



(11)

EP 3 085 473 A1

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
26.10.2016 Bulletin 2016/43

(51) Int Cl.: **B22C 9/10** ^(2006.01) **B22D 27/06** ^(2006.01)

(21) Application number: **16165915.6**

(22) Date of filing: **19.04.2016**

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
 GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
 PL PT RO RS SE SI SK SM TR**
 Designated Extension States:
BA ME
 Designated Validation States:
MA MD

- **MARCIN, John Joseph**
Marlborough, CT Connecticut 06447 (US)
- **BULLIED, Steven J.**
Pomfret Center, CT Connecticut 06259 (US)
- **VERNER, Carl R.**
Windsor, CT Connecticut 06095 (US)
- **BRENEMAN, Ryan C.**
West Hartford, CT Connecticut 06117 (US)

(30) Priority: 24.04.2015 US 201514695291

(74) Representative: **Ice-ton, Greg James
Dehns
St Bride's House
10 Salisbury Square
London EC4Y 8JD (GB)**

(71) Applicant: **United Technologies Corporation**
Farmington, CT 06032 (US)

(72) Inventors:
• **SHAH, Dilip M.**
Glastonbury, CT Connecticut 06033 (US)

(54) **CASTING WITH REUSABLE, PRECISION, MOTION-CONTROLLED, WITHDRAWABLE CORES**

(57) A method of manufacturing includes providing a casting assembly, providing a material 78 having solid, transition, and liquid phases, heating the material 78 to form the liquid phase, supplying the material 78 to the casting assembly, cooling the material 78, monitoring the solidification of the material 78 from the liquid phase through the transition phase, and moving one of the casting mold or the reusable core 58 in a first direction relative to the other when a substantial portion of the reusable core 58 contacts the transition phase. The casting assembly comprises a casting mold and a reusable core 58 inserted within the casting mold.

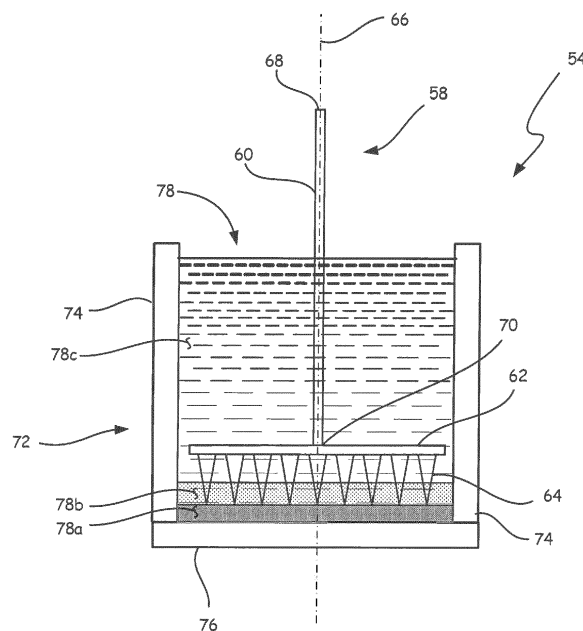


FIG. 3A

Description

BACKGROUND

[0001] Conventional casting generally involves pouring liquid metal into a sacrificial mold made from low-cost, consumable materials. The sacrificial mold materials have melting points higher than the liquid metal and are effectively chemically inert for the duration of a single casting process. This casting process is regularly used to produce low-cost, relatively simplistic parts using manual sand casting and to produce high-cost, relatively complex aerospace parts (e.g. blades and vanes) using lost wax investment casting. Although the cost per mold is relatively low, the molds are destroyed during each casting and require reproduction for subsequent castings.

[0002] Die casting generally involves pouring liquid metal into a durable metal mold made from two precision-machined dies. Contrary to conventional casting processes, die casting processes aim to rapidly mass-produce cast parts without reproducing and preparing sacrificial molds. Commonly, this process is used to cast low melting metals (e.g. aluminum and copper). Die casting is also used to cast high melting alloys (e.g. nickel alloys). However, in such processes the die life is further limited.

[0003] Contrary to conventional casting and die casting processes in which the solidification process is largely uncontrolled (i.e. solidification is omnidirectional), directional solidification processes control the location and rate of solidification to form unidirectional grain structures within the solidified metal. In its simplest form, directional solidification of a casting is achieved by progressively depowering heating elements, thereby cooling the casting from one end of the mold to the other. Continuous casting is another form of directional solidification in which liquid metal is poured into a vertically-oriented, water-cooled copper mold. Typically, the copper molds have a cylindrical, square or I-beam cross section and an open-ended bottom. As liquid metal flows through the mold, the metal along the water-cooled surfaces of the mold solidifies and, as the remainder of the metal cools, this process forms long, continuous billets of cast metal. In its most advanced form, directional solidification casting is practiced in conjunction with the investment casting process to form single crystal cast parts. In this process, a mold full of liquid metal is cooled from one end by a water-cooled plate. As the mold and water-cooled plate are slowly moved from a hot zone to a cool zone in the direction of the water-cooled plate, the liquid material solidifies and forms columns of crystal or single crystal in the direction of withdrawal.

[0004] In each casting process, a core can be suspended within the mold to form a hollow cavity. However, when conventional casting or directional investment casting processes are used, the core becomes encapsulated in the solidified material. To remove the core and thereby expose the hollow cavity, a chemical leaching or heating process is used to chemically remove or burn the core.

The chemical leaching and/or baking processes destroy the core. When a die casting process is used, the core is susceptible to damage when the cast part is removed from the mold. Moreover, when a continuous casting process is used, the cores are fixed and thus, the castings are limited to fixed cross-sections. Therefore, a need exists for an improved casting process that utilizes reusable cores to improve manufacturing time and reduce manufacturing expense.

SUMMARY

[0005] A method of manufacturing includes providing a casting assembly, providing a material having solid, transition, and liquid phases, heating the material to form the liquid phase, supplying the material to the casting assembly, cooling the material, monitoring the solidification of the material from the liquid phase through the transition phase, and moving one of the casting mold or the reusable core in a first direction relative to the other when a substantial portion of the reusable core contacts the transition phase. The casting assembly comprises a casting mold and a reusable core inserted within the casting mold.

[0006] A method of manufacturing a die-cast component includes providing a casting assembly, providing a material having solid, transition, and liquid phases, and heating the material to form the liquid phase. The casting assembly comprises a permanent casting mold having first and second halves that mate along a plane and a core plate rotatably mounted relative to the permanent casting mold. The core plate has an axis of rotation parallel to the plane and defines a plurality of passages extending therethrough. The method further includes supplying the material to the casting assembly through the plurality of passages of the core plate and controlling the solidification of the material such that the core plate is positioned substantially within the transition phase. The material has a solid phase when the material temperature is less than or equal to the solidus temperature. The material has a transition phase when the material temperature is between the solidus and liquidus temperatures. The material has a liquid phase when the material temperature is greater than or equal to the liquidus temperature.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007]

FIG. 1A is a flow chart showing a method for manufacturing a cast component using a durable, non-wettable core coupled with controlled movement of one or more parts of the casting assembly.

FIG. 1B is a flow chart showing another method for manufacturing a cast component using a durable, non-wettable core coupled with controlled movement of one or more parts of the casting assembly.

FIG. 2A is a schematic plan view of a durable, non-wettable core in an extended state.

FIG. 2B is a schematic showing the casting of a component using the core from FIG. 2A

FIG. 2C is a schematic plan view of the core from FIG. 2A in a retracted state.

FIG. 2D is a schematic showing the creation of hollow cavities using the durable, non-wettable, core from FIG. 2C.

FIGs. 3A and 3B are schematics showing the creation of hollow cavities using a durable, non-wettable, core coupled with directional solidification.

FIG. 4 is a schematic showing the creation of staggered hollow cavities using a durable, non-wettable, core coupled with directional solidification.

FIG. 5A is a schematic plan view of a durable, non-wettable core having a volute supported by several spokes.

FIG. 5B is a schematic showing the creation of hollow cavities using the core from FIG. 3A coupled with directional solidification.

FIG. 6A is schematic showing the creation of a die-cast component using a perforated core plate.

FIG. 6B is a schematic plan view of the core plate of FIG. 5A.

DETAILED DESCRIPTION

[0008] The present invention relates to casting apparatuses and processes, and in particular, to casting apparatuses and processes that couple precision movement with one or more durable, non-wettable cores.

[0009] FIG. 1A is a flow chart showing method 10a for manufacturing a cast component. Method 10a utilizes a durable, non-wettable core (not shown in FIG. 1) in connection with precision movement to create a cast component having internal hollow cavities. Forming hollow cavities within cast components through method 10a provides several benefits. Among those benefits are avoiding the manufacturing cost and process time as well as the environmental consequences associated with creating and removing sacrificial cores from cast components through chemical leaching or baking processes.

[0010] Generally, method 10a includes steps 12, 14, 16, 18, 20, 22, 24a, 26, and 28. Step 12 involves providing a casting assembly. The casting assembly includes, at a minimum, a casting mold to define the exterior features of the cast component and a durable, non-wettable core to define the interior features (i.e. one or more hollow cavities) of the cast component. To establish the cast component geometry, the core is positioned relative to the casting mold. Step 14 involves providing a material characterized by solid, transition, and liquid phases. The boundaries between each phase are marked by a solidus temperature and a liquidus temperature of the material. The material takes a solid phase when the material temperature is less than or equal to the solidus temperature and takes a liquid phase when the material temperature

is greater than or equal to the liquidus temperature. Between the solidus and liquidus temperatures, the material forms a transition phase characterized by a viscous fluid relative to the material in the liquid phase. Following step 14, the material is prepared for casting by heating it until the material is substantially in the liquid phase. Heating the material prior to casting is accomplished by one or more methods well known in the art (e.g., using a combustion or induction furnace). Once the material forms a liquid phase, it is delivered to the casting assembly in step 18. The material is poured into the casting assembly, thus filling at least a portion of the casting assembly. Next, step 20 involves cooling the material in the region adjacent the core. In particular, the material is cooled near a portion of the core used to form internal hollow cavities within the cast component and is not necessarily the entire core. While the material is cooling, its material temperature approaches the liquidus temperature. During this time, various process parameters are monitored to evaluate the solidification process in step 22. Among the monitored process parameters are the material temperature in the region adjacent to the core, the bulk material temperature, the temperature of the casting mold, the furnace temperature, and other environmental parameters such as ambient temperature and the like. Once the material bounding the core enters the transition phase and the viscosity of the material is sufficient to support the hollow cavities within the material, one of the casting mold and the core is held stationary while the other is moved in a direction relative to the other in step 24a. In some embodiments, the casting mold is heated in order to reduce a rate of solidification. If the component is fully formed in step 26, the cast component is removed from the casting mold in step 28. However, if the component is not fully formed (i.e. additional hollow cavities are required), steps 18 through 24a are repeated until the cast component is fully formed and removed in step 28. Moreover, repeating steps 18 through 24a (or alternatively 24b as described below) occurs when material is periodically supplied to the casting assembly in order to better control the solidification rate of the material.

[0011] Alternatively, FIG. 1B is a flow chart showing method 10b, which is substantially similar to method 10a except method 10b includes step 24b instead of step 24a. Step 24b involves moving the casting mold in a first direction relative to the core and moving the core in a second direction relative to the casting mold, the first direction being different than the second direction. Combining the motion of the casting mold and core allows method 10b to be applied to directional solidification processes. In one embodiment, movement of the casting mold controls the rate and direction of solidification by moving the casting mold from a melting zone (i.e. a furnace) to a solidification zone (i.e. a cooler region adjacent to the furnace). In such an embodiment, the movement of the core controls the formation of hollow cavities within the cast component during the solidification process.

[0012] For the core to be successfully implemented in

methods 10a and 10b, the core is designed to withstand multiple casting cycles without replacement. A core withstanding only a few casting cycles is sufficiently durable if the manufacturing costs (e.g., material cost, manufacturing time, labor) are reduced by eliminating chemical leaching and/or baking steps associated with sacrificial cores. To attain core durability, the core is constructed from one or more materials that produce a non-wettable surface (i.e. a surface that inhibits the ability of a liquid to wet or cover the surface). Additionally, the core material has thermal shock resistance and erosion resistance sufficient to enable the core to survive multiple casting cycles that produce cast components within manufacturing tolerances. For example, melting metals such as tin, zinc, copper, and aluminum as well as the alloys associated with such materials requires core materials with lower temperature resistance than the core materials used for melting iron and nickel base alloys. In some embodiments, the core is constructed from silicide or ternary intermetallic metals (e.g., MAX phase materials) with appropriate ceramic coatings for casting higher temperature materials such as iron and nickel base alloys. Typically, ceramic coatings include alumina and yttria-stabilized zirconia based coatings. In other embodiments used for manufacturing relatively thin cast components, thin metallic sheets with thermal barrier and/or environmental coatings are used to create thin cast components that are not achievable with brittle materials.

[0013] Movement of the core and/or the casting mold is a repeated motion or pattern of motion used to define the desired shape of the cast component. Depending on the motion of the core and/or casting mold, voids, porosity, foam structures, and lattice structures are created. Such motion can be controlled remotely or with embedded digital motors and/or actuators.

[0014] Typically, the casting material is a metal (e.g., aluminum, carbon steel, and nickel and associated alloys). However, methods 10a and 10b can be applied to other materials such as organic and inorganic salts, paraffin wax, plastics, or food items such as confectionary sugar syrup or gelatins. When such nonmetal materials are used, the resulting cast component (i.e. foam, lattice, cored material) can be used for cosmetic reasons.

[0015] As will be appreciated by those skilled in the art, methods 10a and/or 10b apply to conventional casting, die-casting, and directional solidification casting processes as will be described in greater detail below. Although the following casting molds and cores will be described in the following embodiments with a particular geometry, it is understood that other geometries can be implemented so long as the geometries are compatible with methods 10a and/or 10b as described generally above.

[0016] FIG. 2A is a schematic plan view of durable, non-wettable core 30 shown in an extended state. Core 30 includes structures 32, 34, and 36. Structure 32 extends along axis 33, which intersects the geometric center of structure 32. Structure 34 has one or more protrusions

34a, and structure 36 has one or more protrusions 36a for forming hollow cavities within a cast component (not shown in FIG. 2A). Structures 34 and 36 are attached to structure 32 in a manner that allows structures 34 and 36 to move or retract relative to structure 32. As such, structure 32 is generally disposed between structures 34 and 36. In some embodiments, structures 34 and 36 are attached to opposing faces of structure 32.

[0017] FIG. 2B is a schematic showing the casting of a component using core 30 from FIG. 2A in a conventional casting process. Core 30 includes structures 32, 34, and 36 having axis 33 and protrusions 34a and 36a as discussed above. To cast a component using a conventional casting process, core 30 is assembled within casting assembly 38 which also includes casting mold 40. Core 30, configured in an extended position, is positioned relative to mold 40. In some embodiments, core 30 is inserted within mold 40 such that axis 33 of structure 32 intersects a geometric center of mold 40. However, in other embodiments, core 30 is positioned at an angle relative to mold 40 and/or offset from the geometric center of mold 40 as necessary to produce a cast component having the desired geometry.

[0018] To form a cast component, material 42 is melted and poured into casting assembly 38 in accordance with method 10a. After material 42 conforms to the surfaces of core 30 and mold 40, casting assembly 38 is placed in a cooling environment. Omnidirectional heat loss from material 42 through casting assembly 38 causes material 42, initially in a liquid phase, to form a transition phase. Portions of material 42 adjacent to mold 40 but that is not contacting mold 30 can solidify. When the remaining portions of material 42 adjacent to core 30 are relatively viscous (i.e., form transition phase), core 30 is removed.

[0019] Prior to removal, structures 34 and 36 are retracted relative to structure 32 of core 30 as depicted in FIG. 2C. In some embodiments, structure 34 slides along a mating face of structure 32 in a direction indicated by arrow 44 towards and generally perpendicular to axis 33 while structure 36 moves in an opposing direction along another mating face of structure 32 as indicated by arrow 46. Thus, core 30 takes a retracted form that allows core 30 to be removed from casting assembly 38.

[0020] FIG. 2D is a schematic showing the creation of hollow cavities 50 and 52 by withdrawing core 30 in a withdrawal direction indicated by arrow 48 from casting assembly 38. As can be seen in FIG. 2D, the retracted state of core 30 permits structures 32, 34, and 36 to be withdrawn from casting assembly 38 without interfering with solidifying material 42. In some embodiments, protrusions 36a and 34a (not shown in FIG. 2D) have a triangular cross-section as shown in FIG. 2D and form similarly-shaped hollow cavities 50 and 52, respectively. However, other protruding shapes are possible so long as the viscosity of material 42 adjacent to core 30 immediately prior to withdrawal is sufficient to support the internal features (e.g., hollow cavities 50 and 52) once core 30 is removed. The required viscosity of material 42 de-

depends on the size of the internal feature to be formed and the properties and temperature of material 42 when core 30 is withdrawn from material 42.

[0021] FIGs. 3A and 3B are schematics of casting assembly 54 showing the creation of hollow cavities 56 (see FIG. 3B) using durable, non-wettable, core 58 coupled with directional solidification. Core 58 includes shaft 60, plate 62, and at least one protrusion 64. Shaft 60 extends along axis 66, which intersects the geometric center of shaft 60. Shaft 60 has opposing ends 68 and 70. Plate 62 is attached to shaft 60 at end 70 and has at least one protrusion 64 extending therefrom in a direction opposite shaft 60. In some embodiments, core 58 has a plurality of protrusions 64 extending from plate 62, being spaced along plate 62 so as to form a comb-like shape. To form casting assembly 54, core 58 is positioned relative to casting mold 72. Casting mold 72 includes side mold 74 that encircles core 58 and chill plate 76 disposed at an end of casting mold 72 abutting and/or attached to side mold 74.

[0022] To form a cast component, material 78 is supplied to casting assembly 54. In some embodiments, material 78 fills the interior volume of casting assembly 54 defined by casting mold 72 and core 58. In other embodiments, material 78 is fed to casting assembly 54 at an average feed rate. In such embodiments, the feed rate can be characterized by periodically supplying material 78 to casting assembly 54 to better control the solidification of material 78 in casting assembly 54.

[0023] Chill plate 76 is configured to cool material 78 to promote solidification of material 78 while side mold 74 is insulated and/or heated to prevent premature solidification of material 78. In some embodiments, chill plate 76 is a water-cooled metal plate (e.g., a water-cooled copper plate). This arrangement of casting mold 72 causes material 78 to solidify adjacent to chill plate 76 while material 78 remains in a liquid or transition phase elsewhere within casting mold 72. Thus, material 78 forms solid phase 78a, transition phase 78b, and liquid phase 78c, in sequential order, extending from a region adjacent chill plate 76.

[0024] Referring now to FIG. 3B, casting mold 72 is moved relative to core 58 when material 78 within transition phase 78b has a viscosity sufficient to form hollow cavities 56. Solid phase 78a and transition phase 78b grow to encompass a substantial portion of protrusions 64 of core 58. Because solid phase 78a generally causes material 78 to contract, distal ends of protrusions 64 (i.e. and end opposite plate 62) are tapered in some embodiments to counteract this contraction and promote relative movement of casting mold 72 relative to core 58. Furthermore, casting mold 72 is moved in a direction indicated by arrow 80, which is generally parallel to axis 66 of core 58. To further promote solidification of material 78, casting mold 72 is typically moved from a melting region to a solidification region. The melting region (e.g., the interior of a furnace) has a temperature sufficient to maintain material 78 in liquid phase 78c while the solid-

ification region (e.g., the exterior of a furnace), has a temperature sufficient to maintain material 78 in solid phase 78a. Thus, the solidification of material 78 promotes directional grain structures in solid phase 78a and hollow cavities 56 are formed without using chemical leaching or baking processes to remove core 58.

[0025] FIG. 4 is a schematic showing the creation of staggered hollow cavities 81a and 81b using casting assembly 54 as previously described above. However, instead of restraining core 58 and moving casting mold 72 to form hollow cavities 56 (see FIG. 3B), core 58 is moved in directions indicated by bi-direction arrow 83a and/or bi-directional arrow 83b. In some embodiments, core 58 is moved in a direction that is perpendicular to the withdrawal direction of casting mold 72 indicated by arrow 80. Thus, by moving both casting mold 72 and core 58, hollow cavities 81a and 81b are formed in a staggered pattern. The sizes of hollow cavities 81a and 81b are determined by the rate at which core 58 and casting mold 72 are moving relative to one another.

[0026] FIGs. 5A and 5B are schematic views of casting assembly 82 showing the creation of hollow cavities 84 using durable, non-wettable core 86. Casting assembly 82 includes core 86 and casting mold 87. Core 86 includes hollow shaft 88 and spokes 90 supporting volute 92. Hollow shaft 88 extends along axis 94, which intersects a geometric center of core 86, and has opposing ends 96 and 98 (see FIG. 5B). Spokes 90 extend from end 96 of hollow shaft 88 in an outward and generally perpendicular direction relative to axis 94. Casting mold 87 includes side mold 100 and chill plate 102, each being substantially similar to side mold 74 and chill plate 76.

[0027] To form a cast component, material 104 is supplied to casting assembly 82. In some embodiments, material 104 fills the interior volume of casting assembly 82 defined by casting mold 87 and core 86. In other embodiments, material 104 is fed to casting assembly 82 at an average feed rate. In such embodiments, the feed rate can be characterized by periodically supplying material 104 to casting assembly 82 to better control the solidification of material 104 in casting assembly 82. Material 104 forms solid phase 104a, transition phase 104b, and liquid phase 104c as a result of chill plate 102 cooling material 104 from an end of casting mold 87. In any embodiment, spokes 90 are shaped (e.g., tapered) such that material 104 readily flows along spokes 90 and through volute 92.

[0028] In a process similar to the directional casting process described in FIGs. 3A and 3B, FIG. 5B shows casting mold 87 moving relative to core 86. Casting mold 87 movement occurs when material 104 within transition phase 104b has a viscosity sufficient to form hollow cavities 84. Continued cooling of material 104 by chill plate 102 causes solid phase 104a and transition phase 104b to grow until phases 104a and 104b encompass a substantial portion of volute 92. Because solid phase 104a generally causes material 104 to contract, edges of volute 92 facing chill plate 102 are tapered in some embod-

iments to counteract this contraction and promote relative movement of casting mold 87 relative to core 86. In some embodiments, casting mold 87 is moved in a direction indicated by arrow 106, which is generally parallel to axis 94 of core 86. To further promote solidification of material 104, casting mold 87 is typically moved from a melting region to a solidification region. The melting region (e.g., the interior of a furnace) has a temperature sufficient to maintain material 104 in liquid phase 104c while the solidification region (e.g., the exterior of a furnace), has a temperature sufficient to maintain material 104 in solid phase 104a. Thus, the solidification of material 104 promotes directional grain structures in solid phase 104a and hollow cavities 84 are formed without using chemical leaching or baking processes to remove core 86. The end result of this process is to cast a spiral roll of sheet metal without using a consumable core. In a directional solidification process this will allow casting of long single crystal sheet metal, not attainable by solidification furnaces currently available.

[0029] FIG. 6A is schematic of casting assembly 108 showing the creation of a die-cast component using perforated core plate 110 and casting mold 112. Casting assembly 108 includes core plate 110, casting mold 112, material inlet 114, and shot tube 116. Core plate 110 is disposed between casting mold 112 and shot tube 116. To form a cast component, material 118 is fed through inlet 114 into shot tube 116. Piston 120 includes shaft 122 and head 124. Actuating piston 120 along shot tube 116 in a direction towards core plate 110 forces material 118 through core plate 110 into casting mold 112. As material 118 is fed through core plate 110, casting mold 112 is moved parallel to core plate 110 as indicated by bi-directional arrow 126. Thus, an oscillating casting mold 112 creates porosity within material 118, which has a transition phase as it flows through core plate 110 and solidifies within casting mold 112. The porosity within material 118 increases as the oscillating motion of casting mold 112 increases. Conversely, the porosity within material 118 decreases as the oscillating motion of casting mold 112 decreases. To facilitate removal of the cast component (not shown in FIG. 6A), casting mold 112 is split in at least two halves 128a and 128b that have mating surfaces. In some embodiments, halves 128a and 128b mate along a common plane. Internal surfaces 130a and 130b of each mold half 128a and 128b, respectively, define the exterior surfaces of a cast component (not shown in FIG. 6A).

[0030] FIG. 6B is a schematic plan view of core plate 110 of FIG. 6A. When viewed as shown in FIG. 6B, core plate 110 has a cross-section that conforms to shot tube 116. Core plate 110 includes at least one passage 132 through which material 118 traverses core plate 110 from shot tube 116 to casting mold 112. In some embodiments, core plate 110 includes a plurality of passages 132, although multiple passages 132 are not required.

Discussion of Possible Embodiments

[0031] The following are non-exclusive descriptions of possible embodiments of the present invention.

[0032] A method of manufacturing includes providing a casting assembly, providing a material having solid, transition, and liquid phases, heating the material to form the liquid phase, supplying the material to the casting assembly, cooling the material, monitoring the solidification of the material from the liquid phase through the transition phase, and moving one of the casting mold or the reusable core in a first direction relative to the other when a substantial portion of the reusable core contacts the transition phase. The casting assembly comprises a casting mold and a reusable core inserted within the casting mold. The material has a solid phase at a temperature less than or equal to the solidus temperature. The material has a transition phase at a temperature between the solidus and liquidus temperatures. The material has a liquid phase at a temperature greater than or equal to the liquidus temperature.

[0033] The method of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations and/or additional components:

[0034] A further embodiment of the foregoing method, wherein the reusable core can move relative to the casting mold.

[0035] A further embodiment of any of the foregoing methods can further include removing the reusable core from the casting mold. The viscosity of the material adjacent to the reusable core at a time immediately preceding the removal of the core can be sufficient to form one or more hollow cavities within the material.

[0036] A further embodiment of any of the foregoing methods can further include heating the casting assembly during the removal of the core to reduce a rate of solidification of the material.

[0037] A further embodiment of any of the foregoing methods, wherein the reusable core can further comprise a first structure that extends into the casting mold along a central axis and a second structure attached to the first structure such that the second structure is movable relative to the first structure in a direction substantially perpendicular to the central axis.

[0038] A further embodiment of any of the foregoing methods, wherein the reusable core can further comprise a protrusion extending from the second structure configured to form a hollow cavity within the material, wherein a distal end of the protrusion can be tapered.

[0039] A further embodiment of any of the foregoing methods wherein the casting mold can move relative to the reusable core, and wherein during the solidification of the material, a substantial portion of the reusable core can be immersed in the transition phase.

[0040] A further embodiment of any of the foregoing methods, wherein the casting mold can move from a first zone having a first temperature sufficient to form the liquid

phase to a second zone having a second temperature sufficient to form a solid phase.

[0041] A further embodiment of any of the foregoing methods, wherein the casting assembly can further comprise a plate forming an end of the casting mold configured to cool the material.

[0042] A further embodiment of any of the foregoing methods can further include forming a unidirectional crystalline structure within the material.

[0043] A further embodiment of any of the foregoing methods can further include forming a passage extending through at least a portion of the material, wherein the passage can be formed by the relative movement of the casting mold to the reusable core.

[0044] A further embodiment of any of the foregoing methods, wherein the reusable core can comprise a shaft extending in the casting mold along a central axis, a plate having a first face affixed to the shaft and a second face opposite the first face, and a plurality of protrusions extending from the second face, each protrusion having a tapered distal end.

[0045] A further embodiment of any of the foregoing methods, wherein the reusable core can comprise a hollow shaft extending in the casting mold along a central axis, a plurality of spokes affixed to an outer surface of the hollow shaft that extend outward from and generally perpendicular to the axis, and a volute affixed to the outer surface of the hollow shaft and the plurality of spokes, wherein the volute extends in a circumferential direction about the axis.

[0046] A further embodiment of any of the foregoing methods can further include moving the reusable core in a second direction relative to the casting mold, wherein the second direction is different from the first direction.

[0047] A further embodiment of any of the foregoing methods, wherein the second direction can be substantially perpendicular to the first direction.

[0048] A further embodiment of any of the foregoing methods can further include forming a first plurality of cavities and a second plurality of cavities within the material, wherein the second plurality of cavities can be offset from the first plurality of cavities.

[0049] A further embodiment of any of the foregoing methods, wherein the material can be periodically supplied to the casting assembly.

[0050] A method of manufacturing a die-cast component includes providing a casting assembly, providing a material having solid, transition, and liquid phases, and heating the material to for the liquid phase. The casting assembly comprises a permanent casting mold having first and second halves that mate along a plane and a core plate rotatably mounted relative to the permanent casting mold. The core plate has an axis of rotation parallel to the plane and defines a plurality of passages extending therethrough. The method further includes supplying the material to the casting assembly through the plurality of passages of the core plate and controlling the solidification of the material such that the core plate is

positioned substantially within the transition phase. The material has a solid phase at a temperature less than or equal to the solidus temperature. The material has a transition phase at a temperature between the solidus and liquidus temperatures. The material has a liquid phase at a temperature greater than or equal to the liquidus temperature.

[0051] The method of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations and/or additional components:

[0052] A further embodiment of any of the foregoing methods can further include oscillating the core plate about the axis to form porosity within the material.

[0053] While the invention has been described with reference to an exemplary embodiment(s), it will be understood by those skilled in the art that various changes may be made without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment(s) disclosed, but that the invention will include all embodiments falling within the scope of the appended claims.

Claims

1. A method of manufacturing includes:

providing a casting assembly comprising:

a casting mold; and
a reusable core (58) inserted within the casting mold;

providing a material (78) that has a solidus temperature and a liquidus temperature, wherein the material has a solid phase at a temperature less than or equal to the solidus temperature, a transition phase at a temperature between the solidus and liquidus temperatures, and a liquid phase at a temperature greater than or equal to the liquidus temperature;
heating the material (78) to form the liquid phase;
supplying the material (78) to the casting assembly;
cooling the material (78);
monitoring a solidification of the material (78) from the liquid phase through the transition phase; and
moving one of the casting mold or the reusable core (58) in a first direction relative to the other when a substantial portion of the reusable core (58) contacts the material (78) in the transition phase.

2. The method of claim 1, wherein the reusable core (58) moves relative to the casting mold.
3. The method of claim 2 and further including:
- removing the reusable core (58) from the casting mold, wherein a viscosity of the material (78) surrounding the reusable core (58) at a time immediately preceding the removal of the core is sufficient to form one or more hollow cavities within the material (78).
4. The method of claim 3 and further including:
- heating the casting assembly during the removal of the core (58) to reduce a rate of solidification of the material (78).
5. The method of claim 2, wherein:
- the reusable core (58) comprises:
- a first structure that extends into the casting mold along a central axis; and
- a second structure attached to the first structure such that the second structure is movable relative to the first structure in a direction substantially perpendicular to the central axis, and wherein
- the reusable core (58) further comprises:
- a protrusion extending from the second structure configured to form a hollow cavity within the material, wherein a distal end of the protrusion is tapered.
6. The method of any preceding claim, wherein the casting mold moves relative to the reusable core (58), and wherein during the solidification of the material, a substantial portion of the reusable core is immersed in the transition phase, and preferably wherein the material is periodically supplied to the casting assembly
7. The method of claim 6, wherein the casting mold moves from a first zone having a first temperature sufficient to form the liquid phase to a second zone having a second temperature sufficient to form the solid phase.
8. The method of claim 6, wherein:
- the casting assembly further comprises:
- a plate forming an end of the casting mold configured to cool the material.
9. The method of claim 8 and further including:
- forming a unidirectional crystalline structure within the material.
10. The method of claim 6 and further including:
- forming a passage extending through at least a portion of the material, wherein the passage is formed by the relative movement of the casting mold to the reusable core.
11. The method of claim 6, wherein:
- the reusable core (58) comprises:
- a shaft extending in the casting mold along a central axis;
- a plate having a first face affixed to the shaft and a second face opposite the first face; and
- a plurality of protrusions extending from the second face, each protrusion having a tapered distal end.
12. The method of claim 6, wherein:
- the reusable core (58) comprises:
- a hollow shaft extending in the casting mold along a central axis;
- a plurality of spokes affixed to an outer surface of the hollow shaft that extend outward from and generally perpendicular to the axis; and
- a volute affixed to the outer surface of the hollow shaft and the plurality of spokes, wherein the volute extends in a circumferential direction about the axis.
13. The method of claim 6 and further including:
- moving the reusable core (58) in a second direction relative to the casting mold, wherein the second direction is different from the first direction.
14. The method of claim 13, wherein the second direction is substantially perpendicular to the first direction.
15. The method of claim 14 and further including:
- forming a first plurality of cavities and a second plurality of cavities within the material, wherein the second plurality of cavities are offset from the first plurality of cavities.

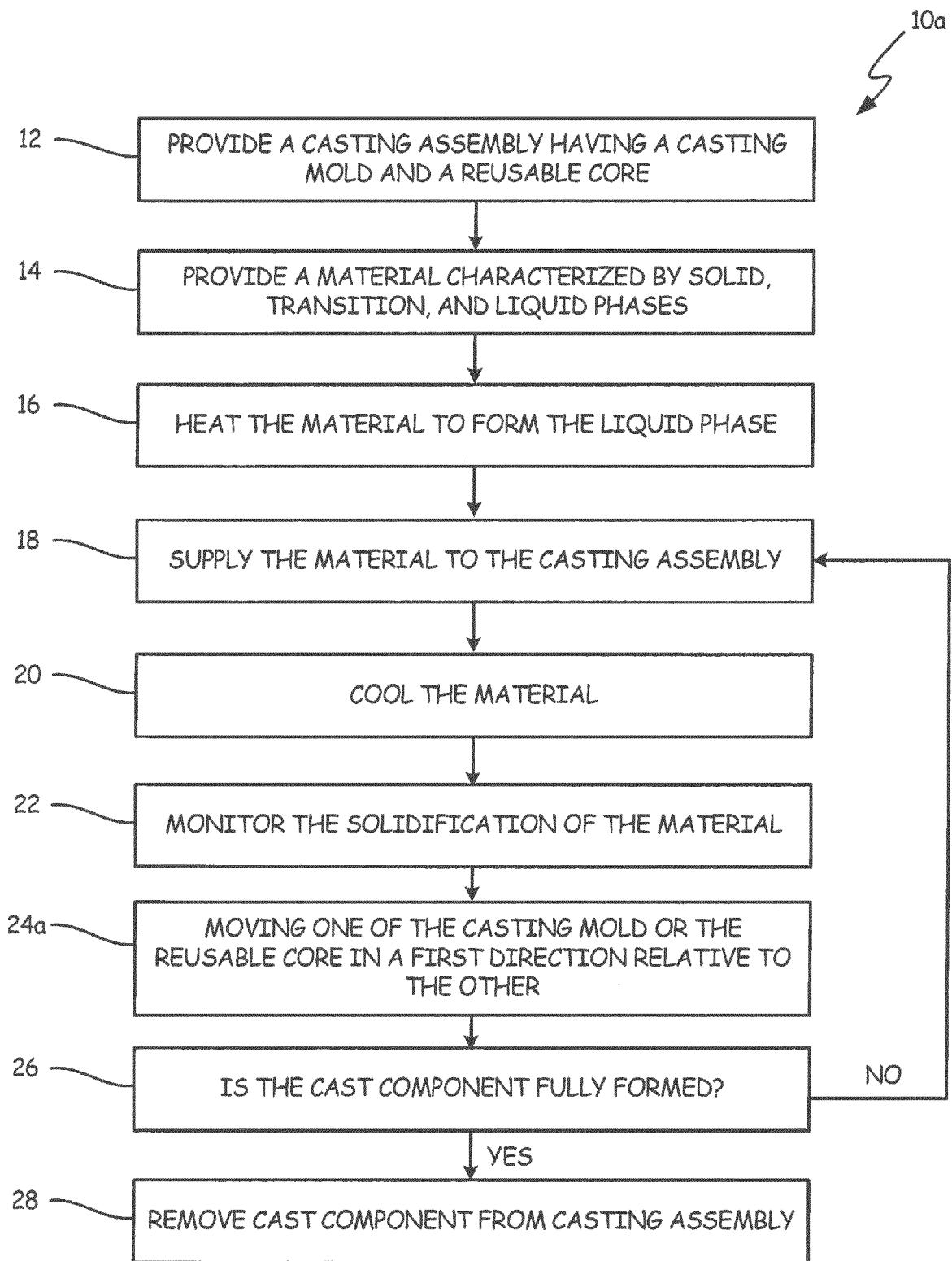
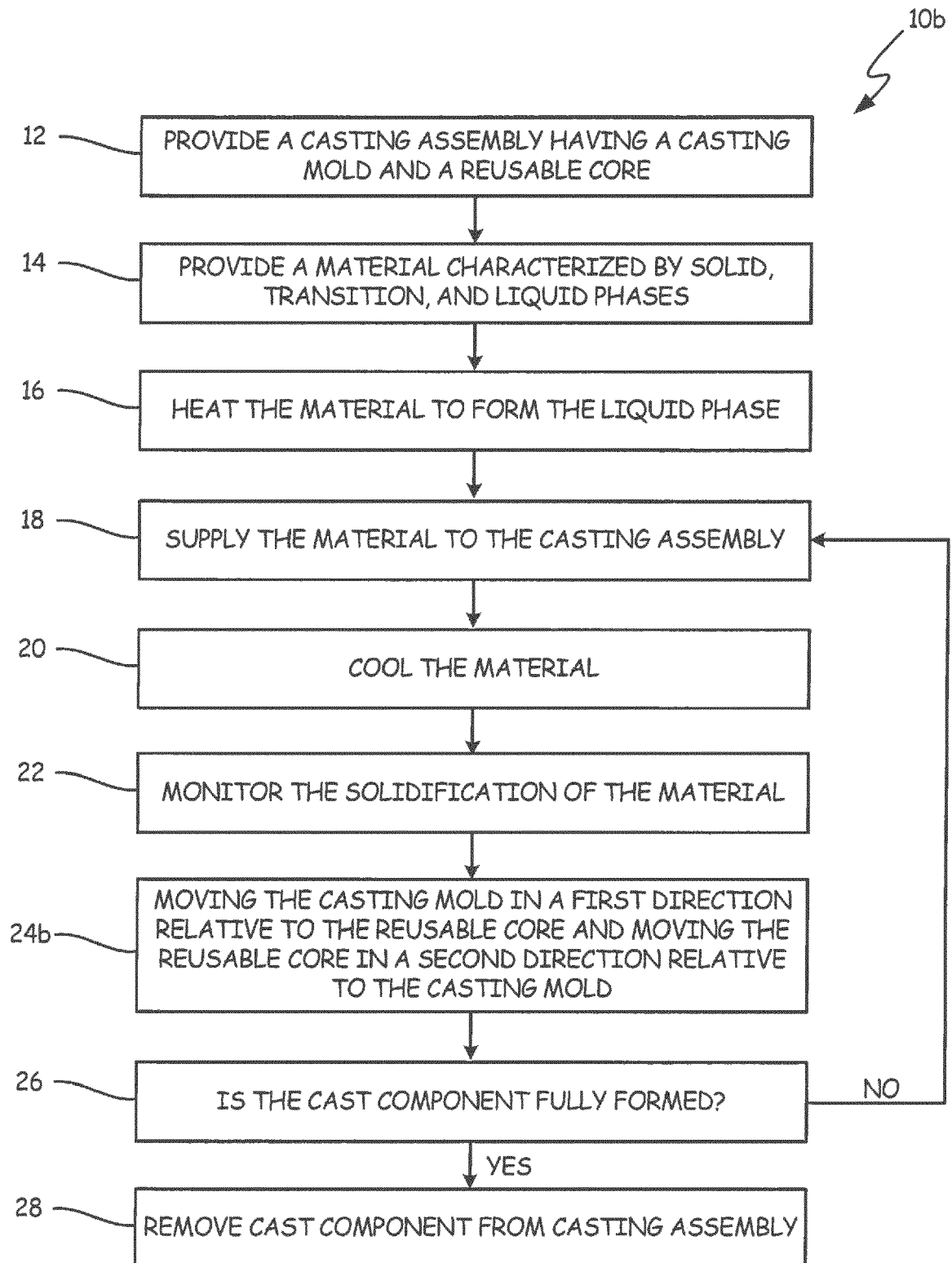


FIG. 1A

**FIG. 1B**

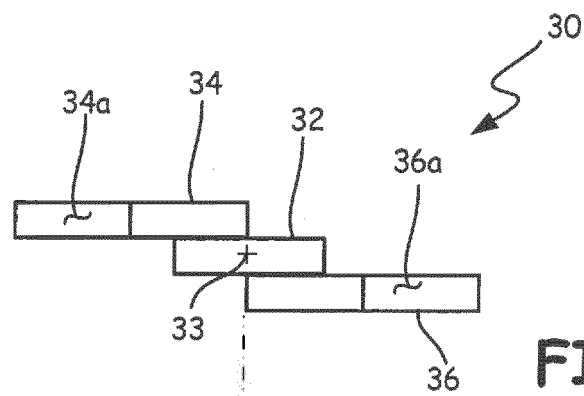


FIG. 2A

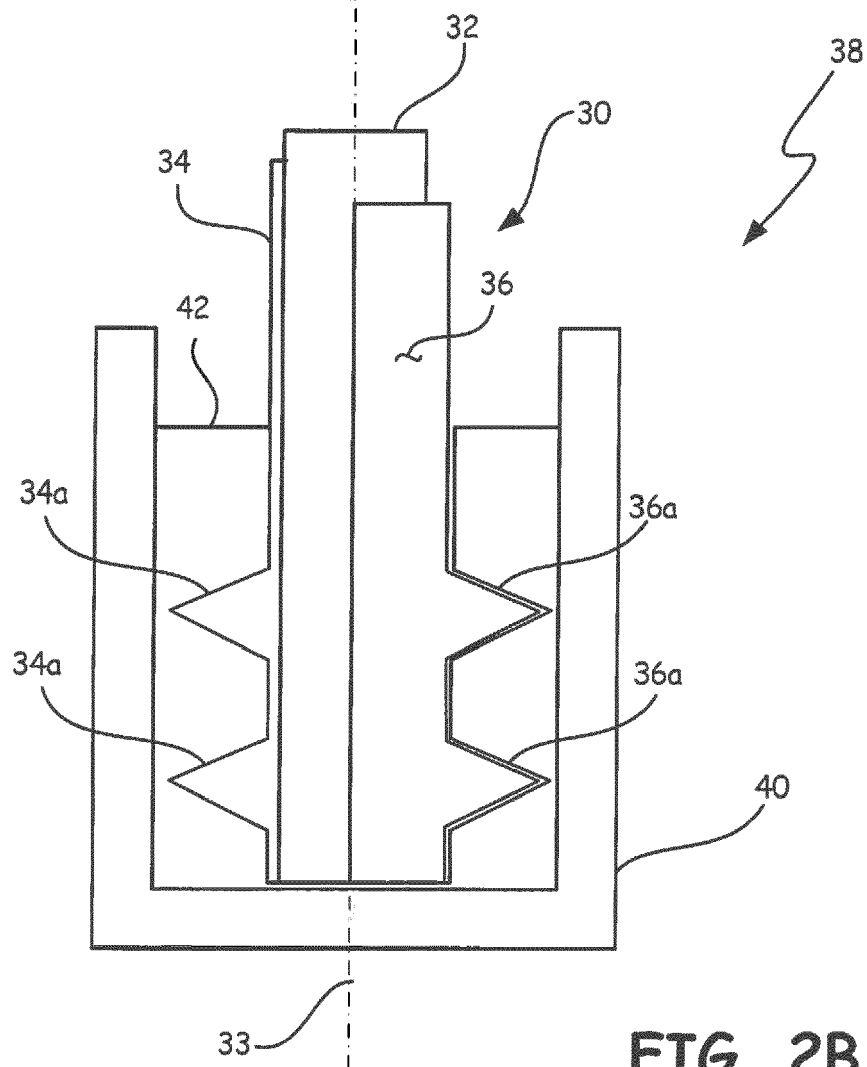
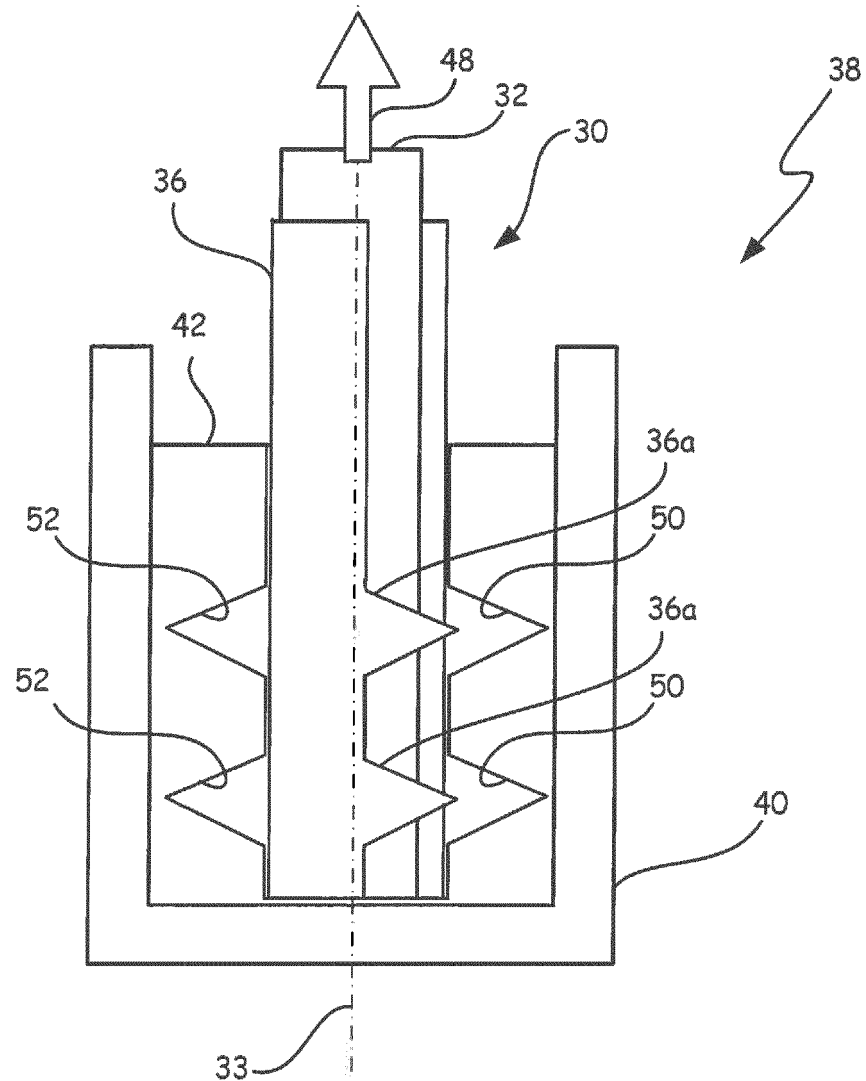
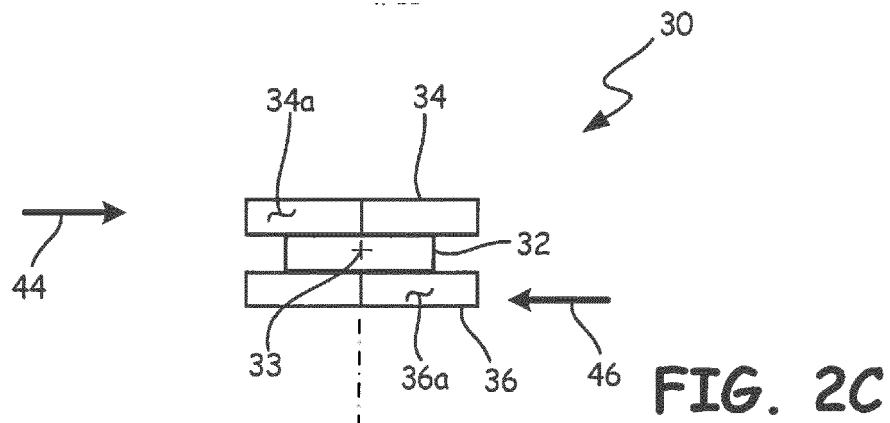


FIG. 2B



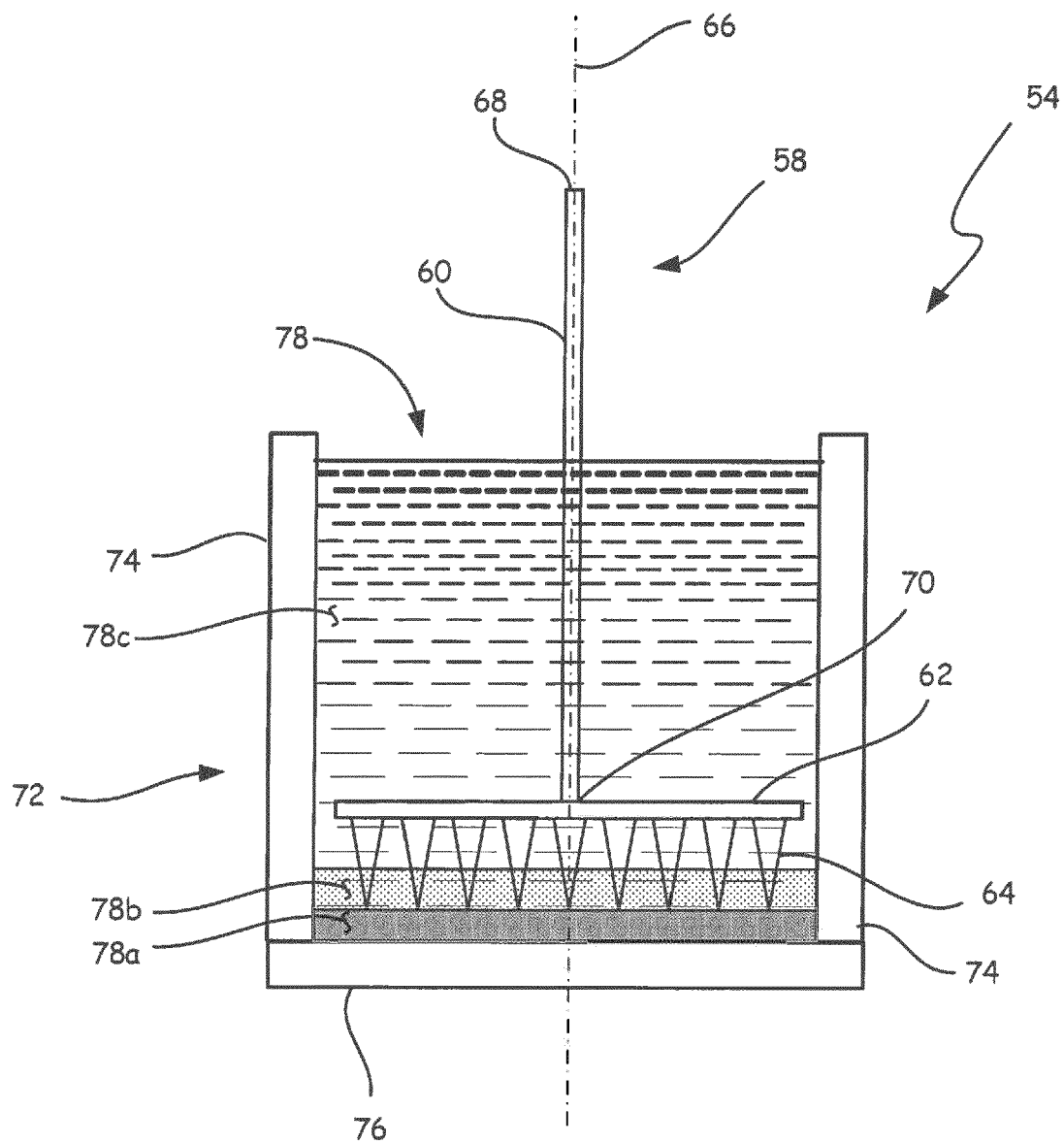


FIG. 3A

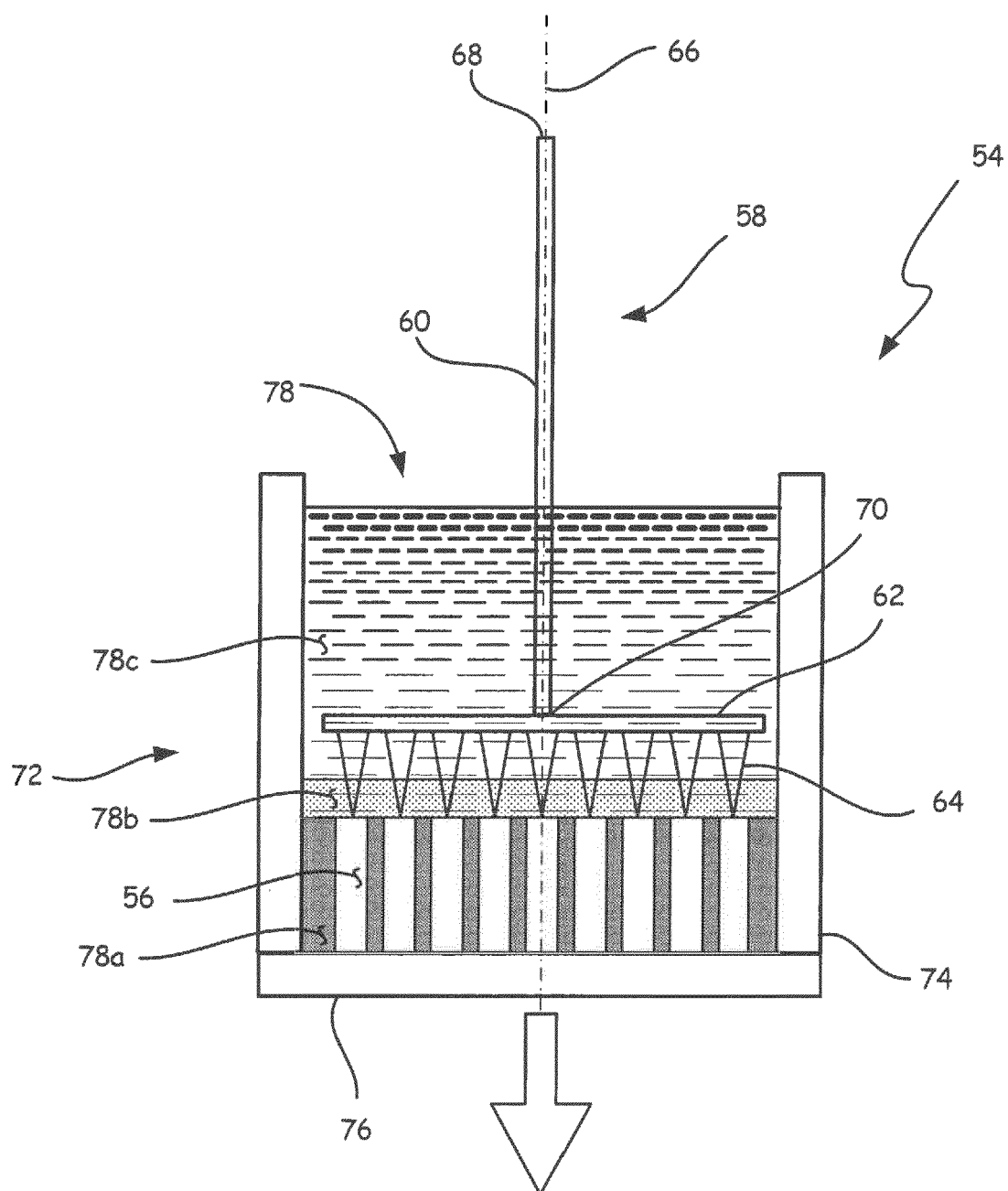


FIG. 3B

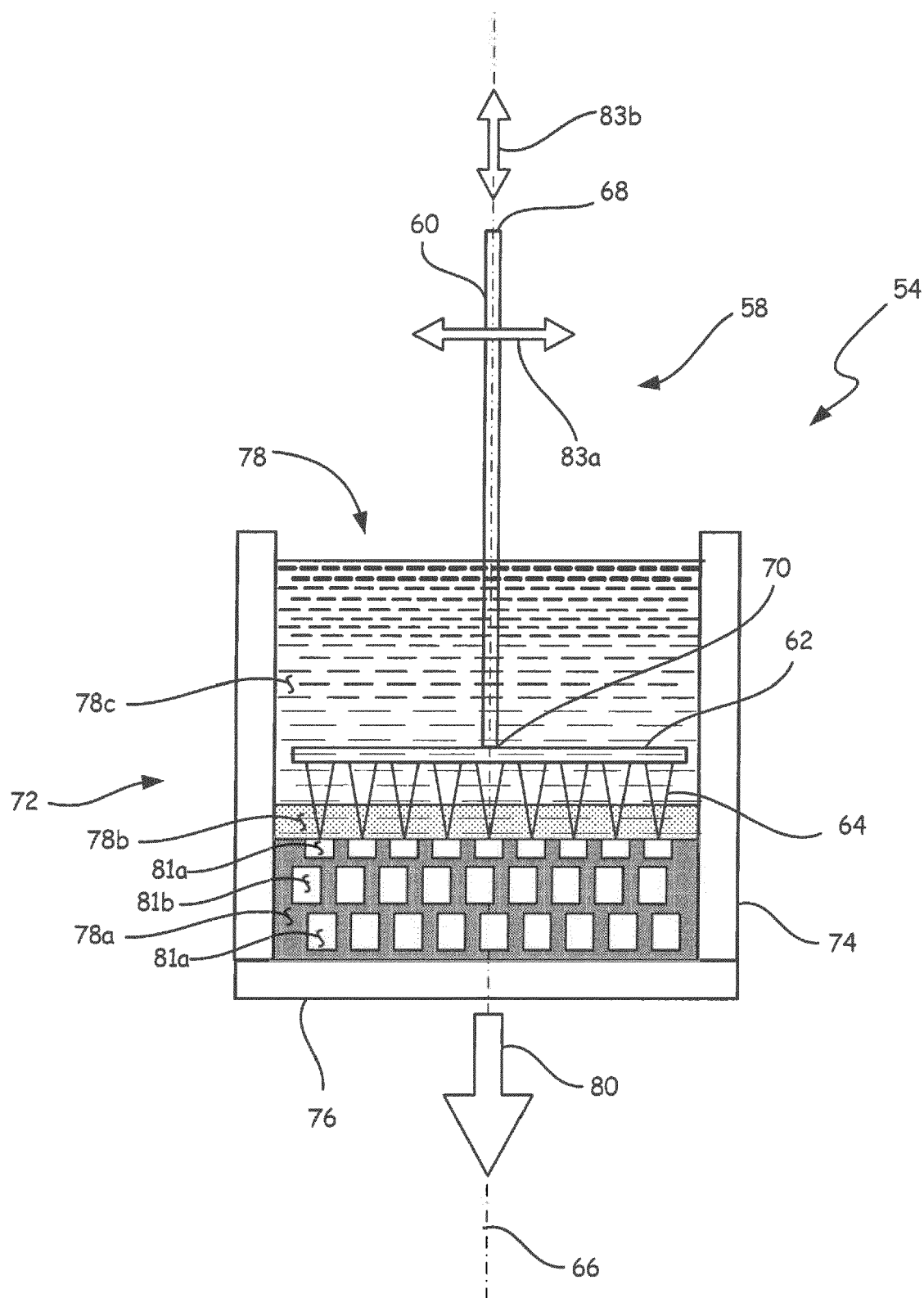


FIG. 4

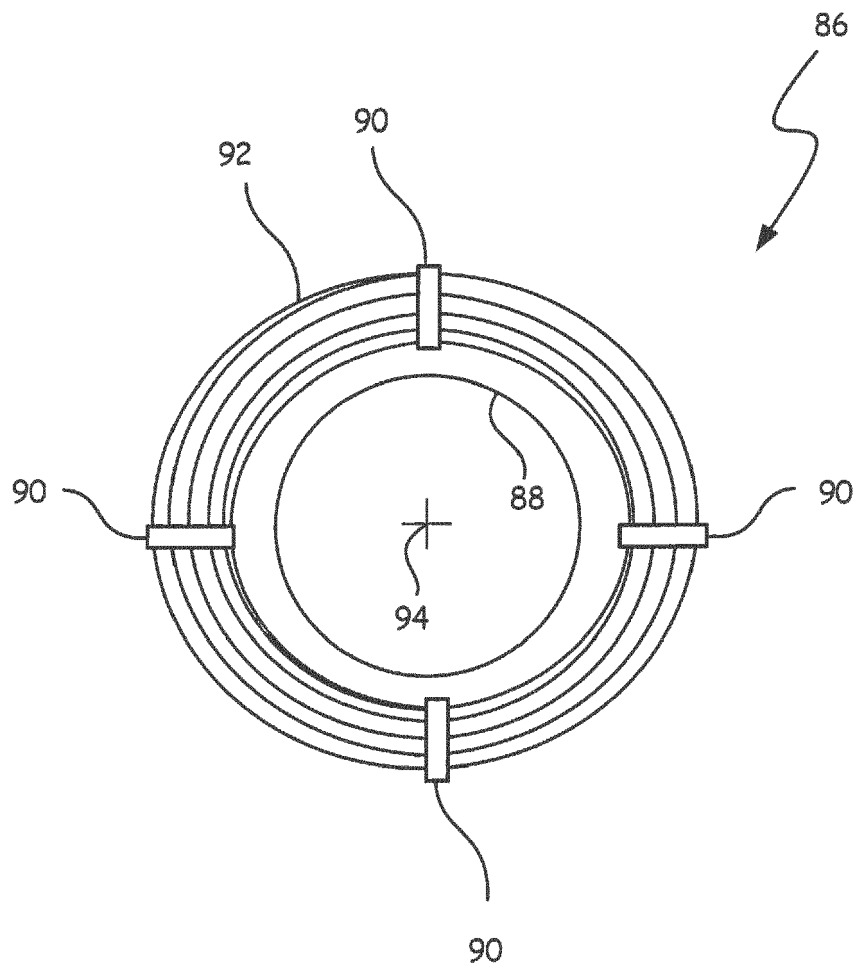


FIG. 5A

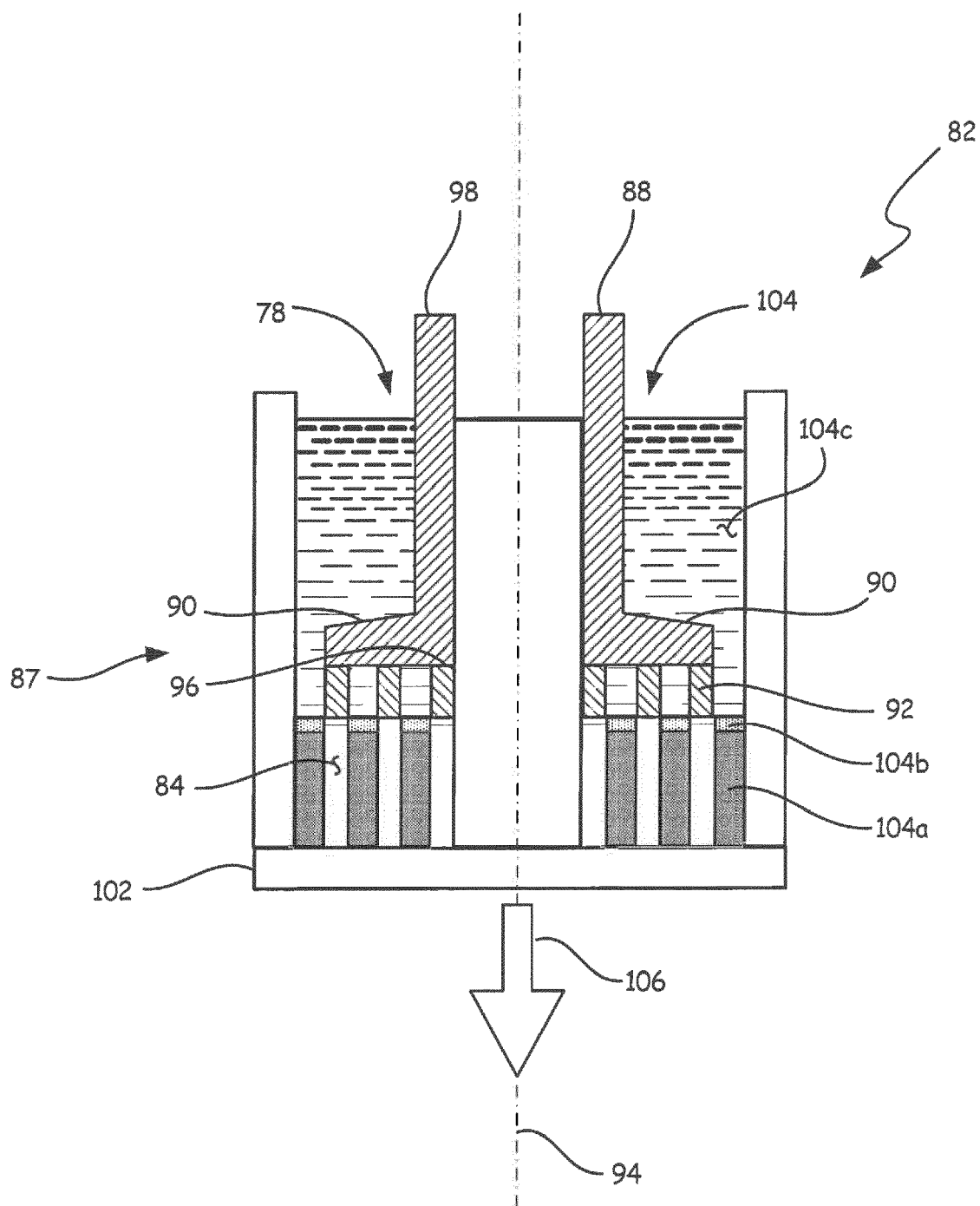


FIG. 5B

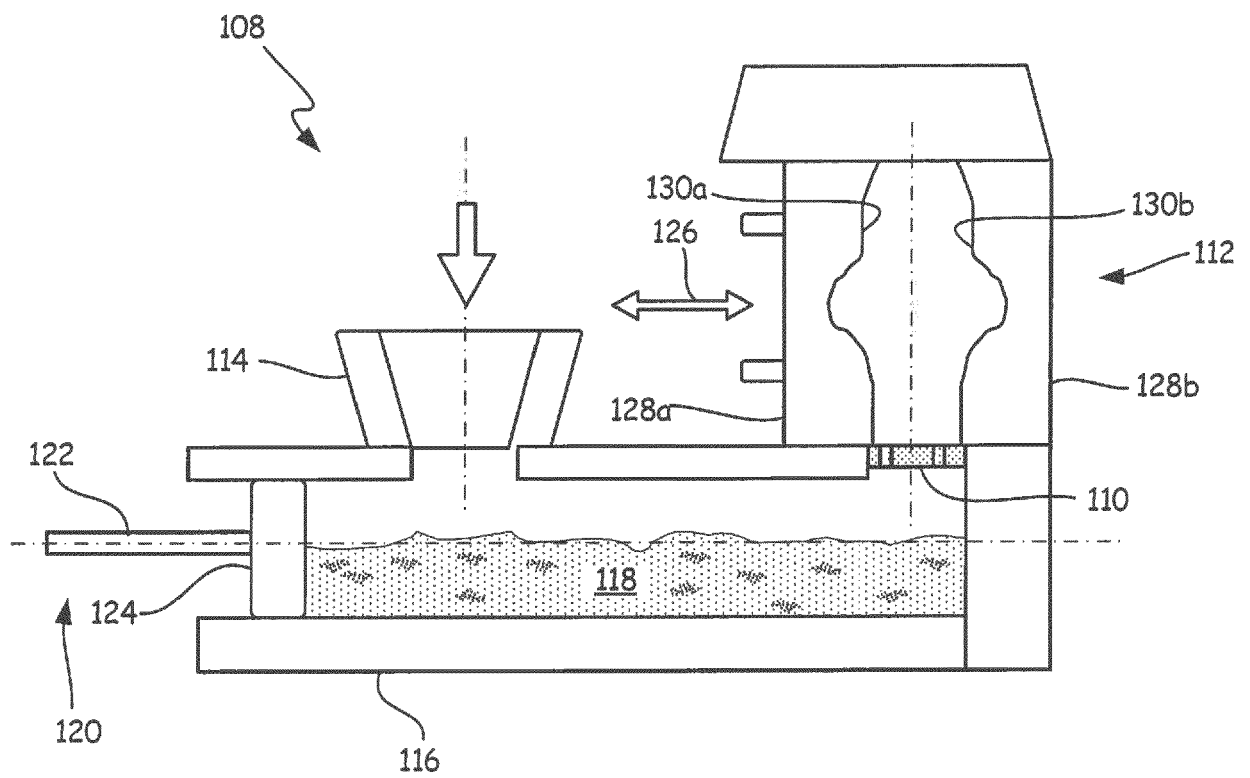


FIG. 6A

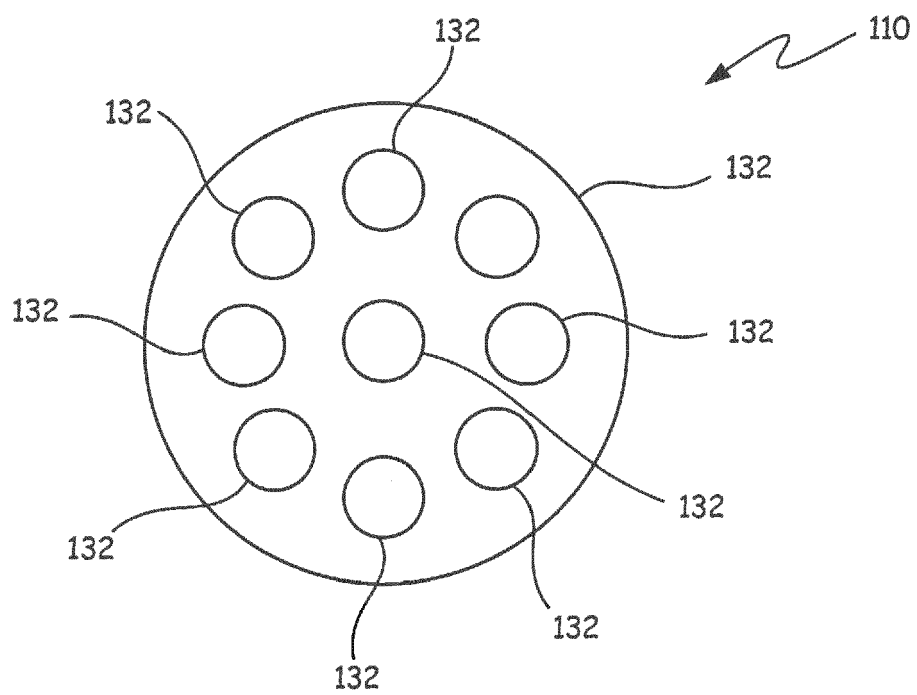


FIG. 6B



EUROPEAN SEARCH REPORT

Application Number
EP 16 16 5915

5

10

15

20

25

30

35

40

45

50

55

1

EPO FORM 1503 03.82 (P04C01)

DOCUMENTS CONSIDERED TO BE RELEVANT				
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)	
X	US 4 779 665 A (OUMET LARRY J [US]) 25 October 1988 (1988-10-25)	1,2	INV. B22C9/10 B22D27/06	
A	* the whole document *	3-15		

X	US 4 779 666 A (RUHLANDT GERALD K [US] ET AL) 25 October 1988 (1988-10-25)	1,2		
A	* the whole document *	3-15		

X	GB 543 810 A (GLACIER CO LTD; VICTOR ALBERT BONIFAS) 13 March 1942 (1942-03-13)	1,2	TECHNICAL FIELDS SEARCHED (IPC) B22C B22D	
A	* the whole document *	3-15		

The present search report has been drawn up for all claims				
Place of search		Date of completion of the search		Examiner
Munich		24 August 2016		Baumgartner, Robin
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document				

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 16 16 5915

5

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

24-08-2016

10

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4779665 A	25-10-1988	NONE	
US 4779666 A	25-10-1988	NONE	
GB 543810 A	13-03-1942	NONE	

15

20

25

30

35

40

45

50

55

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82