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(54) **DIE CASTING IN INVESTMENT MOLD**

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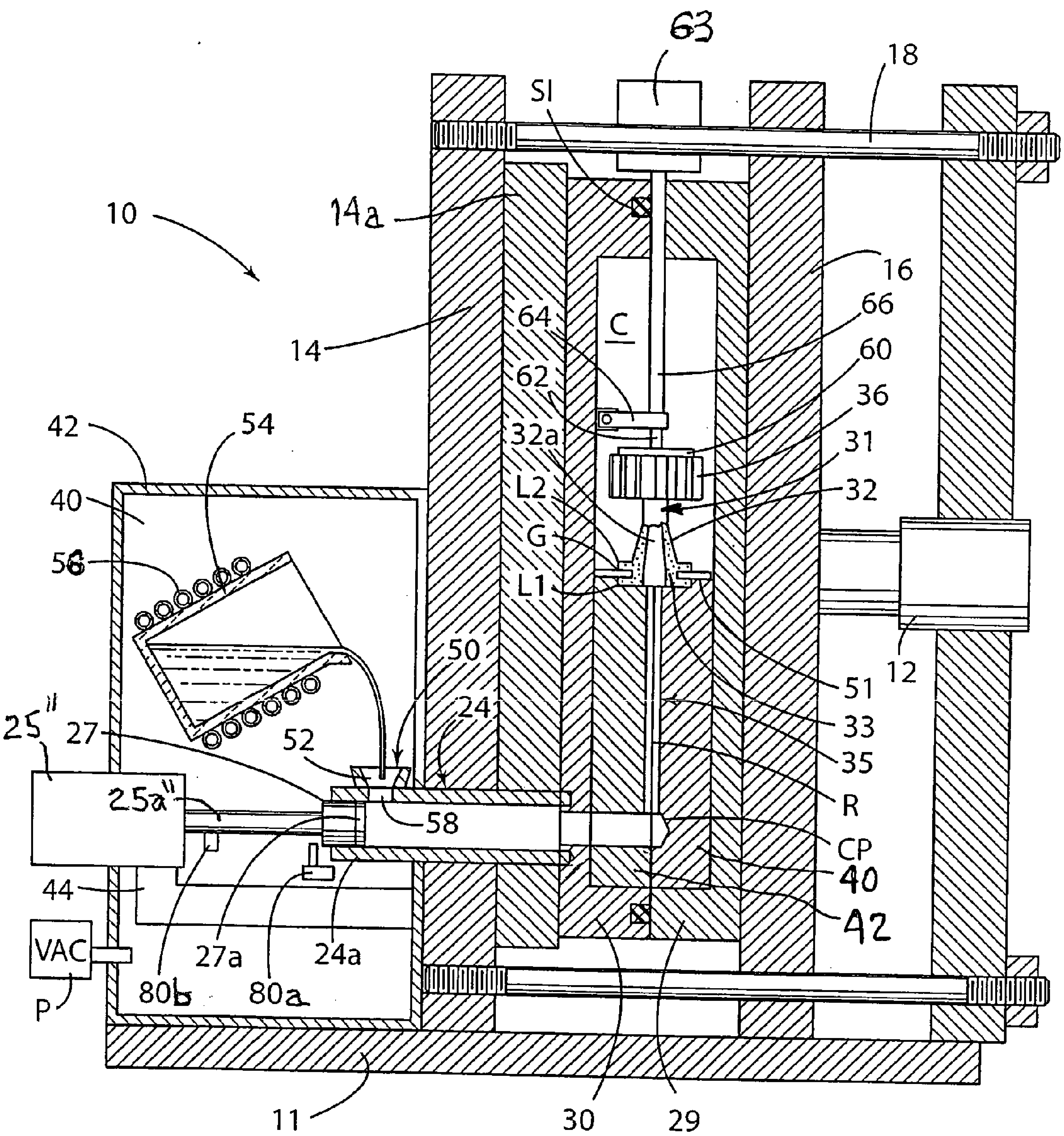
(57) **ABSTRACT**

Method and apparatus for casting a metallic material involves the steps of providing a non-metallic mold in a mold-receiving chamber disposed in at least one of relatively movable first and second members, communicating a mold cavity in the mold to a gating passage disposed in at least one of the first and second metallic members, communicating the gating passage to a shot sleeve, and flowing metallic material from the shot sleeve to the gating passage and into the non-metallic mold.



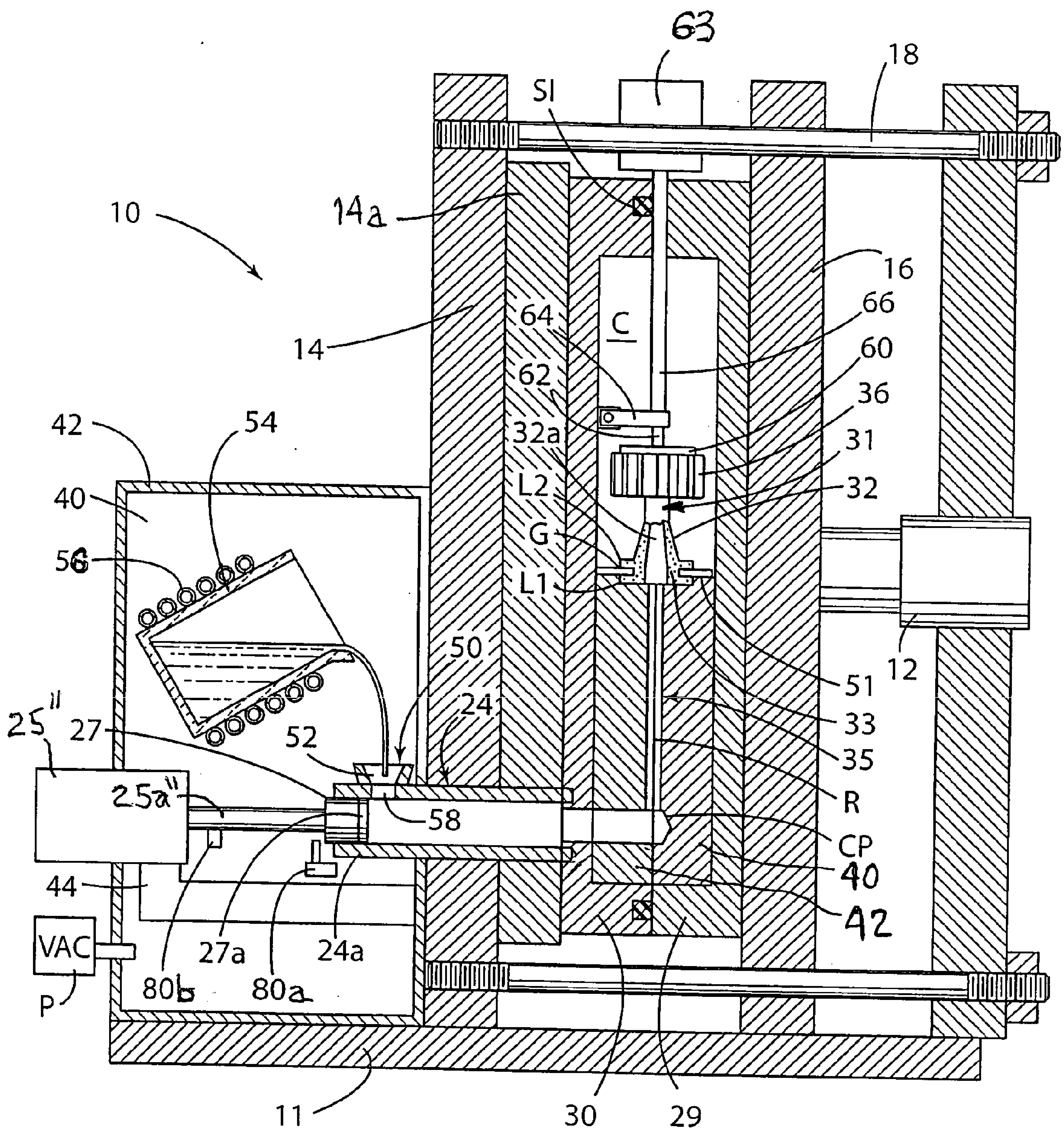

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FIG. 1

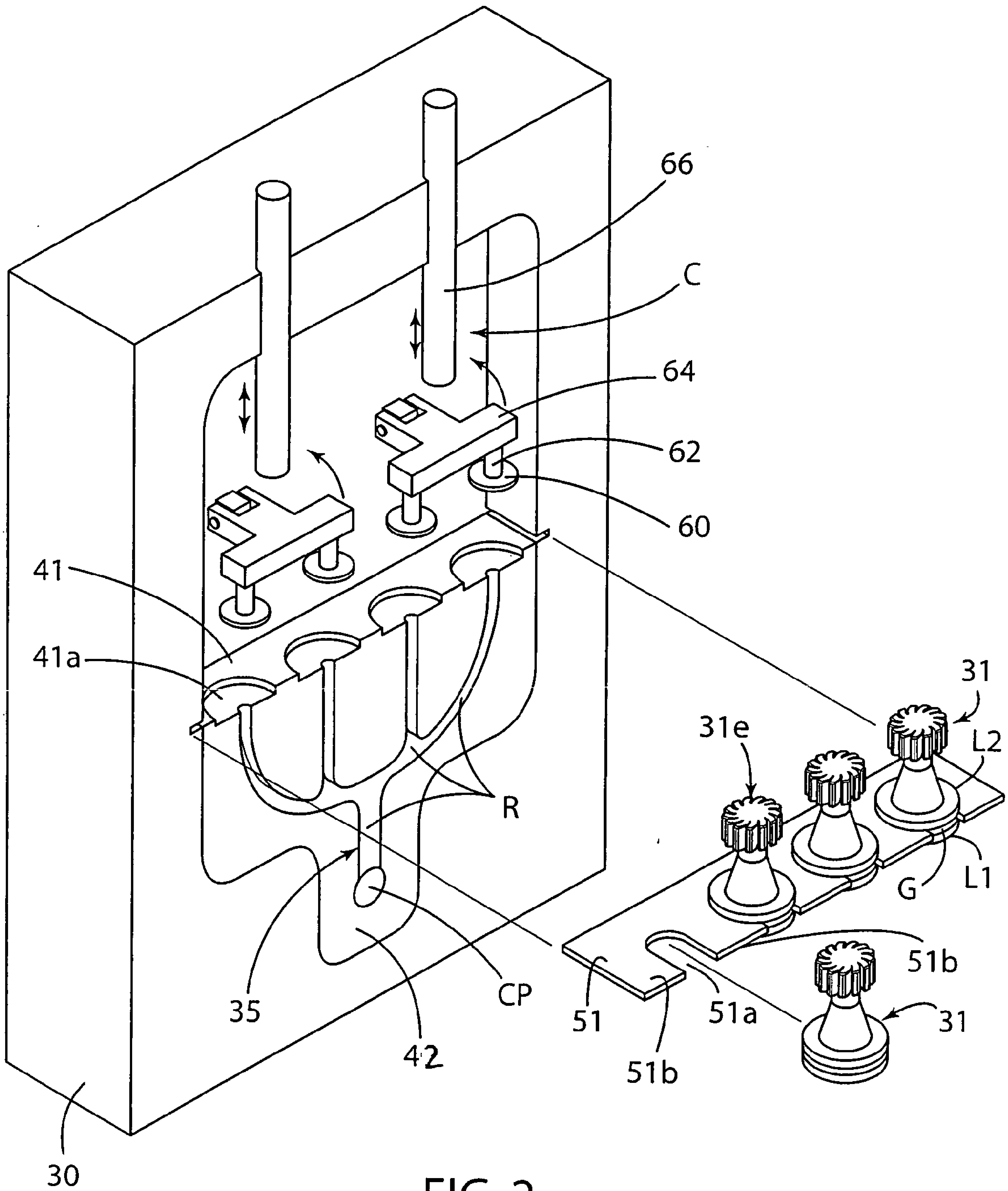

FIG. 2

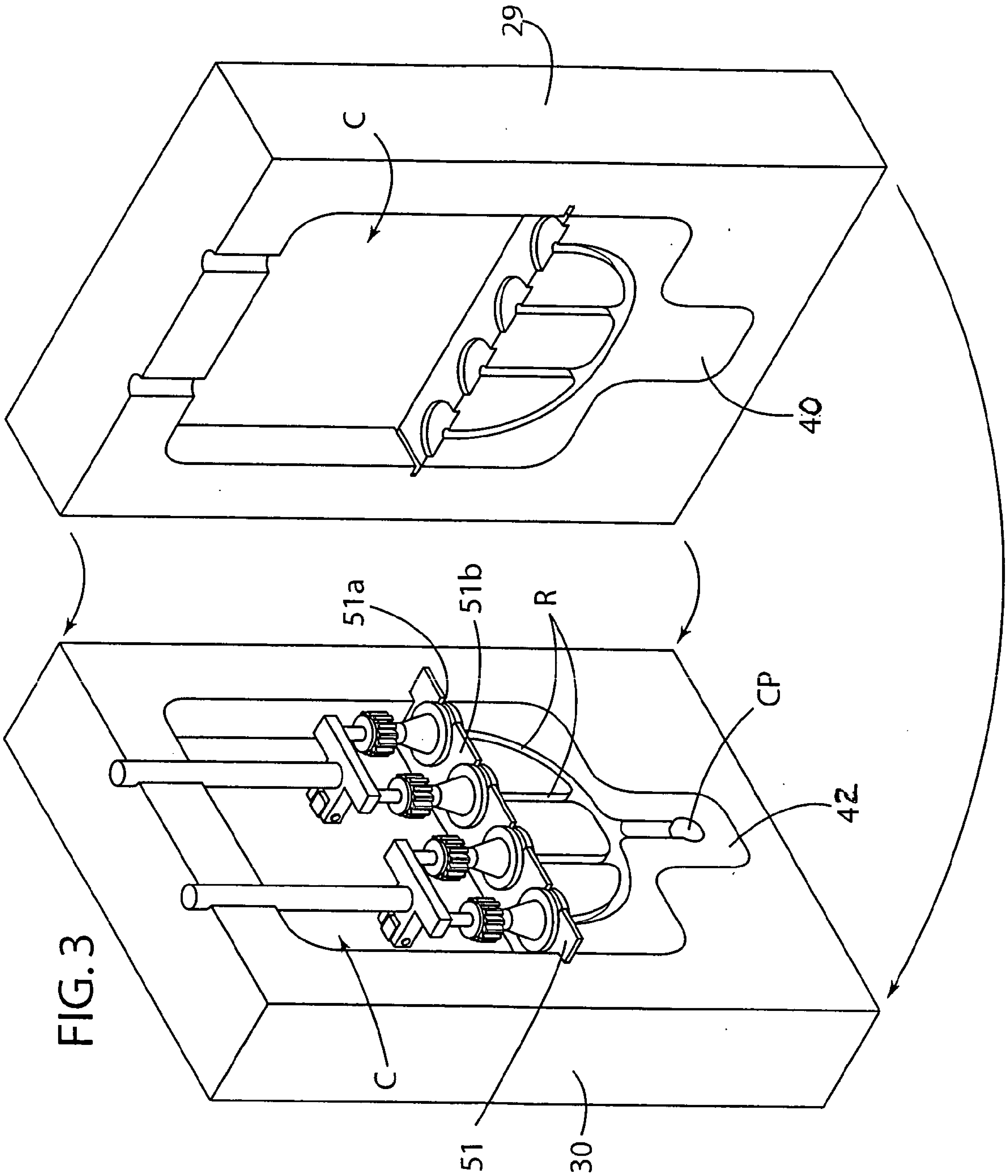

FIG. 3

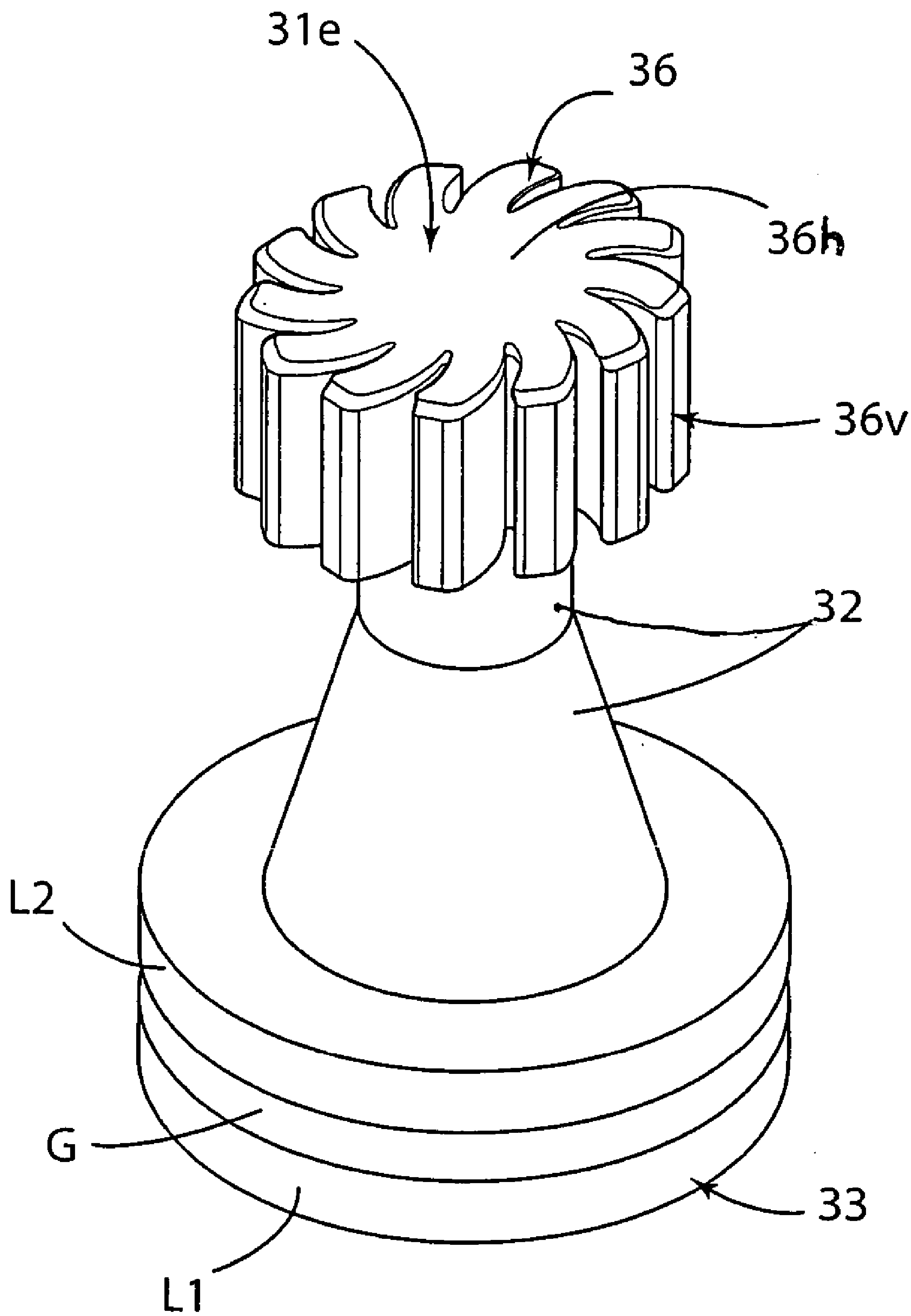

FIG. 4

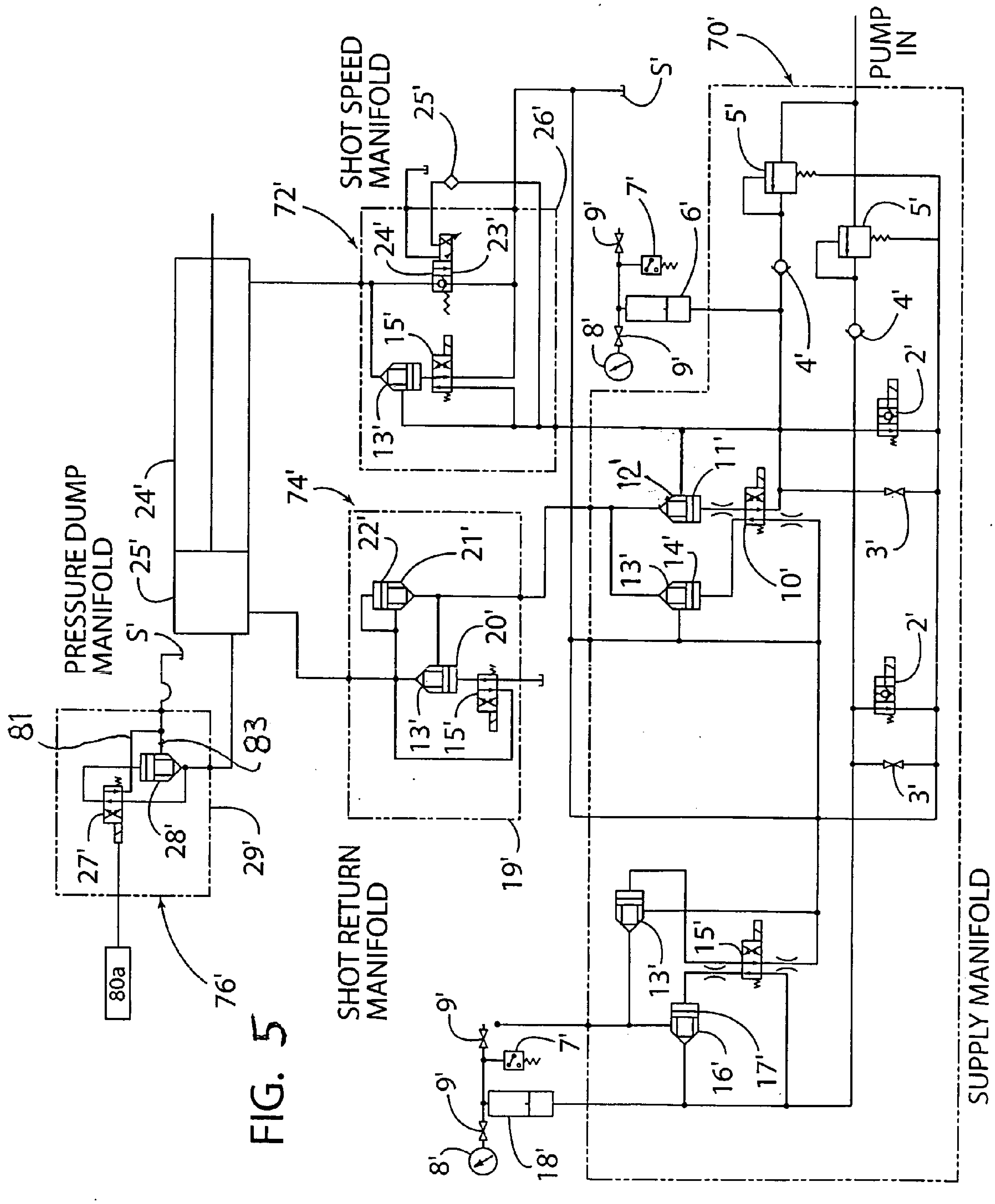
SHOT SPEED MANIFOLD
PUMP IN
PRESSURE DUMP MANIFOLD
SHOT RETURN MANIFOLD
SUPPLY MANIFOLD
80a
70'
72'
74'
76'
81
83

FIG. 5

DIE CASTING IN INVESTMENT MOLD

FIELD OF THE INVENTION

[0001] The present invention relates to casting of metals and alloys and, more particularly, to casting of metals, alloys, and intermetallics under pressure in a non-metallic investment mold.

BACKGROUND OF THE INVENTION

[0002] Titanium based alloys (e.g. Ti-6Al-4V) and intermetallics (e.g. TiAl) are used as cast components in the aerospace industry. Many such cast components are made by the well known gravity investment casting process wherein an appropriate melt is cast into a preheated ceramic investment shell mold formed by the lost wax process.

[0003] Although commonly used, investment casting of complex shaped components of such titanium based materials can be characterized by relatively high costs and low yields. Low casting yields are attributable to several factors, in particular inadequate filling of certain mold cavity regions such as especially thin wall mold cavity regions. For example, filling of thin wall mold cavity regions having a thickness of less that 0.050-0.060 inch with a titanium alloy or titanium aluminide melt is difficult due to melt fluidity, low superheat, and out-gassing problems.

[0004] In attempts to improve filling of the ceramic investment shell mold, high mold preheat temperatures (e.g. above 700 degrees F.) have been tried. However, such an approach is disadvantageous in that the molten titanium alloy or titanium aluminide can react with the mold at such high temperatures to form deleterious phases on the surface of the castings produced in such shell molds. This phase must then be removed by chemical treatment. Moreover, it is oftentimes necessary to increase the thickness of one or more thin wall mold cavity regions when the mold is being made in order to subsequently achieve satisfactory mold filling during casting. The result is an oversize casting that must then be mechanically and/or chemically treated to reduce cast dimensions to print dimensions for the particular component involved.

[0005] U.S. Pat. No. 6,070,643 describes vacuum die casting of oxygen reactive alloys such as titanium alloys, nickel based superalloys, and cobalt superalloys in metal molds. Drawbacks of using metal die casting molds include the high cost of the metal dies and the presence of die parting line between the metal dies, which parting line sometimes limits the complexity of the die cavity and thus the casting that can be die cast. A further drawback of using metal dies when die casting titanium aluminide material is the generation of cracking in the casting as a result of rapid solidification of the melt in the metal mold.

[0006] Permanent mold casting of reactive metals and alloys such as titanium and titanium and nickel based alloys using permanent, reusable, multi-part metal molds based on iron and titanium is described in Colvin U.S. Pat. No. 5,287,910. Casting of aluminum, copper, and iron based castings using permanent metal molds is described in U.S. Pat. No. 5,119,865.

[0007] An object of the present invention to provide method and apparatus for die casting metals and alloys, especially titanium alloys, titanium aluminides and others, under pressure in an investment mold in a manner that overcomes the above-discussed disadvantages and drawbacks.

SUMMARY OF THE INVENTION

[0008] The present invention provides method and apparatus for casting a metallic material involving the steps of providing a non-metallic mold in a mold-receiving chamber disposed in at least one of relatively movable first and second members, communicating a mold cavity in the mold to a gating passage disposed in at least one of the first and second metallic members, communicating the gating passage to a shot sleeve, and flowing metallic material under pressure from the shot sleeve to the gating passage and into the non-metallic mold.

[0009] In an illustrative embodiment of the invention, the first and second members are relatively movable by being mounted on respective first and second platens of a die casting machine.

[0010] In another illustrative embodiment of the invention, the metallic material is flowed by movement of a plunger in the shot sleeve. The plunger is moved in response to hydraulic pressure to flow the metallic material, and the hydraulic pressure is vented to a sump a preselected distance before the end of the injection stoke of the plunger.

[0011] Casting apparatus pursuant to another embodiment of the invention comprises relatively movable first and second metallic members at least one of which includes a mold-receiving chamber and at least one of which includes a gating passage for receiving metallic material from a shot sleeve, a non-metallic mold disposed in the chamber in a position to communicate to the gating passage, and means communicated to the shot sleeve for flowing the metallic material through the gating passage into the non-metallic mold.

[0012] In a further illustrative embodiment of the invention, a ceramic investment shell mold is held in position in the chamber to communicate to the gating passage, while the mold is supported in the chamber against force of molten metallic material introduced into the mold via the gating passage. For example, a support plate abuts the closed end of the mold and is biased thereagainst. The mold can include an open pour cup or other feature that communicates to the gating passage. The mold also typically includes a sprue passage between the pour cup and the one or more mold cavities to convey molten metallic material thereto. The mold cavities of the shell mold can be evacuated to subambient pressure, such as less than 100 microns, to die cast a reactive metal or alloy such as a titanium alloy, titanium aluminide, nickel base superalloy, cobalt base superalloy, and others. The mold can include a pour cup or other feature that communicates to the gating passage. The mold also typically includes a sprue passage between the pour cup and the one or more mold cavities to convey molten metallic material thereto.

[0013] The invention is useful in casting molten metals or alloys, such as titanium alloys and titanium aluminide alloys, that otherwise have difficulty in filling thin wall mold cavity regions using conventional investment casting processes. For example, the invention is useful in casting titanium alloy or titanium aluminide turbocharger compressor and turbine wheels having multiple airfoil vanes of thin wall thickness (e.g. 0.025 to 0.200 inch wall thickness) disposed about a hub. The invention likewise is useful in casting compressor blades and turbine blades having thin-wall airfoils (e.g. 0.025 to 0.35 inch wall thickness.)

[0014] Moreover, the invention can be used to cast complex investment molds having backlocks, undercuts, or other features that can not be cast using metal dies. Practice of the invention permits complex mold geometries to be cast, without the need for significant chemical and/or mechanical rework of the die cast component.

[0015] Further details and advantages of the present invention will become more readily apparent from the following detailed description taken with the following drawings.

DESCRIPTION OF THE DRAWINGS

[0016] FIG. **1** is a schematic side elevation of a casting machine pursuant to an embodiment of the invention for practicing a method of the present invention with the vacuum chamber shown broken away.

[0017] FIG. **2** is a perspective, exploded view of one of a pair of mold-receiving members connected to the platens of a die casting machine.

[0018] FIG. **3** is a perspective, exploded view of the pair of mold-receiving members.

[0019] FIG. **4** is a perspective view of the investment shell mold.

[0020] FIG. **5** is a diagram of the hydraulic fluid system for the plunger.

DETAILED DESCRIPTION OF THE INVENTION

[0021] Referring to FIG. **1**, a die casting machine **10** adapted to practice an embodiment of the present invention is shown. For purposes of illustration and not limitation, the casting machine is shown adapted to cast a molten metallic material, which includes metals, alloys, intermetallics, and thixotropic metallic material, under hydraulic pressure into one or more evacuated non-metallic investment shell molds **31** (four molds shown), the number of molds **31** being cast being selected as desired for a particular casting job. Such metallic materials for casting include, but are not limited to, titanium alloys, titanium aluminide alloys, nickel base superalloys, cobalt base superalloys and other materials that have difficulty in filling certain thin or narrow regions of an investment mold cavity and/or are reactive with oxygen.

[0022] An embodiment of the invention will be described below with respect to vacuum casting of titanium alloy turbocharger wheels having multiple airfoil vanes of thin wall thickness disposed about a hub. Each non-metallic investment shell mold **31** includes a mold cavity-forming region **36** that defines a respective turbocharger wheel shape therein. Although only one mold cavity-forming region **36** is shown, each mold **31** can include one or more mold cavity-forming regions **36**.

[0023] The die casting machine is shown comprising a base **11** which includes a reservoir (not shown) therein for hydraulic fluid that is used by hydraulic actuator **12** to move the movable die platen **16** relative to the fixed (stationary) die platen **14** to open and close the die platens **14**, **16**. The platen **16** is disposed for movement on stationary guide rods or bushings **18**. A die platen clamping linkage mechanism (not shown) is connected to the movable die platen **16** in conventional manner not considered part of the present invention. The die casting apparatus also comprises a tubular, horizontal shot sleeve **24** having intermediate section that is received in the stationary die platen **14** and a mold-receiving member or plate **30** fastened to the platen extension **14*a*** by bolts, clamps, and other fastening means. The shot sleeve **24** extends into a vacuum melting chamber **40** where the metal or alloy to be die cast is melted under high vacuum conditions, such as less than 100 microns, in the event an oxygen reactive metal or alloy, such as titanium alloy, titanium aluminide alloy, superalloy, etc., is to be cast.

[0024] The vacuum chamber **40** is defined by a vacuum housing wall **42** that extends about and encompasses or surrounds the charging end section **24*a*** of the shot sleeve **24** and the plunger hydraulic actuator **25"** having ram **25*a*"**. The chamber wall **42** is vacuum tight sealed about the stationary, horizontal shot sleeve and plunger support member **44**. The vacuum chamber **40** is evacuated by a conventional vacuum pump P connected to the chamber **40**. The base **11** and the vacuum housing wall **42** rest on a concrete floor or other suitable support.

[0025] A cylindrical plunger **27** is disposed in the cylindrical bore of the shot sleeve **24** for movement by ram **25*a*"** between a start injection position located to the left of a melt entry or inlet **50** in FIG. **1** and a finish injection position proximate mold-receiving member or plate **30**. The melt inlet **50** comprises a melt-receiving vessel **52** mounted on the shot sleeve **24**. The melt-receiving vessel **52** is disposed beneath a melting crucible **54** to receive a charge of molten metal or alloy therefrom for die casting. The invention is not limited to a hydraulic plunger as a means for introducing the molten metallic material under superambient pressure in the mold **31**. For example, superambient gas pressure may be applied at the end of the shot sleeve with or without the plunger present for introducing the molten metallic material under pressure into the mold **31**.

[0026] The melting crucible **54** may be an induction skull crucible comprising copper segments in which a charge of solid metal or alloy to be die cast is melted. The charge of solid metal or alloy can be positioned in the crucible **54** before a vacuum is established in chamber **40** and melted by energization of induction coils **56** after the vacuum is established. Alternately, the solid metal or alloy charge can be charged into the crucible **54** in evacuated chamber **40** via a vacuum port (not shown) and melted by energization of induction coils **56**. Known ceramic or refractory lined crucibles also can be used in practicing the present invention. Any melting method such as arc melting, electron beam melting, and others may be employed in practice of the invention. The crucible **54** can be tilted to pour the molten metal or alloy charge into the melt-receiving vessel **52**, which is communicated to the shot sleeve **24** via an opening **58** in the shot sleeve wall. The molten metal or alloy charge is introduced through opening **58** into the shot sleeve **24** in front of the plunger **27**.

[0027] The plunger **27** is moved from the start injection position to the finish injection position by conventional hydraulic actuator **25**". Typical radial clearances between the shot sleeve **24** and the plunger **27** are in the range of 0.001 to 0.008 inch.

[**0028**] A die casting machine having the features described above is disclosed in U.S. Pat. No. 6,070,643 of common assignee herewith, the teachings of which patent are incorporated herein by reference.

[**0029**] Pursuant to an embodiment of the invention, the die casting machine **10** is modified or adapted to cast a molten metallic material under hydraulic pressure into one or more evacuated non-metallic (e.g. ceramic) investment shell molds **31**, which can be made by the well known lost wax process. Such an investment shell mold **31** is made by repeatedly dipping one or more fugitive patterns (such as wax or plastic patterns) of the component to be cast connected as part of a pattern assembly in a ceramic flour slurry, draining excess ceramic slurry, and applying a coarse ceramic stucco on the wet slurry followed by air or oven drying until a shell mold of desired wall thickness is built up on the patterns. The one or more patterns then are selectively removed by steam autoclaving, flash dewaxing, and other conventional pattern removal techniques, leaving an empty ceramic shell mold with one or more cavities where the one or more patterns formerly resided. The ceramic shell mold then is fired at elevated temperature to develop adequate mold strength for casting. Manufacture of ceramic shell molds using the lost wax process is well known and described in U.S. Pat. Nos. 4,966,225; 5,983,982; 6,749,006 and many others. For purposes of illustration and not limitation, the invention can be practiced using conventional colloidal silica-bonded or sodium silicate-bonded investment shell molds, although other investment shell molds can be used.

[**0030**] The particular ceramic flours and stucco materials from which the investment molds **31** are made depends on the metal or alloy to be die cast in the mold as well as the parameters of casting, such a melt superheat, mold preheat temperature and others.

[**0031**] Referring to FIGS. **1-4**, ceramic investment shell molds **31** for casting a turbocharger wheel are shown. Each shell mold **31** includes a pour cup **33**, a sprue **32**, and a turbocharger wheel-shaped mold cavity-forming region **36**. Molten metal or alloy flows through the pour cup **33** and through a passage **32***a* in the sprue **32** and into the mold cavity-forming region **36**. The turbocharger wheel-shaped mold cavity-forming region **36** has an airfoil or vane-forming cavity regions **36***v* of small or narrow dimension (thickness) spaced apart on a hub-forming cavity region **36***h*. The airfoil or vane-forming regions **36***v* have a small internal thickness typically between 0.025 to 0.100 inch to form the thin walls of the airfoils or vanes on the hub of the die cast turbocharger wheel. Those skilled in the art will appreciate that the molds **31** can be ganged to provide a ganged mold such that one pour cup and multiple sprues and runners can be used to supply molten metallic material to the ganged mold. The invention is not limited to the type of non-metallic, refractory or ceramic mold that is used.

[**0032**] The pour cup **33** forms a first annular lip L**1** that is axially spaced form a second annular lip L**2** formed as part of each mold to define a peripheral positioning groove G about the pour cup. The invention envisions providing a ceramic core (not shown) in the turbocharger wheel-shaped mold cavity-forming region **36** of each mold **31** in order to produce an internal cavity in the cast turbocharger wheel at selected location(s). The ceramic core can be configured to produce the desired internal cavity in the cast turbocharger wheel, or other casting produced in the mold **31**. The invention also envisions providing a reinforcement material or preform, porous or solid, in the mold cavity **36** so as to be incorporated in the cast component.

[**0033**] Referring to FIGS. **1-4**, pursuant to one embodiment of the invention, the mold-receiving member **30** is adapted to mate with a mold-receiving member **29** to form a chamber C for receiving the molds **31** and to form a mold gating system **35** therebetween when the members **29**, **30** are abutted at a vertical parting plane. The gating system is formed by machined, replaceable gating inserts **40**, **42** that are received in respective members **29**, **30** and that are coplanar at their outermost surfaces with those of the respective members **29**, **30** in which they are received. When the members **29**, **30** are abutted at the parting plane, the gating inserts form a gating system that comprises runners R that communicate with a common passage CP that communicates with the end of the shot sleeve **24**. A respective runner R extends from the passage CP to a respective mold **31**. The members **29**, **30** as well as inserts **40**, **42** typically are steel or other suitable permanent metal or alloy (metallic material) and are mounted on or connected to respective platens **14**, **16** of the die casting machine.

[**0034**] An O-ring vacuum seal S**1** is provided between the members **29**, **30** for establishing a vacuum tight seal therebetween, FIG. **1**. The vacuum seal S**1** extends about and surrounds the gating system **35**.

[**0035**] The molds **31** are shown positioned in the chamber C with their pour cups **33** residing in complementary configured cylindrical-shaped recesses **41***a* on a shelf or ledge **41** forming the bottom wall of the chamber C when the members **29**, **30** are abutted at the parting plane. In FIGS. **2-3**, one-half of the ledge or shelf **41** as well as each recess **41***a* is shown formed on the member **29** and the other half is formed on member **30**. The molds **31** thereby are positioned vertically inverted such that their rear closed ends **31***e* face upwardly.

[**0036**] The end surface of each pour cup **33** sealingly engages the shelf or ledge **41** in the recesses **41***a* to prevent molten material from leaking out at the interface when the mold is clamped or pressed on the ledge as described below. A flat seal or gasket optionally may be used if needed between the pour cup end surface and the ledge **41** to this end. The molds **31** are positioned relative to the runners R using a fixed positioning plate **51** having slots **51***a* formed between fingers **51***b*. Each mold **31** is inserted in a respective slot **51***a* with the adjacent fingers **51***b* being received in the mold positioning groove G to this end. One half of each mold pour **33** thereby is positioned to straddle a respective runner R to receive molten material therefrom. The positioning plate **51** is fixedly fastened to one of the members **29**, **30** in a horizontal orientation such that the fingers **51***b* are received in the facing other of the members **29**, **30** overlying the shelf or ledge of that member.

[**0037**] When so positioned, the pour cup **33** and the sprue passage **32***a* of each mold **31** communicates to the shot sleeve **24** via the gating system for receiving molten metallic material from the shot sleeve **24** as pushed by the plunger **27**. The shot sleeve **24** is sealingly received in the member **30**.

[0038] Each mold **31** is supported in position in the chamber C against upward force of molten metallic material introduced into the mold via the gating system. For example, the upwardly facing closed end of each mold **31** is abutted by a respective support plate **60**. Support plates **60** are connected to shafts **62** each of which is mounted on a hinge **64** such that the plates **60** can be brought into position to abut the closed ends **31***e* of the molds after they are positioned in positioning plate **51**. The support plates **60** are pressed gently toward the closed end of the molds by a main shaft **66** connected to a respective hinge **64** and a pressing device **63**, such as a spring, pneumatic cylinder, hydraulic cylinder, and/or mechanical clamp, to bias the shafts **66** downwardly.

[0039] The vacuum chamber **40** then is evacuated to a suitable level for melting the particular charge (e.g. less than 100 microns for titanium alloys such as Ti-6Al-4V alloy and titanium aluminide such as TiAl) by vacuum pump P. The investment mold **31** in chamber C is concurrently evacuated to the same vacuum level through the connection to the vacuum melting chamber **40** via the shot sleeve **24** and by virtue of being isolated from surrounding ambient air atmosphere by the vacuum seal S1 between members **29**, **30**. Optionally or in addition, the mold **31** can be evacuated using a separate vacuum conduit or line communicated to the mold interior.

[0040] The investment mold **31** typically is at ambient (room) temperature when it is placed in the chamber C. Alternately, the mold **31** can be preheated to a suitable elevated temperature before being placed in the chamber C. Still further, heaters (not shown) can be provided in the chamber C to heat or maintain the temperature of the mold **31**.

[0041] The solid charge of the metal or alloy in crucible **54** is melted by energizing induction coil **56**, the melt then is poured under vacuum into the shot sleeve **24** via the melt inlet **50** with the plunger **27** initially positioned at the start injection position of FIG. **1**. The molten metal or alloy is poured into the shot sleeve **24** and resides therein for a preselected dwell time to insure that no molten metal gets behind the plunger **27**. The melt can be poured directly from the crucible **54** via inlet **50** into the shot sleeve **24**, thereby reducing time and metal cooling before injection can begin.

[0042] The plunger **27** then is advanced in the shot sleeve **24** by actuator **25"** to inject the molten metal or alloy under hydraulic pressure through the gating system and into the mold cavity **36** via the mold pour cup **33** and sprue **32**. The molten metal or alloy is forced at velocities, such as 10-120 inches per second for titanium alloys and titanium aluminides, down the shot sleeve **24** and into the evacuated mold cavity **36** in the investment mold **31**.

[0043] The plunger **27** is advanced in the shot sleeve **24** using a hydraulic system shown in FIG. **5** that comprises a supply manifold **70'**, shot speed manifold **72'** for controlling speed of the plunger, shot return manifold **74'** for controlling the return of the plunger **27** to its start injection position, and a pressure dump manifold **76'** for dumping or returning fluid pressure to a tank S' when the plunger **27** is a preselected distance from its final injection position. The hydraulic system is controlled by a programmable logic controller (not shown). However, the limit switch **80***a*, which is fastened to the fixed support frame for actuator (hydraulic cylinder) **25"**, is directly electrically connected to a relay (not shown) which in turn is directly electrically connected to the directional valve **27'** of the pressure dump manifold **76'** to control energization of the directional valve **27'**. The limit switch **80***a* is activated by the switch trip member **80***b*, which is fastened to the ram **25***a*" and which trips or actuates limit switch **80***a* shown in FIG. **1** as it travels with the ram. Before the limit switch **80***a* is tripped, the directional valve **27'** is deenergized in a manner to maintain cartridge valve **28'** closed (e.g. valve **27'** is always in a deenergized state except when the limit switch **80***a* is tripped). When the limit switch **80***a* is tripped, the directional valve **27'** is energized to vent the normally closed pressure holding valve **28'** to return tank S' via line **81** and allow hydraulic pressure downstream of the valve **28'** to vent through open valve **28'** to line **83** to tank S'. The pressure dump manifold **76'** functions to control fluid pressure on the mold **31** as the molten metallic material is injected under pressure therein so as to avoid cracking of the mold **31** during casting. The location of the switch **80***a* and thus the preselected distance from the final injection position where fluid pressure is dumped can be determined empirically and adjusted to avoid mold cracking. Components of the hydraulic system are described below.

[0044] Components of the hydraulic system of FIG. **6** include:

[0045] **1'**—manifold;

[0046] **2'**—SV310-00 115AP directional valve from Vickers Hydraulics (hereafter Vickers);

[0047] **3'**—NS 800 S flow control valve from Parker Hannifin Corp. (hereafter Parker);

[0048] **4'**—CV5-10-PO5 check valve from Vickers;

[0049] **5'**—PRV 1-10 SO 24 pressure regulator from Vickers;

[0050] **6'**—A9K2310D3 KPN 10 gal. accumulator from Parker;

[0051] **7'**—A9675 3AA pressure switch from Barksdale Control Products, Barksdale, Inc.;

[0052] **8'**—pressure gage (3000 psi);

[0053] **9'**—flow control (¼ inch NPT);

[0054] **10'**—DG4S4 012A 50 directional valve from Vickers;

[0055] **11'**—SO63C 10 02 P cover (ports) from Oilgear Company (hereafter oilgear);

[0056] **12'**—SEO 63 10 K1 0001.5/3V5 insert (cartridge valve) from Oilgear;

[0057] **13'**—CV1 16 D11 2L10 insert (cartridge valve) from Vickers;

[0058] **14'**—CVCS 16A S2 10 cover (ports) from Vickers;

[0059] **15'**—DG4V 3S 2A MFW B60 directional valve from Vickers;

[0060] **16'**—CV1 40D1 2L10 cover (ports) from Vickers;

[0061] **17'**—CVCS 40D1 S2 10 cover (ports) from Vickers;

[0062] **18'**—A7K 1155 K3 K PL 5 gal. accumulator from Parker;

[0063] 19'—manifold;

[0064] 20'—CVCS 16D1 S2 10 cover (ports) from Vickers;

[0065] 21'—SE6310 K2 000 A1.5/3P insert (cartridge valve) from Oilgear;

[0066] 22'—S063 A10P cover (ports) from Oilgear;

[0067] 23'—TDAD1097E40LAF proportional valve from Parker;

[0068] 24'—WO 0179-1 63MM-40MM adapter from Parker;

[0069] 25'—15 P1 10 B M 50 MM1 filter from Parker;

[0070] 26'—manifold;

[0071] 27'—DG4S4 012A B 60 directional valve from Vickers;

[0072] 28'—CVC 50 D2 S2 10 insert (cartridge valve) from Vickers; and

[0073] 29'—manifold

[0074] After the molten metal or alloy has been injected, the members **29**, **30** are opened by movement of platen **16** away from platen **14** within a typical time period that can range from 5 to 25 seconds following injection to provide enough time for the molten metal or alloy to form at least a solidified surface on the cast component(s) in the mold cavity **36**. The mold **31** then is removed from the chamber C and transported to a demolding station where the investment mold **31** is removed from the cast component by conventional techniques forming no part of the invention. The metallic material solidified in the mold cavity **36** typically is substantially solidified by the time the mold **31** is removed from the chamber C. The casting then can be inspected visually and by techniques according to customer requirements.

[0075] In die casting titanium alloys, titanium aluminide, nickel base superalloys, and cobalt based superalloys, the shot sleeve **24** contacting the molten metal or alloy can be made of an iron based material, such as H-13 tool steel, or a refractory material such as based on Mo alloy, W alloy, or TZM alloy, ceramic material such as alumina, or combinations thereof that are compatible with the metal or alloy being melted and die cast. The forward plunger tip **27*a*** can comprise a permanent or alternately a disposable tip that is thrown away after each molten metal or alloy charge is injected in the investment mold **31**. A plunger tip can comprise a copper based alloy such as a copper-beryllium alloy, or steel, graphite, or other appropriate material.

[0076] The particular casting parameters employed to die cast a component will depend upon several factors including mold size, gating, pour weight, and the fragility of the investment mold to the melt injection pressures involved. The injection pressure is selected to retain the investment mold **31** intact (no mold cracking under pressure) while achieving a satisfactory fill of the mold cavity regions. The nominal weight of metal or alloy in the crucible **54** depends on the mold size and the number of components to be die cast in the mold.

[0077] The following EXAMPLE is offered to further illustrate the invention without limiting it.

EXAMPLE 1

[0078] Turbocharger wheels have been successfully die cast of titanium and titanium aluminide (TiAl) alloys in conventional lost wax investment shell molds **31** by practice of the invention. In general, the turbocharger wheels were made using casting parameters in the following ranges: melt injection pressure settings: 400-1800 psi, melt injection velocities (plunger speed): 10-120 in/sec, melt superheat: 0 to 75 degrees F., mold preheat: room temperature to 600 degrees F., lost wax investment shell mold wall thickness: 0.20 to 1.0 inch, shot sleeve length and diameter: 17.38 inches and 2.80 inches; and limit switch **80*a*** set to dump plunger fluid pressure when the plunger **27** is about 0.75 inch from its final injection position.

[0079] Although the mold **31** is illustrated above for making cast turbocharger wheels, the invention is not so limited and can practiced to make other components that include, but are not limited to, internal combustion engine valves, automotive or truck turbocharger compressor and turbine wheels, compressor and turbine blades and vanes for gas turbine engines, and medical components including hip stems, acetabular knees, tibial trays, and spinal components.

[0080] Further, while the invention has been described in terms of specific embodiments thereof, it is not intended to be thereto but rather only to the extent set forth in the following claims.

We claim:

1. A method of casting a metallic material, comprising

providing a non-metallic mold in a mold-receiving chamber disposed in at least one of relatively movable first and second members,

communicating a mold cavity in the mold to a gating passage disposed in at least one of the first and second metallic members,

communicating the gating passage to a shot sleeve, and

flowing metallic material under pressure from the shot sleeve to the gating passage and into the non-metallic mold.

2. The method of claim 1 including holding the mold in position in the chamber to communicate to the gating passage.

3. The method of claim 2 wherein the mold is held by a plate received in a groove of the mold.

4. The method of claim 1 including supporting the mold in position in the chamber against force of the metallic material introduced into the mold via the gating passage.

5. The method of claim 4 wherein the mold is abutted at the closed end of the mold by a support plate.

6. The method of claim 5 wherein the support plate is pressed toward the closed end of the mold.

7. The method of claim 1 wherein the metallic material is introduced into the mold which is unheated prior to being disposed in the chamber.

8. The method of claim 1 including disposing a ceramic investment shell mold in the chamber.

9. The method of claim 4 wherein the mold cavity includes a cavity region having a thickness of 0.35 inch or less.

10. The method of claim 1 wherein the mold cavity is configured as a turbocharger wheel-shaped cavity having multiple vane-forming cavity regions of said thickness spaced apart on a hub-forming cavity region.

11. The method of claim 1 wherein the mold cavity is configured as an airfoil-forming region of said thickness.

12. The method of claim 1 wherein the first and second members are relatively movable by being mounted on respective first and second platens of a die casting machine.

13. The method of claim 1 wherein the mold includes a pour cup communicated to the mold cavity by a sprue passage, said pour cup being communicated to the gating passage.

14. The method of claim 1 including evacuating the mold cavity to subambient pressure.

15. The method of claim 14 evacuating the mold cavity via the shot sleeve communicated thereto.

16. The method of claim 15 wherein the subambient pressure is about 100 microns or less.

17. The method of claim 1 including melting the metallic material in a vacuum chamber communicated to the shot sleeve.

18. The method of claim 1 wherein the metallic material is selected from the group consisting of titanium alloy, titanium aluminide, nickel base superalloy, and cobalt base superalloy.

19. The method of claim 1 wherein a plunger in the shot sleeve is moved in response to hydraulic pressure to flow the metallic material and wherein the hydraulic pressure is vented to a sump a preselected distance before the end of the injection stoke of the plunger.

20. Casting apparatus, comprising:

a) relatively movable first and second members at least one of which includes a mold-receiving chamber and at least one of which includes a gating passage for receiving metallic material from a shot sleeve,

b) a non-metallic mold disposed in the chamber in a position to receive the metallic material from the gating passage, and

c) means communicated to the shot sleeve for flowing metallic material under pressure through the gating passage into the non-metallic mold.

21. The apparatus of claim 20 wherein the mold comprises a ceramic investment shell mold.

22. The apparatus of claim 20 wherein the first and second members are connected to respective first and second platens of a die casting machine, said first and second platens being relatively movable.

23. The apparatus of claim 20 wherein the means for flowing comprises a plunger in the shot sleeve.

24. The apparatus of claim 23 wherein the plunger is moved in response to hydraulic pressure and a hydraulic pressure control system includes means for venting hydraulic pressure to a sump at a preselected distance before the end of the injection stoke of the plunger.

25. The apparatus of claim 20 includes a mold-holding member in the chamber for holding the non-metallic mold in said position.

26. The apparatus of claim 24 wherein the mold-holding member comprises a plate received in a groove on the mold.

27. The apparatus of claim 20 including a mold-supporting member in the chamber for supporting the mold against force of the metallic material introduced into the mold via the gating passage.

28. The apparatus of claim 27 wherein the mold-supporting member comprises a support plate abutting a closed end of the mold.

29. The apparatus of claim 28 wherein the support member is pressed toward the closed end of the mold.

30. The apparatus of claim 20 wherein the mold includes at least one mold cavity that includes a cavity region having a thickness of 0.100 inch or less.

31. The apparatus of claim 30 wherein said at least one mold cavity is configured as a turbocharger wheel-shaped cavity having multiple vane-forming cavity regions of said thickness spaced apart on a hub-forming cavity region.

32. The apparatus of claim 30 wherein said at least one more mold cavity is configured as an airfoil-forming region of said thickness.

33. The apparatus of claim 20 wherein the mold includes a pour cup communicated to one or more mold cavities by a sprue passage, said pour cup being communicated to the gating passage.

34. The apparatus of claim 20 including means for evacuating the interior of the mold to subambient pressure.

35. The apparatus of claim 34 wherein said means comprises the shot sleeve which is under subambient pressure and communicated to the mold interior.

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