(54) Title: HOLLROWS CASTING SYSTEMS AND METHODS

(57) Abstract: Casing systems and methods form a hollows metal casting, in which the hollows metal casting comprises a fine-grain, homogeneous microstructure. The microstructure is essentially oxide- and sulfide-free, segregation defect free, and essentially free of voids caused by air entrapped during solidification of the metal from a liquidus state to a solid state. The casting system (3) with forming hollows castings comprises an electroslag refining system; a nuculated casting system (2) in which a casting is solidified; and a cooled mandrel (205) disposed at least in a liquidus portion (148) of the casting (145) in the nuculated casting system. The liquidus portion of the metal casting is solidified around the cooled mandrel in a manner sufficient to form a hollows casting with microstructure that comprises a fine-grain, homogeneous microstructure that is essentially oxide- and sulfide-free, segregation defect free, and essentially free of voids caused by air entrapped during solidification from a liquidus state to a solid state.
HOLLOWS CASTING SYSTEMS AND METHODS


BACKGROUND OF THE INVENTION

The invention relates to casting systems and methods for forming castings. In particular, the invention related to clean metal nucleated casting systems and methods that form tubular castings.

Metals, such as iron- (Fe), nickel- (Ni), titanium- (Ti), and cobalt- (Co) based alloys, are often used in turbine component applications, in which fine-grained microstructures, homogeneity, and essentially defect-free compositions are desired. Problems in superalloy castings and ingots are undesirable as the costs associated with superalloy formation are high, and results of these problems, especially in ingots formed into turbine components are undesirable. Conventional systems for producing castings have attempted to reduce the amount of impurities, contaminants, and other constituents, which may produce undesirable consequences in a component made from the casting. However, the processing and refining of relatively large bodies of metal, such as superalloys, is often accompanied by problems in achieving homogeneous, defect-free structure. These problems are believed to be due, at least in part, to the bulky volume of the metal body and the amount and depth of the liquidus metal during the casting and solidification of the ingot.

One such problem that may often arise with respect to superalloys comprises controlling the grain size and other microstructure of the refined metals. Typically, refining processing involves multiple steps, such as sequential heating and melting, forming, cooling, and reheating of the large bodies of metal because the volume of the metal being refined is generally of at least about 5,000 pounds and can be greater than about 35,000 pounds. The metal is then processed into a desired configuration or shape, in which this processed metal can be used for various applications. Also, the
once processed metal, if intended for tubular, hollow, ring, or annular (hereafter "hollows") applications, must be further processed from the original as-cast configuration to the desired hollows confirmation. This further processing may include, but is not limited to, extruding, roll forming, ring rolling, and other machining processes. This further processing is, of course, costly and time consuming.

Problems of alloy or ingredient segregation also occur as processing is performed on large bodies of metal. Often, a lengthy and expensive sequence of processing steps is selected to overcome the above-mentioned difficulties, which arise through the use of bulk processing and refining operations of metals. A known such sequence used in industry, involves vacuum induction melting; followed by electroslag refining (such as disclosed in US Patent Nos. 5,160,532; 5,310,165; 5,325,906; 5,332,197; 5,348,566; 5,366,206; 5,472,177; 5,480,097; 5,769,151; 5,809,057; and 5,810,066, all of which are assigned to the Assignee of the instant invention); followed, in turn, by vacuum arc refining (VAR) and followed, again in turn, by mechanical working through forging and drawing to achieve a fine microstructure. While the metal produced by such a sequence is highly useful and the metal product itself is quite valuable, the processing is quite expensive and time-consuming. Further processing may be needed for hollows applications of the casting. Further, the yield from such a sequence can be low, which results in increased costs. Furthermore, the processing sequence does not ensure defect-free metals, and ultrasonic inspection is generally employed to identify and reject any components that include such defects, which results in further increase in costs.

A conventional electroslag refining process typically uses a refining vessel that contains a slag-refining layer floating on a layer of molten refined metal. An ingot of unrefined metal is generally used as a consumable electrode and is lowered into the vessel to make contact with the molten electroslag layer. An electric current is passed through the slag layer to the ingot and causes surface melting at the interface between the ingot and the slag layer. As the ingot is melted, oxide inclusions or impurities are
exposed to the slag and removed at the contact point between the ingot and the slag. Droplets of refined metal are formed, and these droplets pass through the slag and are collected in a pool of molten refined metal beneath the slag. The refined metal may then be formed into a casting or ingot (collectively referred to hereinafter as “castings”), which is typically in the shape of a solid bar.

The above-discussed electroslag refining and the resultant casting may be dependent on a relationship between the individual process parameters, such as, but not limited to, an intensity of the refining current, specific heat input, and melting rate. This relationship involves undesirable interdependence between the rate of electroslag refining of the metal, metal ingot and casting temperatures, and rate at which a refined molten metal casting is cooled from its liquidus state to its solid state, all of which may result in poor metallurgical structure in the resultant casting.

Further, the above-described conventional electroslag refining may not provide for the controlling of an amount and depth of the liquidus portion in a casting. A reduced solidification rate may result in the casting having properties and characteristics that are not desirable. For example, and in no way limiting, the undesirable characteristics may include inhomogeneous microstructure, defects including (but not limited to) impurities, voids and inclusions, segregations, and a porous (non-dense) material resulting from entrapped air due to slow solidification.

Another problem that may be associated with the above-described conventional electroslag refining processing comprises the formation of a relatively deep metal pool in an electroslag crucible. A deep melt pool causes a varied degree of ingredient macrosegregation in the metal that leads to a less desirable microstructure, such as a microstructure that is not a fine-grained microstructure, or segregation of the elemental species so as to form an inhomogeneous structure. A subsequent processing operation has been proposed in combination with the electroslag refining process to overcome this deep melt pool problem. This subsequent processing may be vacuum arc remelting (VAR). Vacuum arc remelting is initiated when an ingot is processed by vacuum arc steps to produce a relatively shallow melt pool, whereby an

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improved microstructure, which may also possess a lower hydrogen content, is produced. Following the vacuum arc refining process, the resulting ingot is then mechanically worked to yield a metal stock having a desirable fine-grained microstructure. Such mechanical working may involve a combination of steps of forging, drawing, and heat treatment. This thermo-mechanical processing requires large, expensive equipment, as well as costly amounts of energy input.

An attempt to provide a desirable casting microstructure has been proposed in US Patent No. 5,381,847, in which a vertical casting process attempts to control grain microstructure by controlling dendritic growth. The process may be able to provide a useable microstructure for some applications, however, the vertical casting process does not control the source metal contents, including but not limited to impurities, oxides, and other undesirable constituents. Also, this process is not known to produce a casting ready for hollows applications. The process, as set forth in the patent, also does not control the depth or the liquidus portion or provide anything to enhance the solidification rate of the casting, which may adversely impact the casting’s microstructure and characteristics.

Therefore, a need exists to provide a metal casting process that produces a casting with a relatively homogeneous, fine-grained microstructure, in which the process does not rely upon multiple processing steps that controls the depth of the liquidus portion of the casting. Also, a need exists to provide a metal casting process and system that produces castings suitable for hollows applications. Further, a need exists to provide a metal casting system that produces a casting with a relatively homogeneous, oxide-free, fine-grained microstructure. Additionally, a need exists to provide a metal casting process and system that produces a casting that is essentially free of oxides and/or entrapped air due to slow solidification rates.

SUMMARY OF THE INVENTION

An aspect of the invention sets forth a casting system for forming a hollows metal casting. The hollows metal casting comprises a fine-grain, homogeneous
microstructure. The microstructure is essentially oxide- and sulfide-free, segregation defect free, and essentially free of voids caused by air entrapped during solidification of the metal from a liquidus state to a solid state. The casting system with for forming hollows castings comprises an electroslag refining system; a nucleated casting system in which a casting is solidified; and a cooled mandrel assembly disposed at least in a liquidus portion of the casting in the nucleated casting system. The liquidus portion of the metal casting is solidified around the cooled mandrel assembly in a manner sufficient to form a hollows casting with microstructure that comprises a fine-grain, homogeneous microstructure that is essentially oxide- and sulfide-free, segregation defect free, and essentially free of voids caused by air entrapped during solidification from a liquidus state to a solid state.

A further aspect of the invention provides a method for forming a hollows metal casting, in which the hollows metal casting comprises a fine-grain, homogeneous microstructure. The microstructure is essentially oxide- and sulfide-free, segregation defect free, and essentially free of voids caused by air entrapped during solidification of the metal from a liquidus state to a solid state. The casting method for forming hollows castings comprises providing a source of liquid metal; providing a nucleated casting system in which a hollows casting is solidified; and providing a cooled mandrel assembly disposed at least in a liquidus portion of the casting in the nucleated casting system. The liquidus portion of the metal casting is solidified around the cooled mandrel assembly in a manner sufficient to form a hollows casting with microstructure that comprises a fine-grain, homogeneous microstructure that is essentially oxide- and sulfide-free, segregation defect free, and essentially free of voids caused by air entrapped during solidification from a liquidus state to a solid state.

These and other aspects, advantages and salient features of the invention will become apparent from the following detailed description, which, when taken in conjunction with the annexed drawings, where like parts are designated by like reference characters throughout the drawings, disclose embodiments of the invention.
BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a generalized schematic illustration of a clean metal nucleated casting system with a cooled mandrel assembly having a source of melted metal and a nucleated casting system;

Figure 2 is a schematic illustration of a clean metal nucleated casting system with a cooled mandrel assembly; an electroslag refining system; and a nucleated casting system;

Figure 3 is a partial schematic, vertical sectional illustration of the clean metal nucleated casting system, as illustrated in Fig. 2, that illustrates details of the electroslag refining system;

Figure 4 is a partial schematic, vertical section illustration in detail of the electroslag refining system of the clean metal nucleated casting system for producing a casting; and

Figure 5 is a partial schematic, part sectional illustration of the electroslag refining system of the clean metal nucleated casting system for producing a casting.

DESCRIPTION OF THE INVENTION

Casting systems and methods for forming castings for hollows applications, as embodied by the invention, can be provided on casting systems, such as, but not limited to, vertical casting systems and casting systems that include vertical casting with electroslag refining and cold-induction guides. The systems and methods for forming castings for hollows applications, will be described hereinafter with respect to vertical casting with electroslag refining and cold-induction guides, as illustrated in Figs. 2-5. This description is not intended to limit the invention in any way, and the scope of the invention comprises casting systems and methods for forming castings for hollows applications, with other metal formation processes and systems, such as melted metal supplied from a refined metal source 100 (Fig. 1).
The casting systems and methods for forming castings for hollows applications can produce a casting with essentially oxide free and impurity free characteristics. The casting that is formed can also be dense and essentially non-porous. The term "casting" includes any casting, such as a preform, ingot, and the like. The term "essentially free" means that any constituents in the material do not adversely influence the material, for example its strength and related characteristics, and the term "essentially non-porous" means that the material is dense, amounts of entrapped air are minimal, and does not adversely influence the material.

The clean-liquid metal source for the casting systems and methods for forming castings for hollows applications 100, as embodied by the invention, can comprise any appropriate liquid metal source 100 (Fig. 1), such as, but not limited to, an electroslag refining apparatus, which can provide a clean liquid metal due to the electroslag refining steps. For example, and in no way limiting the invention, the electroslag refining apparatus can comprise an electroslag refining (ESR) system in cooperation with a cold-induction guide (CIG), as set forth in the above-mentioned patents to the Assignee of the instant invention.

Alternatively, the source for the casting systems and methods for forming castings for hollows applications can comprise a vertical casting arrangement, as disclosed in US Patent No. 5,381,847. Therefore, a nucleated casting system may permit a plurality of molten metal droplets to be formed and pass through a cooling zone, which is formed with a length sufficient to allow up to about 30 volume percent of each of the droplets to solidify on average. The droplets are then received by a mold and solidification of the metal droplets is completed in the mold, such as, but not limited to, auxiliary cooling, as embodied by the invention. The droplets retain liquid characteristics and readily flow within the mold, when less than about 30 volume percent of the droplets is solid.

In order to enhance the solidification rate of the liquidus portion of the metal, the casting systems and methods for forming castings for hollows applications provide coolant, such as, but not limited to water, directly onto a centrally disposed cooled
mandrel assembly. The mandrel is cooled by an appropriate coolant, such as, but not limited to, water, and for exemplary purposes only may be referred to as a “water-cooled mandrel”. The mandrel comprises a shaft-like element, which can be solid and alternatively provided with a cylindrical tubular structure and will maintain its structure when in contact with the refined liquid metal in the casting system. Thus, the mandrel (also known as a shaft, axle, rod, or similar structurally descriptive term) remains un-melted and structurally sound in the casting system so that the casting will solidify around it.

The mandrel assembly is disposed in the casting and comprises at least a mandrel, for example a solid or tubular mandrel, and a source of coolant supplied to the mandrel for cooling the mandrel and casting. For example, but not limiting the invention, the mandrel assembly extends from a solidus portion into a liquidus portion of the casting. The mandrel assembly thus permits the casting to solidify into a casting with an annular configuration that is suitable for hollows applications. The mandrel assembly enhances cooling of the liquidus portion of the casting by following coolant to portions of the casting, as well as providing air that will enhance the cooling of the casting. The coolant and air can reduce the temperature of the liquidus portion of the casting, and provide expedited cooling and enhanced solidification of the liquidus portion of the casting. The expedited cooling and enhanced solidification of the liquidus portion will reduce the amount of entrapped gas that can be generated during operation or retained therein, thus forming a dense casting that contains few entrapped gas voids.

Further, the expedited cooling and enhanced solidification rates of the liquidus portion will enhance the microstructural characteristics of the casting by reducing the grain size, providing an essentially segregation free microstructure, and a homogeneous microstructure. The casting process for forming castings for hollows applications, as embodied by the invention, can produce a casting possessing a homogeneous, fine-grained microstructure for many metals and alloys, including, but not limited to, nickel- (Ni) and cobalt- (Co) based superalloys, iron- (Fe), titanium-
(Ti), alloys, which are often used in turbine component applications. The castings formed by the hollows casting method, as embodied by the invention, avoid conversion into a final hollows configuration, thus reducing processing steps.

Therefore, a casting method including for forming castings for hollows applications can be used to produce high quality forgings that can be used in many applications, such as but not limited to rotating equipment applications, such as, but not limited to, disks, rotors, blades, vanes, wheel, buckets, rings, shafts, wheels, and other such elements, and other turbine component applications. The description of the invention will refer to turbine components formed from hollows castings, however, this is merely exemplary of the applications within the scope of the invention.

Referring to the accompanying drawings, Fig. 1 illustrates a casting system 3 with a generalized source 100, and Fig. 2 illustrates a semi-schematic, part-sectional, elevational view of an exemplary casting system 3, as embodied by the invention. Figures 3-5 illustrate details of features illustrated in Fig. 2. The casting system 3 will be initially discussed with a description of the electroslag refining system 1 and the nucleated casting system 2 to facilitate the understanding of the invention.

Figure 1 is a schematic illustration of a casting system 3 for forming castings for hollows applications, as embodied by the invention, for producing a casting 145. In Fig. 1, the metal for the clean metal nucleated casting system 3 and its associated clean metal nucleated casting processes is provided by any appropriate source 100, such as but not limited to, an electroslag refining system 1 (as illustrated in Figs. 2-5). The clean metal is fed to a nucleated casting system 2. The source 100 and nucleated casting system 2 cooperate to form a clean metal nucleated casting system 3, which in turn forms the auxiliary cooling onto a liquidus portion of the casting, as embodied by the invention.

In Fig. 1, a cooled mandrel assembly 200 is disposed in the casting assembly 3, for example disposed at least in the liquidus portion 148 of the casting 145. The cooled mandrel assembly 200 comprises a mandrel 205, in which the mandrel comprises at
least one of a solid mandrel and a tubular mandrel, as illustrated. The mandrel 205 is
disposed in at least the liquidus portion 148 of the casting 145 and can extend to
through the solidus portion of the casting 145, as illustrated by the dashed lines in Fig.
1.

The cooled mandrel assembly 200 also comprises a cooling system 300, which
provides coolant to the mandrel 205. The cooling system 300 comprises a coolant
supply 305 and a coolant conduit 310. Coolant is supplied to the mandrel 205, for
example in the form of a spray 315. The spray 315 is applied to the mandrel on at
least one surface. For example, if the mandrel 205 comprises a tubular mandrel, the
coolant can be applied to the interior of the mandrel 205, the exterior of the mandrel
205, or both the interior and exterior of the mandrel 205. Of course with a solid
mandrel 205, the coolant is applied to the exterior of the mandrel 205. The cooled
mandrel assembly 200 thus assists in cooling the liquidus portion 148 of the casting
145 by thermal conduction. The cooling system 300 will also decrease the depth of
the liquidus portion 148, which is desirable to enhance cooling of the casting 145 and
to avoid undesirable microstructure therein.

A cooling system 300 of the cooled mandrel assembly 200 (Fig. 1), as embodied by
the invention, can extract heat from the liquidus portion 148 of the casting 145 to
expedite its cooling and enhance its solidification. The coolant can comprise any
appropriate coolant, such as, but not limited to, water (as noted above) and an inert
cooling gas that will not react with the material of the casting. Exemplary cooling
gases within the scope of the invention comprise, but are not limited to, argon,
nitrogen, and helium. In the cooling system 300, the coolant exits the cooling system
300 in the form of a spray 315 after passing through a coolant conduit 310 from the
coolant supply 305. The coolant conduit 310 can comprise any appropriate conduit
that allows passage of the coolant. The shape and configuration of the coolant
conduit 310 may take any shape and configuration as long as the coolant can be
directed to the mandrel 205.
The cooling system 300, as embodied by the invention, can comprise a configuration as illustrated. Further, the cooling system 300 can comprise a plurality of one or all of the elements of the cooling system 300. For example, and in no way limiting of the invention, the cooling system 300 can comprise one source that is in fluidic communication with a plurality of coolant conduits to form a plurality of sprays. Further, the cooling system 300 can comprise a plurality of supplies 305, each communicating with a coolant conduit 310 and coolant spray 315. Also, a coolant conduit 310 may form a plurality of sprays 315 from a single coolant conduit. The above descriptions are merely exemplary and are not intended to limit the invention in any manner.

The electroslag refining system 1 introduces a consumable electrode 24 of metal to be refined directly into an electroslag refining system 1, and refines the consumable electrode 24 to produce a clean, refined metal melt 46 (hereafter “clean metal”). The source of metal for the electroslag refining system 1 as a consumable electrode 24 is merely exemplary, and the scope of the invention comprises, but is not limited to, the source metal comprising an ingot, melt of metal, powder metal, and combinations thereof. The description of the invention will refer to a consumable electrode, however this is merely exemplary and is not intended to limit the invention in any manner. The clean metal 46 is received and retained within a cold hearth structure 40 that is mounted below the electroslag refining apparatus 1. The clean metal 46 is dispensed from the cold hearth structure 40 through a cold finger orifice structure 80 that is mounted and disposed below the cold hearth structure 40.

The electroslag refining system 1 can provide essentially steady state operation in supplying clean metal 46 if the rate of electroslag refining of metal and rate of delivery of refined metal to a cold hearth structure 40 approximates the rate at which molten metal 46 is drained from the cold hearth structure 40 through an orifice 81 of the cold finger orifice structure 80. Thus, the clean metal nucleated casting process can operate continuously for an extended period of time and, accordingly, can process a large bulk of metal. Alternatively, the clean metal nucleated casting process can be
operated intermittently by intermittent operation of one or more of the features of the clean metal nucleated casting system 3.

Once the clean metal 46 exits the electroslag refining system 1 through the cold finger orifice structure 80, it enters into the nucleated casting system 2. Then, the clean metal 46 can be further processed to produce a relatively large ingot of refined metal. Alternatively, the clean metal 46 may be processed through to produce smaller castings, ingots, castings, or formed into continuous cast castings. The clean metal nucleated casting process effectively eliminates many of the processing operations, such as those described above that, until now, have been necessary in order to produce a metal casting having a desired set of material characteristics and properties.

In Fig. 2, a vertical motion control apparatus 10 is schematically illustrated. The vertical motion control apparatus 10 comprises a box 12 mounted to a vertical support 14 that includes a motive device (not illustrated), such as but not limited to a motor or other mechanism. The motive device is adapted to impart rotary motion to a screw member 16. An ingot support structure 20 comprises a member, such as but not limited to a member 22, that is threadedly engaged at one end to the screw member 16. The member 22 supports the consumable electrode 24 at its other end by an appropriate connection, such as, but not limited to, a bolt 26.

An electroslag refining structure 30 comprises a reservoir 32 that is cooled by an appropriate coolant, such as, but not limited to, water. The reservoir 32 comprises a molten slag 34, in which an excess of the slag 34 is illustrated as the solid slag granules 36. The slag composition used in the clean metal nucleated casting process will vary with the metal being processed. A slag skull 75 may be formed along inside surfaces of an inner wall 82 of reservoir 32, due to the cooling influence of the coolant flowing against the outside of inner wall 82, as described hereinafter.

A cold hearth structure 40 (Figs. 2-5) is mounted below the electroslag refining structure 30. The cold hearth structure 40 comprises a hearth 42, which is cooled by an appropriate coolant, such as water. The hearth 42 contains a skull 44 of solidified
refined metal and a body 46 of refined liquid metal. The reservoir 32 may be formed integrally with the hearth 42. Alternatively, the reservoir 32 and hearth 42 may be formed as separate units, which are connected to form the electroslag refining system 1.

A bottom orifice 81 of the electroslag refining system 1 is provided in the cold finger orifice structure 80, which is described with reference to Figs. 4 and 5. A clean metal 46, which is refined by the electroslag refining system 1 so as to be essentially free of oxides, sulfides, and other impurities, can traverse the electroslag refining system 1 and flow out of the orifice 81 of the cold finger orifice structure 80.

A power supply structure 70 can supply electric refining current to the electroslag refining system 1. The power supply structure 70 can comprise an electric power supply and control mechanism 74. An electrical conductor 76 that is able to carry current to the member 22 and, in turn, carry current to the consumable electrode 24 connects the power supply structure 70 to the member 22. A conductor 78 is connected to the reservoir 32 to complete a circuit for the power supply structure 70 of the electroslag refining system 1.

Figure 3 is a detailed part-sectional illustration of the electroslag refining structure 30 and the cold hearth structure 40 in which the electroslag refining structure 30 defines an upper portion of the reservoir 32 and the cold hearth structure 40 defines a lower portion 42 of the reservoir 32. The reservoir 32 generally comprises a double-walled reservoir, which includes an inner wall 82 and outer wall 84. A coolant 86, such as but not limited to water, is provided between the inner wall 82 and outer wall 84. The coolant 86 can flow to and through a flow channel, which is defined between the inner wall 82 and outer wall 84 from a supply 98 (Fig. 4) and through conventional inlets and outlets (not illustrated in the figures). The cooling water 86 that cools the wall 82 of the cold hearth structure 40 provides cooling to the electroslag refining structure 30 and the cold hearth structure 40 to cause the skull 44 to form on the inner surface of the cold hearth structure 40. The coolant 86 is not essential for operation of the electroslag refining system 1, clean metal nucleated casting system 3, or
electroslag refining structure 30. Cooling may insure that the liquid metal 46 does not contact and attack the inner wall 82, which may cause some dissolution from the wall 82 and contaminate the liquid metal 46.

In Fig. 3, the cold hearth structure 40 also comprises an outer wall 88, which may include flanged tubular sections, 90 and 92. Two flanged tubular sections 90 and 92 are illustrated in the bottom portion of Fig. 3. The outer wall 88 cooperates with the nucleated casting system 2 to form a controlled atmosphere environment 140, which is described hereinafter.

The cold hearth structure 40 comprises a cold finger orifice structure 80 that is shown detail Figs. 4 and 5. The cold finger orifice structure 80 is illustrated in Fig. 3 in relation to the cold hearth structure 40 and a stream 56 of liquid melt 46 that exits the cold hearth structure 40 through the cold finger orifice structure 80. The cold finger orifice structure 80 is illustrated (Figs. 3 and 4) in structural cooperation with the solid metal skull 44 and liquid metal 46. Figure 5 illustrates the cold finger orifice structure 80 without the liquid metal or solid metal skull, so details of the cold finger orifice structure 80 are illustrated.

The cold finger orifice structure 80 comprises the orifice 81 from which processed molten metal 46 is able to flow in the form of a stream 56. The cold finger orifice structure 80 is connected to the cold hearth structure 40 and the cold hearth structure 30. Therefore, the cold hearth structure 40 allows processed and generally impurity-free alloy to form the skulls 44 and 83 by contacting walls of the cold hearth structure 40. The skulls 44 and 83 thus act as a container for the molten metal 46. Additionally, the skull 83 (Fig. 4), which is formed at the cold finger orifice structure 80, is controllable in terms of its thickness, and is typically formed with a smaller thickness than the skull 44. The thicker skull 44 contacts the cold hearth structure 40 and the thinner skull 83 contacts the cold finger orifice structure 80, and the skulls 44 and 83 are in contact with each other to form an essentially continuous skull.
A controlled amount of heat may be provided to the skull 83 and thermally transmitted to the liquid metal body 46. The heat is provided from induction heating coils 85 that are disposed around the cold hearth structure. An induction-heating coil 85 can comprise a cooled induction-heating coil, by flow of an appropriate coolant, such as water, into it from a supply 87. Induction heating power is supplied from a power source 89, which is schematically illustrated in Fig. 4. The construction of the cold finger orifice structure 80 permits heating by induction energy to penetrate the cold finger orifice structure 80 and heat the liquid metal 46 and skull 83, and maintain the orifice 81 open so that the stream 56 may flow out of the orifice 81. The orifice may be closed by solidification of the stream 56 of liquid metal 46 if heating power is not applied to the cold finger orifice structure 80. The heating is dependent on each of the fingers of the cold finger orifice structure 80 being insulated from the adjoining fingers, for example being insulated by an air or gas gap or by a suitable insulating material.

The cold finger orifice structure 80 is illustrated in Fig. 5, with both skulls 44 and 83 and the molten metal 46 are omitted for clarity. An individual cold finger 97 is separated from each adjoining finger, such as finger 92, by a gap 94. The gap 94 may be provided and filled with an insulating material, such as, but not limited to, a ceramic material or insulating gas. Thus, the molten metal 46 (not illustrated) that is disposed within the cold finger orifice structure 80 does not leak out through the gaps, because the skull 83 creates a bridge over the cold fingers and prevents passage of liquid metal 46 therethrough. Each gap extends to the bottom of the cold finger orifice structure 80, as illustrated in Fig. 5, which illustrates a gap 99 aligned with a viewer's line-of-sight. The gaps can be provided with a width in a range from about 20 mils to about 50 mils, which is sufficient to provide an insulated separation of respective adjacent fingers.

The individual fingers may be provided with a coolant, such as water, by passing coolant into a conduit 96 from a suitable coolant source (not shown). The coolant is then passed around and through a manifold 98 to the individual cooling tubes, such as
cooling tube 100. Coolant that exits the cooling tube 100 flows between an outside surface of the cooling tube 100 and an inside surface of a finger. The coolant is then collected in a manifold 102, and passed out of the cold finger orifice structure 80 through a water outlet tube 104. This individual cold finger water supply tube arrangement allows for cooling of the cold finger orifice structure 80 as a whole.

The amount of heating or cooling that is provided through the cold finger orifice structure 80 to the skulls 44 and 83, as well as to the liquid metal 46, can be controlled to control the passage of liquid metal 46 through the orifice 81 as a stream 56. The controlled heating or cooling is done by controlling the amount of current and coolant that pass in the induction coils 85 to and through the cold finger orifice structure 80. The controlled heating or cooling can increase or decrease the thickness of the skulls 44 and 83, and to open or close the orifice 81, or to reduce or increase the passage of the stream 56 through the orifice 81. More or less liquid metal 46 can pass through the cold finger orifice structure 80 into the orifice 81 to define the stream 56 by increasing or decreasing the thickness of the skulls 44 and 83. The flow of the stream 56 can be maintained at a desirable balance, by controlling coolant water and heating current and power to and through the induction heating coil 85 to maintain the orifice 81 at a set passage size along with controlling the thickness of the skulls 44 and 83.

The operation of the electroslag refining system 1 of the clean metal nucleated casting system 3 will now be generally described with reference to the figures. The electroslag refining system 1 of the clean metal nucleated casting system 3 can refine ingots that can include defects and impurities. A consumable electrode 24 is melted by the electroslag refining system 1. The consumable electrode 24 is mounted in the electroslag refining system 1 in contact with molten slag in the electroslag refining system. Electrical power is provided to the electroslag refining system and ingot. The power causes melting of the ingot at a surface where it contacts the molten slag and the formation of molten drops of metal. The drops are collected after they pass through the molten slag as a body of refined liquid metal in the cold hearth structure.
below the electroslag refining structure 30. Oxides, sulfides, contaminants, and other impurities that originate in the consumable electrode 24 are removed through dissolution in to the slag as the droplets form on the surface of the ingot and pass through the molten slag. The molten drops are drained from the electroslag refining system 1 at the orifice 81 in the cold finger orifice structure 80 as a stream 56. The stream 56 that exits the electroslag refining system 1 of the clean metal nucleated casting system 3 that forms castings comprises a refined melt that is essentially free of oxides, sulfides, contaminants, and other impurities.

The rate at which the metal stream 56 exits the cold finger orifice structure 80 can further be controlled by controlling a hydrostatic head of liquid metal 46 above the orifice 81. The liquid metal 46 and slag 44 and 83 that extend above the orifice 81 of the cold finger orifice structure 80 define the hydrostatic head. If a clean metal nucleated casting system 3 with an electroslag refining system 1 is operated with a given constant hydrostatic head and a constant sized orifice 81, an essentially constant flow rate of liquid metal can be established.

Typically, a steady state of power is desired so the melt rate is generally equal to the removal rate from the clean metal nucleated casting system 3, as a stream 56. However, the current applied to the clean metal nucleated casting system 3 can be adjusted to provide more or less liquid metal 46 and slag 44 and 83 above the orifice 81. The amount of liquid metal 46 and slag 44 and 83 above the orifice 81 is determined by the power that melts the ingot, and the cooling of the electroslag refining system 1, which create the skulls. By adjusting the applied current, flow through the orifice 81 can be controlled.

Also, the contact of the consumable electrode 24 with an upper surface of the molten slag 34 can be maintained in order to establish a steady state of operation 1. A rate of consumable electrode 24 descent into the melt 46 can be adjusted to ensure that contact of the consumable electrode 24 with the upper surface of the molten slag 34 is maintained for the steady state operation. Thus, a steady-state discharge from the stream 56 can be maintained in the clean metal nucleated casting system 3. The
stream 56 of metal that is formed in the electroslag refining system 1 of the clean metal nucleated casting system 3 exits electroslag refining system 1 and is fed to a nucleated casting system 2. The nucleated casting system 2 is schematically illustrated in Fig. 2 in cooperation with the electroslag refining system 1.

The nucleated casting system 2 comprises a disruption site 134 that is positioned to receive the stream 56 from the electroslag refining system 1 of the clean metal nucleated casting system 3. The disruption site 134 converts the stream 56 into a plurality of molten metal droplets 138. The stream 56 can be fed to disruption site 134 in a controlled atmosphere environment 140 that is sufficient to prevent substantial and undesired oxidation of the droplets 138. The controlled atmosphere environment 140 may include any gas or combination of gases, which do not react with the metal of the stream 56. For example, if the stream 56 comprises aluminum or magnesium, the controlled atmosphere environment 140 presents an environment that prevents the droplets 138 from becoming a fire hazard. Typically, any noble gas or nitrogen is suitable for use in the controlled atmosphere environment 140 because these gases are generally non-reactive with most metals and alloys within the scope of the invention. For example, nitrogen, which is a low-cost gas, can be in the controlled atmosphere environment 140, except for metals and alloys that are prone to excessive nitriding. Also, if the metal comprises copper, the controlled atmosphere environment 140 may comprise nitrogen, argon, and mixtures thereof. If the metal comprises nickel or steel, the controlled atmosphere environment 140 can comprises nitrogen or argon, or mixtures thereof.

The disruption site 134 can comprise any suitable device for converting the stream 56 into droplets 138. For example, the disruption site 134 can comprise a gas atomizer, which circumscribes the stream 56 with one or more jets 142. The flow of gas from the jets 142 that impinge on the stream can be controlled, so the size and velocity of the droplets 138 can be controlled. Another atomizing device, within the scope of the invention, includes a high pressure atomizing gas in the form of a stream of the gas, which is used to form the controlled atmosphere environment 140. The stream of
controlled atmosphere environment 140 gas can impinge the metal stream 56 to convert the metal stream 56 into droplets 138. Other exemplary types of stream disruption include magneto-hydrodynamic atomization, in which the stream 56 flows through a narrow gap between two electrodes that are connected to a DC power supply with a magnet perpendicular to the electric field, and mechanical-type stream disruption devices.

The droplets 138 are broadcast downward (Fig. 2) from the disruption site 134 to form a generally diverging cone shape. The droplets 138 traverse a cooling zone 144, which is defined by the distance between the disruption site 134 and the upper surface 150 of the metal casting that is supported by the mold 146. The cooling zone 144 length is sufficient to solidify a volume fraction portion of a droplet by the time the droplet traverses the cooling zone 144 and impacts the upper surface 150 of the metal casting. The portion of the droplet 138 that solidifies (hereinafter referred to as the "solid volume fraction portion") is sufficient to inhibit coarse dendritic growth in the mold 146 up to a viscosity inflection point at which liquid flow characteristics in the mold are essentially lost.

The partially molten/partially solidified metal droplets (referred to hereinafter as "semisolid droplets") collect in mold 146. The mold may comprise a unitary and one-piece mold, as illustrated in the broken lines of Fig. 1. Alternatively, the mold may comprises a withdrawal mold, which includes a retractable base 246 that can be withdrawn from sidewalls of the mold 146. The following description of the invention will discuss a withdrawal mold as an exemplary, non-limiting mold, and is not intended to limit the invention in any manner. The retractable base 246 can be connected to a shaft 241 to move base away from the sidewalls in the direction of arrow 242. Further, the shaft 241 may rotate the retractable base 246 in the direction of arrow 243 to provide most portions of the mold to a cooling system, which is described hereinafter. The semisolid droplets behave like a liquid if the solid volume fraction portion is less than a viscosity inflection point, and the semisolid droplets exhibit sufficient fluidity to conform to the shape of the mold. Generally, an upper
solid volume fraction portion limit that defines a viscosity inflection point is less than about 40% by volume. An exemplary solid volume fraction portion is in a range from about 5% to about 40%, and a solid volume fraction portion in a range from about 15% to about 30% by volume does not adversely influence the viscosity inflection point.

The spray of droplets 138 creates a liquidus, upper portion 148 disposed proximate the surface of the casting 145 in the mold 146. The depth of the liquidus, upper portion 148 is dependent on cooling of the liquidus portion, the solidification rate thereof, and various clean metal nucleated casting system 3 factors, such as, but not limited to, the atomization gas velocity, droplet velocity, the cooling zone 144 length, the stream temperature, and droplet size. The liquidus, upper portion 148 can be created with a depth in the mold 146 in a range from about 0.005 inches to about 1.0 inches. An exemplary liquidus, upper portion 148 within the scope of invention comprises a depth in a range from about 0.25 to about 0.50 inches in the mold. In general, the liquidus, upper portion 148 in the mold 146 should not be greater that a region of the casting, where the metal exhibits predominantly liquid characteristics. Typically, expedited solidification of the liquidus portion minimizes gas entrapment and resultant pores in the casting.

The mold 146 can be formed of any suitable material for casting applications, such as but not limited to, graphite, cast iron, and copper. Graphite is a suitable mold 146 material since it is relatively easy to machine and exhibits satisfactory thermal conductivity for heat removal via the cooling systems, as embodied by the invention. As the mold 146 is filled with semisolid droplets 138, its upper surface 150 moves closer to the disruption site 134, and the cooling zone 144 is reduced. At least one of the disruption site 134 or the mold 146 may be mounted on a moveable support and separated at a fixed rate to maintain a constant cooling zone 144 dimension. Thus, a generally consistent solid volume fraction portion in the droplets 138 is formed. Baffles 152 may be provided in the nucleated casting system 2 to extend the controlled atmosphere environment 140 from the electroslag refining system 1 to the
mold 146. The cooling system 500 can extend through the baffles 152, as illustrated in the figures. The baffles 152 can prevent oxidation of the partially molten metal droplets 138 and conserve the controlled atmosphere environment gas 140. Heat that is extracted from the casting 145 completes the solidification process of the liquidus upper portion 148 of the casting 145 to form solidified castings for further use. Sufficient nuclei are formed in casting 145 produced so that upon solidification, a fine equiaxed microstructure 149 can be formed in the casting 145.

The casting system 3, as embodied by the invention, inhibits undesirable dendritic growth, reduces solidification shrinkage porosity of the formed casting and casting, and reduces hot tearing both during casting and during subsequent hot working of the casting and casting. Further, the clean metal nucleated casting system 3 produces a uniform, equiaxed structure in the casting which is a result of the minimal distortion of the mold during casting, the controlled transfer of heat during solidification of the casting in the mold, and controlled nucleation. The clean metal nucleated casting system 3 enhances ductility and fracture toughness of the casting compared to conventionally castings.

While various embodiments are described herein, it will be appreciated from the specification that various combinations of elements, variations or improvements therein may be made by those skilled in the art, and are within the scope of the invention.
WE CLAIM:

1. A casting system for forming a hollows metal casting, the hollows metal casting comprising a fine-grain, homogeneous microstructure that is essentially oxide- and sulfide-free, segregation defect free, and essentially free of voids caused by air entrapped during solidification of the metal from a liquidus state to a solid state, the casting system with for forming hollows castings comprising:

an electroslag refining system;

a nucleated casting system in which a casting is solidified; and

a cooled mandrel assembly disposed at least in a liquidus portion of the casting of the nucleated casting system, wherein the liquidus portion of the metal casting is solidified around the cooled mandrel assembly in a manner sufficient to form a hollows casting with microstructure that comprises a fine-grain, homogeneous microstructure that is essentially oxide- and sulfide-free, segregation defect free, and essentially free of voids caused by air entrapped during solidification from a liquidus state to a solid state.

2. A casting system according to claim 1, wherein the electroslag refining system comprises:

an electroslag refining structure adapted to receive and to hold a refining molten slag,

a source of metal to be refined in the electroslag refining structure;

a body of molten slag in the electroslag refining structure, the source of metal being disposed in contact with the molten slag,

an electric supply adapted to supply electric current to the source of metal as an electrode and through the molten slag to a body of refined metal beneath the slag to keep the refining slag molten and to melt the end of the source of metal in contact with the slag,
an advancing device for advancing the source of metal into contact with the molten slag at a rate corresponding to the rate at which the contacted surface of the electrode is melted as the refining thereof proceeds,

a cold hearth structure beneath the electroslag refining structure, the cold hearth structure being adapted to receive and to hold electroslag refined molten metal in contact with a solid skull of the refined metal formed on the walls of the cold hearth vessel,

a body of refined molten metal in the cold hearth structure beneath the molten slag,

a cold finger orifice structure below the cold hearth adapted to receive and to dispense a stream of refined molten metal that is processed by the electroslag refining system and through the cold hearth structure, the cold finger orifice structure having a orifice,

a skull of solidified refined metal in contact with the cold hearth structure and the cold finger orifice structure including the orifice.

3. A casting system according to claim 1, wherein the nucleated casting system comprises:

a disruption site through which a stream of liquid metal is formed into molten metal droplets; and

a cooling zone that that receives the molten metal droplets, the molten metal droplets being solidified in the cooling zone into semisolid droplets such that, on average, about 5% to about 40% by volume of each semisolid droplet is solid and the remainder of the semisolid droplet is molten; and

a mold that collects the droplets in a liquidus portion and solidifies the droplets around the cooled mandrel, thereby forming a hollows casting having a fine-grain, homogeneous microstructure that is essentially oxide- and sulfide-free and segregation defect free, and essentially free of voids caused by air entrapped during solidification of the metal from a liquidus state to a solid state.
4. A casting system according to claim 2, wherein the nucleated casting system comprises:

a disruption site through which a stream of liquid metal is formed into molten metal droplets; and

a cooling zone that that receives the molten metal droplets, the molten metal droplets being solidified in the cooling zone into semisolid droplets such that, on average, about 5% to about 40% by volume of each semisolid droplet is solid and the remainder of the semisolid droplet is molten; and

a mold that collects the droplets in a liquidus portion and solidifies the droplets around the cooled mandrel, thereby forming a hollows casting having a fine-grain, homogeneous microstructure that is essentially oxide- and sulfide-free and segregation defect free, and essentially free of voids caused by air entrapped during solidification of the metal from a liquidus state to a solid state.

5. A casting system according to claim 1, wherein the liquidus portion of the casting is generated by metal droplets in an upper area of the casting and, within the liquidus portion, on average, less than about 50% by volume of an average droplet is solid.

6. A casting system according to claim 1, wherein the cooled mandrel assembly comprises:

a water-cooled mandrel.

7. A casting system according to claim 6, wherein the water-cooled mandrel comprises at least one of a solid mandrel and a tubular mandrel.

8. A casting system according to claim 1, wherein the casting comprises at least one of nickel-, cobalt-, titanium-, or iron-based metals.

9. A casting system according to claim 1, wherein the casting comprises a turbine component.
10. A casting system with for forming castings for hollows applications for producing a hollows metal casting, the metal casting comprising a fine-grain, homogeneous microstructure that is essentially oxide- and sulfide-free, segregation defect free, and essentially free of voids caused by air entrapped during solidification of the metal from a liquidus state to a solid state, the casting system for forming castings for hollows applications comprising:

a source of liquid metal;

a metal disruption site through which a stream of the liquid metal from the source of liquid metal is formed into molten metal droplets; and

a cooling zone that that receives the molten metal droplets, the molten metal droplets being solidified in the cooling zone into semisolid droplets such that, on average, about 5% to about 40% by volume of each semisolid droplet is solid and the remainder of the semisolid droplet is molten; and

a cooled mandrel assembly disposed at least in a liquidus portion of the casting;

a mold that collects the droplets in a liquidus portion and solidifies the droplets around the cooled mandrel assembly thereby forming a hollows casting having a fine-grain, homogeneous microstructure that is essentially oxide- and sulfide-free and segregation defect free, and essentially free of voids caused by air entrapped during solidification of the metal from a liquidus state to a solid state.

11. A system according to claim 10, wherein the system according to claim 1, wherein the cooled mandrel assembly comprises:

a coolant supply and a coolant conduit to apply coolant directly onto the cooled mandrel assembly.

12. A system according to claim 10, wherein the cooled mandrel assembly comprises at least one of a solid cooled mandrel and a tubular cooled mandrel.
13. A system according to claim 10, wherein the casting comprises at least one of nickel-, cobalt-, titanium-, or iron-based metals.

14. A system according to claim 10, wherein the casting comprises a turbine component.

15. A casting method for forming castings for hollows applications for forming a metal casting, the hollows metal casting comprising a fine-grain, homogeneous microstructure that is essentially oxide- and sulfide-free, segregation defect free, and essentially free of voids caused by air entrapped during solidification of the metal from a liquidus state to a solid state, the method for forming castings for hollows applications comprising:

forming a source of clean refined metal that has oxides and sulfides refined out by electroslag refining;

forming a hollows casting by a nucleated casting process; wherein the step of forming a hollows casting by a nucleated casting process comprises solidifying the casting around a cooled mandrel assembly to from the hollows casting; and the hollows casting microstructure that comprises a fine-grain, homogeneous microstructure is essentially oxide- and sulfide-free, segregation defect free, and essentially free of voids caused by air entrapped during solidification from a liquidus state to a solid state.

16. A method according to claim 15, wherein the step of forming a source comprises electroslag refining that comprises:

providing a source of metal to be refined;

providing an electroslag refining structure adapted for the electroslag refining of the source of metal and providing molten slag in the vessel;

providing a cold hearth structure for holding a refined molten metal beneath the molten slag and providing refined molten metal in the cold hearth structure;
mounting the source of metal for insertion into the electroslag refining structure and into contact with the molten slag in the electroslag refining structure;

providing an electrical power supply adapted to supply electric power;

supplying electric power to electroslag refine the source of metal through a circuit, the circuit comprising the power supply, the source of metal, the molten slag and the electroslag refining structure;

resistance melting of the source of metal where the source of metal contacts the molten slag and forming molten droplets of metal;

allowing the molten droplets to fall through the molten slag;

collecting the molten droplets after they pass through the molten slag as a body of refined liquid metal in the cold hearth structure directly below the electroslag refining structure;

providing a cold finger orifice structure having a orifice at the lower portion of the cold hearth structure; and

draining the electroslag refined metal that collects in the cold hearth orifice structure through the orifice of the cold finger orifice structure.

17. A method according to claim 16, wherein the source of metal comprises an alloy selected from at least one of nickel-, cobalt-, titanium-, or iron-based metals, and the casting formed by the clean metal nucleated casting process comprises at least one of nickel-, cobalt-, titanium-, or iron-based metals.

18. A method according to claim 16, wherein a rate of advance of the source of metal into the refining structure corresponds to the rate of resistance melting.

19. A method according to claim 16, wherein the step of draining comprises forming a stream of molten metal.
20. A method according to claim 16, wherein the electroslag refining structure and the cold hearth structure comprise upper and lower portions of the same structure.

21. A method according to claim 16, wherein the step of supplying electric power comprises forming a circuit in the refined liquid metal.

22. A method according to claim 16, wherein the step of draining comprises establishing a drainage rate that is approximately equivalent to a rate of resistance melting.

23. A method according to claim 16, wherein the step of forming a casting comprises:

   disrupting a stream of clean metal from the source of clean metal into molten metal droplets;

   partially solidifying the molten metal droplets such that, on average, from about 5% to about 40% by volume of each droplet is solid and the remainder of each droplet is molten; and

   collecting and solidifying the partially solidified droplets around the cooled mandrel assembly in a mold forming the hollows casting, in which a turbulent zone is generated by the droplets at an upper surface and, the step of collecting and solidifying the partially solidified droplets collects the droplets in the turbulent zone, and, on average solidifies less than about 50% by volume of the droplet.

24. A method according to claim 23, wherein the step of partially solidifying the molten metal droplets solidifies, on the average, from about 15% to about 30% by volume of the droplet.

25. A method according to claim 23, wherein the step of collecting and solidifying the partially solidified droplets comprises collecting and solidifying about 5% to about 40% by volume of the droplet.
26. A method according to claim 23, wherein the step of disrupting comprises impinging at least one atomizing gas jet on the stream.

27. A method according to claim 16, wherein the step of electroslag refining comprises:

- providing a source of metal to be refined,

- providing an electroslag refining structure adapted for the electroslag refining of the source of metal and providing molten slag in the vessel,

- providing a cold hearth structure for holding a refined molten metal beneath the molten slag and providing refined molten metal in the cold hearth structure,

- mounting the source of metal for insertion into the electroslag refining structure and into contact with the molten slag in the electroslag refining structure,

- providing an electrical power supply adapted to supply electric power,

- supplying electric power to electroslag refine the source of metal through a circuit, the circuit comprising the power supply, the source of metal, the molten slag and the electroslag refining structure;

- resistance melting of the source of metal where the source of metal contacts the molten slag and forming molten droplets of metal,

- allowing the molten droplets to fall through the molten slag,

- collecting the molten droplets after they pass through the molten slag as a body of refined liquid metal in the cold hearth structure directly below the electroslag refining structure,

- providing a cold finger orifice structure having a orifice at the lower portion of the cold hearth structure, and
draining the electroslag refined metal that collects in the cold hearth orifice structure through the orifice of the cold finger orifice structure.

and the step of forming a casting comprises:

disrupting a stream of clean metal from the source of clean metal into molten metal droplets;

partially solidifying the molten metal droplets such that, on average, from about 5% to about 40% by volume of each droplet is solid and the remainder of each droplet is molten; and

collecting and solidifying the partially solidified droplets around the cooled mandrel assembly in a mold forming the casting, in which a turbulent zone is generated by the droplets at an upper surface and, the step of collecting and solidifying the partially solidified droplets collects the droplets in the turbulent zone, and, on average solidifies less than about 50% by volume of the droplet.

28. A method according to claim 16, wherein the cooled mandrel assembly comprises a coolant supply and a coolant conduit that provides coolant to the cooled mandrel assembly.

29. A method according to claim 16, wherein the cooled mandrel assembly comprises at least one of a solid mandrel and a tubular mandrel.

30. A casting method for forming castings for hollows applications for forming a hollows metal casting, the metal casting comprising a fine-grain, homogeneous microstructure that is essentially oxide- and sulfide-free, segregation defect free, and essentially free of voids caused by air entrapped during solidification of the metal from a liquidus state to a solid state, the method comprising:

forming a source of clean refined metal that has oxides and sulfides refined out of the metal;
forming a casting by nucleated casting around a cooled mandrel assembly; wherein

the step of forming a casting by nucleated casting around a cooled mandrel assembly
forms a hollows casting with a microstructure that comprises a fine-grain,
homogeneous microstructure that is essentially oxide- and sulfide-free, segregation
defect free, and essentially free of voids caused by air entrapped during solidification
from a liquidus state to a solid state.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 B22F3/115 B22F9/08 B22D23/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 B22F B22D C22B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the International search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
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<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
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<td>US 3 752 215 A (TORIKAI K) 14 August 1973 (1973-08-14) column 3, line 1 - column 4, line 24; claim 1</td>
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Date of the actual completion of the international search
24 November 2000

Date of mailing of the international search report
01/12/2000

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European Patent Office, P.B. 5816 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx 31 651 epc nl
Fax (+31-70) 340-2016

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