig. 4 is a schematic illustration depicting the columnar grain appearance of a blade cast with the mold of Fig. 1 by withdrawing the mold from the furnace at a relatively slow speed until the dendritic structure extends to the upper end of the mold cavity as shown in Fig. 3 and then rapidly withdrawing the mold from the furnace; and

Fig. 5 is a schematic illustration, generally similar to Fig. 4, of the columnar grain appearance of an airfoil formed by rapidly withdrawing a mold from a furnace.

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.

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. The furnace 12 is of a known construction and may be constructed in accordance with US—A—3,376,915; 3,700,023 and/or 3,714,977.

When molten metal is poured into the basin 22 and the runners 34 to mold cavity 38, the molten metal flows downwardly and solidifies against the chill plate 42. A large number of randomly oriented crystals are nucleated at the chill plate. As this is occurring, a dendritic structure starts to extend upwardly from the metal which is solidified against the chill plate into a competitive growth zone. The chill plate is then slowly lowered from the furnace. As the chill plate is lowered, the most favourably oriented grains or crystals emerge from the competitive growth zone and the dendritic structure continues to grow upwardly into the mold cavity 38. Although it is contemplated that the chill plate could be lowered at many different rates, relatively slow initial lowering rates below about 20 in/hr (50.8 cm/h) are presently preferred. It is contemplated that for some parts it will be preferred to maintain the relatively slow initial withdrawal rate substantially constant. However, for other parts, it may be preferred to vary the initial withdrawal somewhat between speeds which are less than about 20 in/h (50.8 cm/h).

In accordance with a feature of the present invention, once the dendritic structure has reached the upper end 54 of the mold cavity 38, the rate of withdrawal of the mold is substantially increased. This results in relatively rapid solidification of the molten metal remaining in the interstices of the dendritic structure. However, since the basic dendritic structure has already been established throughout the length of the mold cavity, the rapid solidification of the molten metal that remains in the so-called mushy zone does not lead to coarsening of the grain structure.

In practicing the method embodying the invention, the mold 10 is initially lowered from the position shown in Fig. 1 to the position shown in Fig. 2 at relatively slow speeds, that is speeds of approximately 20 in/h (50.8 cm/h) or less. Once the mold 10 has been moved to the partially withdrawn position shown in Fig. 2 and a dendritic structure 56 (Fig. 3) extends from a fully solidified body 58 of metal at the lower end portion of the mold cavity 38 to the upper end 54 of the mold cavity, the rate of downward movement of the chill plate is increased. The interstices of the uppermost portions of the dendritic structure, the so-called mushy zone, are filled with molten metal 60.

It is contemplated that the rate of downward movement of the chill plate will be increased by a substantial extent when the dendritic structure 56 reaches the top of the mold cavity. However, it is believed that the amount by which the rate of withdrawal can be increased will depend upon the article being cast and the specific alloy of which it is formed. However, in one specific instance, the rate of withdrawal of the mold was increased from a speed of less than 20 in/hr (50.8 cm/h) to a speed of more than 34 in/hr (86.36 cm/h) in casting a turbine blade formed of a nickel-base superalloy. Even though the rate of withdrawal of the mold 10 from the furnace assembly 12 was substantially increased, there was no objectionable coarsening of the grains of the cast article. It is believed that this is because the molten metal 60 in the interstices of the dendritic structure solidified without altering the basic dendritic structure which had been established throughout the molten metal in the mold cavity 38 prior to the increased rate of withdrawal of the mold 10 from the furnace assembly 12.

Although it is contemplated that a method in accordance with the present invention can be used during the casting of many different articles, a particularly advantageous use of such a method is the casting of a directionally solidified airfoil. Thus, each of the mold cavities 38 has a lower portion with a configuration corresponding to the configuration of a starter block and the base of the blade. Each of the mold cavities 38 also has a portion which extends upwardly from the base portion of the mold cavity and has a configuration corresponding to the configuration of the airfoil of the blade. The airfoil of the blade has a substantially uniform thickness throughout its axial extent.

A mold cavity 38 with a partially cast blade 62 is shown schematically in Fig. 3. The mold cavity 38 includes a lower end portion 64 which extends upwardly from an upper surface 66 of the chill plate 42. This lower end portion 64 of the mold cavity has a generally rectangular configuration. Directly above the lower end portion 64 of the mold cavity 38 is an intermediate portion 68 having a configuration corresponding to the configuration of the base 70 of the blade 62. An upper portion 72 of the mold cavity 38 extends upwardly from the intermediate portion 69 and has a configuration corresponding to the configuration of an airfoil portion 74 of the blade 62. The mold cavity terminates at the upper end surface 54 which is connected with a runner 34 through which molten metal enters the mold cavity 38.

When the blade 62 is to be cast in the mold cavity 38, molten metal enters the mold cavity through the runner 34. Molten metal flows downwardly through the mold cavity 38 into engagement with the upper surface 66 of the chill plate 42. The molten metal immediately solidifies in the lower end portion 64 of the mold cavity 38. The initially solidified molten metal has a random columnar grain structure next to the chill plate 42. However, the more favorably oriented grains grow rapidly upwardly from the chill plate 42 through a competitive growth zone from which the most favorably oriented grains emerge. These most favorably oriented grains enter the intermediate portion 68 of the mold cavity and solidify to initiate formation of a base portion 70 of the blade 62.

As the molten metal is solidifying, an upwardly extending dendritic structure 56 is formed. This dendritic structure consists of a plurality of most favorably oriented grains which form a plurality of upwardly extending dendrites. As the upward formation of the dendritic structure 56 continues, the molten metal in the interstices of the uppermost portions of dendritic structure solidifies to continue the formation of the base portion 70 of the blade 62.

As the upward growth of the dendritic structure 56 extends into the upper portion 72 of the mold cavity 38, the formation of the base portion 70 of the blade 62 is completed and continued solidification of the molten metal in the interstices of the dendritic structure initiates the formation of the airfoil 74. As the molten metal solidifies to form the lower end portion of the airfoil 74, the dendritic structure grows upwardly to the tip of the airfoil at the surface 54.

At this time, the base 70 of the airfoil has solidified and the lower portion of the airfoil 74 of the blade is solidified. However, the upper portion of the airfoil of the blade has not fully solidified. Thus, there is a basic dendritic structure 56 extending from the solidified lower portion of the airfoil 74 to the tip of the airfoil at the upper end surface 54 of the mold cavity 38. The interstices of the uppermost portions of the basic dendritic structure 56 are filled with molten metal 60. This uppermost portion, containing both solid dendrites and interstices filled with molten metal is known in the art as the mushy zone. The height of the mushy zone can be several inches (several amounts of 2.54 cm), with the specific distance being related to the alloy being cast and how sharp the vertical temperature drop or thermal gradient is in the solidifying metal.

When the dendritic structure 56 has reached the upper end 54 of the mold cavity 38, the rate of withdrawal of the mold 10 from the furnace assembly 12 is substantially increased. Since the dendritic structure has been formed throughout the length of the airfoil 74 of the blade 62, there is coarsening of the grains at the upper end portion or tip of the airfoil due to the increased speed of withdrawal of the mold 10 from the furnace 12. This is true even though the airfoil 74 has a substantially uniform thickness throughout its length.

The blade 62 which results from this casting process has been illustrated schematically in Fig. 4. The grains of the directionally solidified blade extend to the tip end of the airfoil without coarsening of the grains. By way of experimentation, a mold of the same general construction as the mold 10 was withdrawn at a constant relatively high speed from the furnace assembly 12. The resulting blade 80 (see Fig. 5) had a relatively fine grain structure adjacent to its base 82 and at the lower end portion 84 of the airfoil 86. However, the upper or airfoil tip portion 88 of the airfoil was very coarse grained and consisted of two or three crystals. The coarse grained outer end portion of the airfoil 86 of the blade 80 makes the casting unacceptable for use in most circumstances. However, the continuous fine grained structure of the blade 62 (Fig. 4) is quite acceptable for most purposes.

The fine grained structure of the blade 62 could have been obtained by withdrawing the mold from the furnace assembly 12 at a constant and relatively low speed. Thus, an airfoil with the same fine grained structure as has been illustrated schematically in Fig. 4 for the blade 62 could have been obtained by withdrawing the mold 10 from the furnace 12 at a relatively low speeds of approximately 20 in/h (50.8 cm/h) or less. However, this results in a relatively long casting process.

The above described method embodying the present invention substantially decreases the amount of time required to cast the fine grained blade 62 by increasing the rate of withdrawal of the mold 10 from the furnace 12 when the dendritic structure 56 has grown from the solidified body of metal 58 at the lower end portion of the mold 10 to the upper end surface 54 of the mold. Thus, the mold 10 is initially withdrawn at a relatively slow speeds from the furnace 12, that is at a speeds of less than about 20 in/hr (50.8 cm/h). Once the dendritic structure has extended throughout the molten metal in the mold cavity 38, the speed of withdrawal of the mold 10 from the furnace 12 is increased to, for example, a speed of greater than 30 m/hr (76.2 cm/h) for example to 34 in/h (86.36 cm/h).

It should be understood that the specific mold withdrawal rates previously set forth have been for purposes of clarity of illustration and it is contemplated that these withdrawal rates may vary. The specific mold withdrawal rates of less than about 20 in/h (50.8 cm/h) before the dendritic structure extends throughout the molten metal in the mold cavity 34 and the relatively rapid mold withdrawal rate of 34 in/h (86.36 cm/h) after the dendritic structure has grown to the end surface 54 of the mold cavity were used with a nickel base superalloy, specifically PWA 1422 alloy, with a mold which was preheated to approximately 2700°F. The time saved during the process of casting one specific airfoil by using the previously described low and then high speed withdrawal after the dendrites had extended through the molten metal was approximately 26 minutes. Of course, the maximum rate of withdrawal and the time saved on a casting cycle will vary with the characteristics of the article being cast and the specific, relatively slow, speeds at which it is cast using conventional practice.

In view of the foregoing it is apparent that the embodiment decreases the time required to form a directionally solidified (DS) casting without substantial coarsening of the columnar grains of the casting. This is accomplished by initially withdrawing a mold 10 from a furnace 12 at relatively slow speeds. At the mold 10 is slowly withdrawn from the furnace 12, a dendritic structure 56 grows upwardly toward the upper end 54 of the mold cavity 38. The interstices of this dendritic structure 56 are filled with molten metal. When the dendritic structure 56 reaches the upper end 54 of the mold cavity 38, the rate of withdrawal of the mold 10 from the furnace 12 is increased to increase the rate of solidification of the molten metal in the interstices of the dendritic structure 56.

Although it is contemplated that a method in accordance with the present invention may be used to cast many different types of articles, a particularly advantageous use of such a method is the casting of blades 62 having relatively thick bases 70 and thin airfoils 74. During the solidification of the metal in the relatively thick base 70 and a lower portion of the airfoil 74, the mold 10 is slowly withdrawn from the furnace 12. However, as soon as the dendritic structure in the relatively thin airfoil 74 reaches the upper end 54 of the mold cavity, that is the tip of the airfoil, the rate of withdrawal of the mold 10 from the furnace 12 is increased to increase the speed of solidification of the molten metal in the dendritic structure.

Claims

1. A method of casting a directionally solidified article (62) in a mold cavity (38), said method comprising the steps of heating at least a portion of a mold (10) in a furnace (12), pouring molten metal into a cavity (38) in the mold, withdrawing the mold from the furnace at a first rate after having performed said step of pouring molten

metal into the mold cavity, solidifying the molten metal in the mold cavity while performing said step of withdrawing the mold from the furnace at the first rate, said step of solidifying the metal in the mold cavity including the steps of forming a dendritic structure (56) having molten metal in its interstices, solidifying portions of the molten metal in the interstices and continuing the formation of the dendritic structure until the dendritic structure reaches an upper end (54) of the mold cavity while performing said step of solidifying portions of the molten metal in the interstices, and increasing the rate of solidification of the molten metal in the interstices of the dendritic structure when the dendritic structure reaches the upper end of the mold cavity, said step of increasing the rate of solidification of the molten metal includes the step of increasing the rate at which the mold is withdrawn from the furnace from the first rate to a second rate when the dendritic structure reaches the upper end of the mold cavity.

2. A method of casting an article (62) having a relatively thick base (70) and a relatively thin airfoil (74), said method comprising the steps of heating in a furnace (12) at least a portion of a mold (10) having a cavity (38) having a configuration corresponding to the configuration of the article, an upper end portion (72) of the cavity having a configuration corresponding to the configuration of the relatively thin airfoil (74) of the blade, pouring molten metal into the mold cavity, withdrawing the mold from the furnace at a first rate after having performed said step of pouring molten metal into the mold cavity, solidifying the molten metal in the mold cavity to form the relatively thick base of the article while performing said step of withdrawing the mold from the furnace at the first rate, solidifying part of the molten metal in the upper end portion of the mold cavity to form a portion of the relatively thin airfoil of the article while continuing to perform said step of withdrawing the mold from the furnace, said step of solidifying the molten metal to form a portion of the relatively thin airfoil including the step of extending a dendritic structure (56) with molten metal in its interstices upwardly from the solidified metal forming part of the relatively thin airfoil while performing said step of withdrawing the mold from the furnace, increasing the rate at which the mold is withdrawn from the furnace to a second rate which is greater than the first rate when the dendritic structure extends to the upper end (54) of the mold cavity, and solidifying the molten metal in the interstices of the dendritic structure to complete the formation of the relatively thin airfoil while withdrawing the mold from the furnace at the second rate.

3. A method as set forth in claim 1 or 2, further including the step of maintaining the rate at which the mold is withdrawn from the furnace substantially constant at the first rate until the dendritic structure reaches the upper end of the mold cavity.

4. A method as set forth in claim 1, 2 or 3, wherein said second rate of withdrawal is greater than thirty inches per hour (76.2 cm/h).

Patentansprüche

1. Verfahren zum Gießen richtungsmäßig verfestigter Gegenstände (62) in einem Formhohlraum (38) durch die Verfahrensstufen des Vorwärmens zumindest eines Teils einer Form (10) in einer Ofenanlage (12), Eingießens der Metallschmelze in einen Formhohlraum (38), Abziehens der Form aus der Ofenanlage mit einer ersten Geschwindigkeit — nachdem das Eingießen der Metallschmelze in den Formhohlraum stattgefunden hat —, Verfestigens der Metallschmelze in dem Formhohlraum — während des Rückziehens der Form aus der Ofenanlage mit der ersten Geschwindigkeit —, wobei die Verfahrensstufe des Verfestigens des Metalls im Formhohlraum die Verfahrensstufen der Bildung eines dendritischen Gefüges (56) mit Metallschmelze in den Zwischenräumen, Verfestigen von Teilen der Metallschmelze in den Zwischenräumen und Fortsetzung der Bildung des dendritischen Gefüges, bis dieses den oberen Teil (54) des Formhohlraums erreicht hat, umfaßt —, während die Verfestigung von Teilen der Metallschmelze in den Zwischenräumen stattfindet, und des Erhöhens der Erstarrungsgeschwindigkeit der Metallschmelze in den Zwischenräumen des dendritischen Gefüges, wenn dieses den oberen Teil des Formhohlraums erreicht hat, und die Verfahrensstufe der Erhöhung der Erstarrungsgeschwindigkeit der Metallschmelze die Verfahrensstufe der Erhöhung der Geschwindigkeit, mit der die Form aus der Ofenanlage zurückgezogen wird, von einer ersten auf eine zweite Geschwindigkeit umfaßt, sobald das dendritische Gefüge den oberen Teil des Formhohlraums erreicht hat.

2. Verfahren zum Abguß eines Gegenstands (62) mit einer relativ dicken Basis (70) und einem relativ dünnen Flügelteil (74) durch die Verfahrensstufen des Erhitzens eines Teils einer Form (10) mit einem Formhohlraum (38) einer Konfiguration entsprechend dem Gegenstand sowie einem oberen Teil (72) des Formhohlraums mit einer Konfiguration entsprechend der des relativ dünnen Flügelteils (74) in einer Ofenanlage (12), des Eingießens von Metallschmelze in den Formhohlraum, des Zurückziehens der Form aus der Ofeneinheit mit einer ersten Geschwindigkeit nach Einguß der Metallschmelze in den Formhohlraum, des Erstarrens der Metallschmelze in dem Formhohlraum unter Bildung der relativ breiten Basis des Gegenstands während des Rückziehens der Form aus der Ofenanlage mit einer ersten Geschwindigkeit, des teilweisen Erstarrens des Metalls in dem oberen Teil des Formhohlraums unter Bildung eines Teils des relativ dünnen Flügelteils des Gegenstands während des Rückziehens der Form aus dem Ofen — wobei das Verfestigen des Metalls unter Bildung einer Teils des relativ dünnen Flügelteils die Ausbildung eines dendritischen Gefüges (56) in der Metallschmelze der Zwischenräume bis zur Ausbildung

eines verfestigten Metallteils des relativ dünnen Flügelteils, während die Form aus der Ofenanlage zurückgezogen wird umfaßt —, des Erhöhens der Geschwindigkeit, mit der die Form aus der Ofenanlage zurückgezogen wird, auf eine zweite Geschwindigkeit, die größer als die erste Geschwindigkeit ist, sobald sich das dendritische Gefüge bis zum oberen Ende (54) des Formhohlraums erstreckt, und des Verfestigens der Metallschmelze in den Zwischenräumen des dendritischen Gefüges zur Vervollständigung der Bildung des relativ dünnen Flügelteils unter Zurückziehen der Form aus der Ofenanlage mit der zweiten Geschwindigkeit.

3. Verfahren nach Anspruch 1 oder 2 mit der zusätzlichen Verfahrensstufe, daß die Geschwindigkeit des Zurückziehens der Form aus der Ofenanlage im wesentlichen bei der ersten Geschwindigkeit konstant gehalten wird, bis das dendritische Gefüge den oberen Teil des Formhohlraums erreicht hat.

4. Verfahren nach einem der Ansprüche 1, 2 oder 3, worin die zweite Geschwindigkeit des Rückzugs größer als 30 in/h (76,2 cm/h) beträgt.

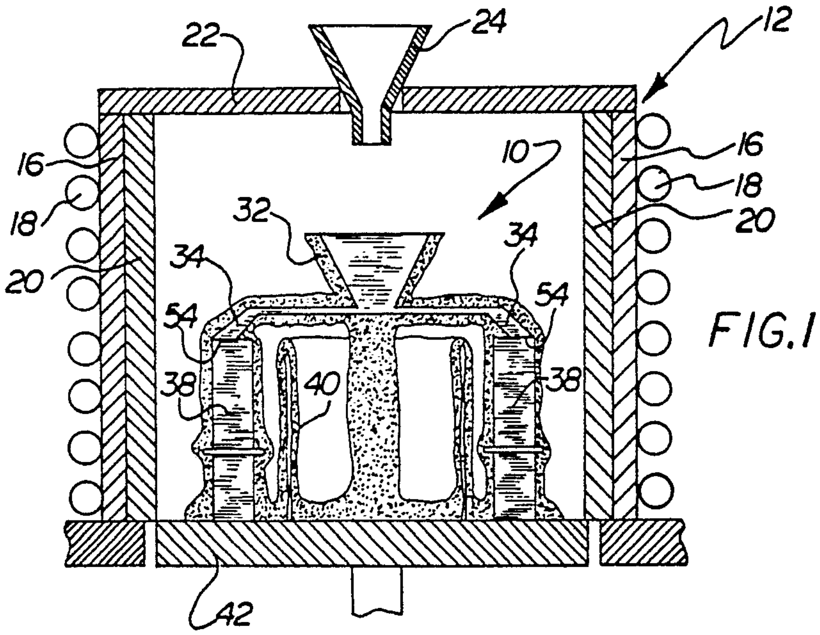
Revendications

1. Un procédé de coulée d'un article solidifié directionnellement (62) dans une cavité de moule (38), ledit procédé comprenant les opérations consistant à chauffer au moins une partie d'un moule (10) dans un four (12), à verser du métal fondu dans une cavité du moule (38), à retirer le moule du four à une première vitesse après avoir réalisé ladite opération de versage du métal fondu dans la cavité du moule, à solidifier le métal fondu dans la cavité du moule tout en effectuant l'opération de retrait du moule du four à la première vitesse, ladite opération de solidification du métal dans le four comprenant les étapes consistant à former une structure dendritique (56) comportant du métal fondu dans ses interstices, à solidifier des parties du métal fondu dans les interstices et à poursuivre la formation de la structure dendritique jusqu'à ce que la structure dendritique atteigne l'extrémité supérieure (54) de la cavité du moule tout en effectuant ladite étape de solidification de parties du métal fondu dans les interstices, et à augmenter la vitesse de solidification du métal fondu dans les interstices de la structure dendritique lorsque la structure dendritique atteint l'extrémité supérieure de la cavité du moule, ladite étape d'augmentation de la vitesse de solidification du métal fondu comprenant l'étape consistant à augmenter la vitesse à laquelle le moule est retiré du four depuis une première vitesse jusqu'à une seconde vitesse quand la structure dendritique atteint l'extrémité supérieure de la cavité du moule.

2. Un procédé de coulée d'un article (62) ayant une base (70) relativement épaisse et un plan aérodynamique (74) relativement mince,. ledit procédé comprenant les opérations consistant à chauffer dans un four (12) au moins une partie d'un moule (10) comprenant une cavité (38) ayant une configuration correspondant à la configuration de l'article, une partie d'extrémité supérieure (72) de la cavité ayant une configuration correspondant à la configuration du plan aérodynamique relativement mince (74) de l'article, à verser du métal fondu dans la cavité du moule, à retirer le moule du four à une première vitesse après avoir effectuer ladite opération de versage du métal fondu dans la cavité du moule, à solidifier le métal fondu dans la cavité du moule pour former la base relativement épaisse de l'article tout en effectuant ladite opération de retrait du moule à partir du four à la première vitesse, à solidifier une partie du métal fondu dans la partie d'extrémité supérieure de la cavité du moule pour former une partie du plan aérodynamique relativement mince de l'article tout en poursuivant ladite opération de retrait du moule à partir du four, ladite opération de solidification du métal fondu pour former une partie du plan aérodynamique relativement mince comprenant l'étape consistant à étendre la structure dendritique (56) avec du métal fondu dans ses interstices vers le haut à partir du métal solidifié faisant partie du plan aérodynamique relativement mince tout en effectuant ladite opération de retrait du moule du four, à augmenter la vitesse à laquelle le moule est retiré du four à une seconde vitesse qui est supérieure à la première vitesse quand la structure dendritique s'étend en direction de l'extrémité supérieure (54) de la cavité du moule, et à solidifier le métal fondu dans les interstices de la structure dendritique pour terminer la formation du plan aérodynamique relativement mince tout en retirant le moule du four à une seconde vitesse.

3. Procédé selon la revendication 1 ou 2, comprenant en outre l'opération consistant à maintenir la vitesse à laquelle le moule est retiré du four sensiblement constante à la première vitesse, jusqu'à ce que la structure dendritique atteigne l'extrémité supérieure de la cavité du moule.

4. Procédé selon la revendication 1, 2 ou 3, dans lequel ladite seconde vitesse de retrait est supérieure à trente pouces par heure (76,2 cm/h).


22
24
12
16
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32
34
54
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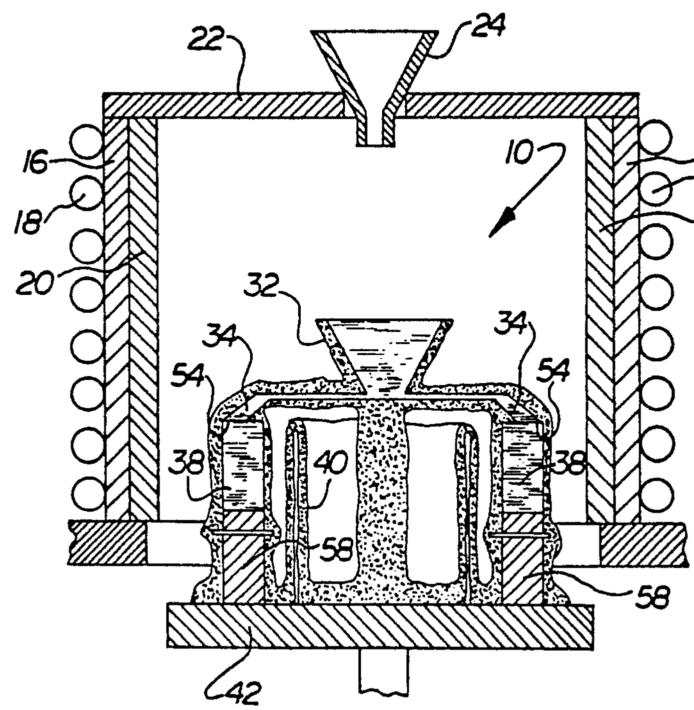
40
42

FIG.1


22
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16
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58
42

FIG.2

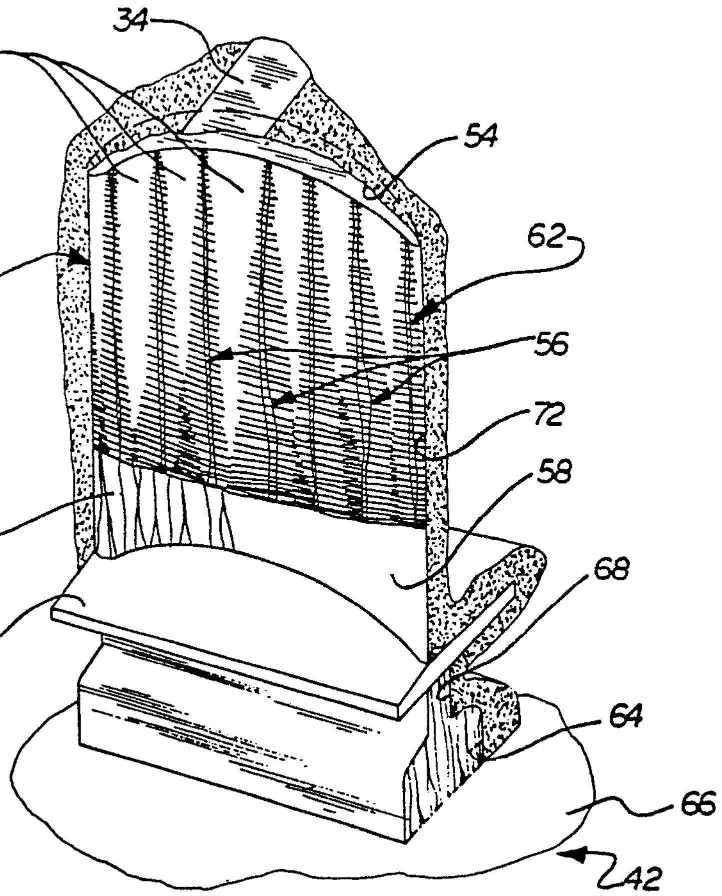
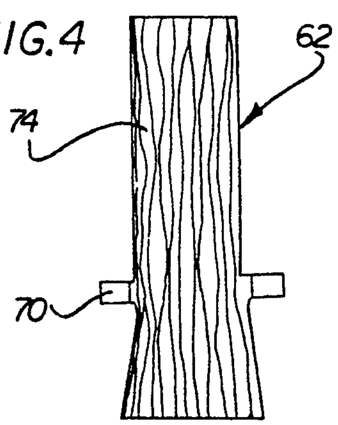


FIG.3

FIG.4



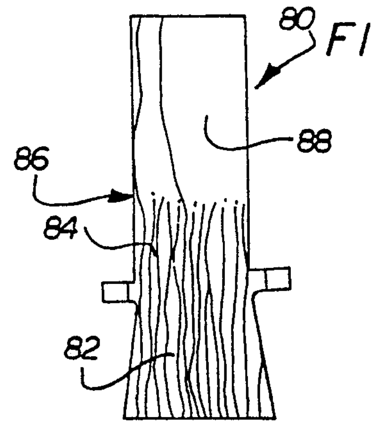


FIG.5