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(54) Title: ULTRA-VACUUM HIGH PRESSURE DIE CASTING PROCESS, AND SYSTEM THEREFORE

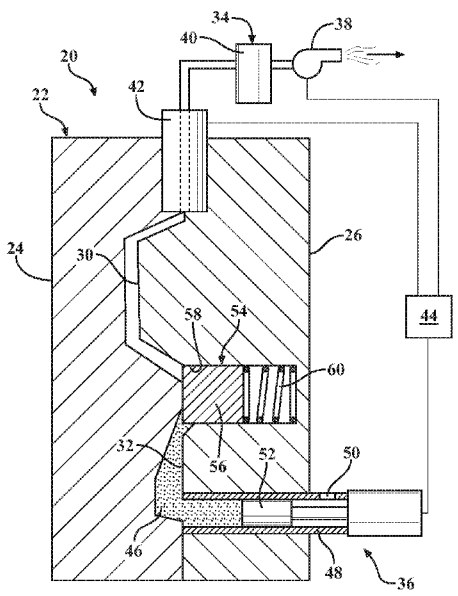


FIG. 1

(57) Abstract: A method of casting an article includes closing a die set (22), which defines a casting cavity (30) and a gate cavity (32). A pressure actuated valve (54) is closed to block fluid communication between the casting cavity (30) and the gate cavity (32). A vacuum system (34) is engaged to remove air and form a vacuum in the casting cavity (30). A molten material (46) is introduced into the gate cavity (32). The molten material (46) is compressed in the gate cavity (32) to increase a fluid pressure of the molten material (46). The pressure actuated valve (54) is opened when the fluid pressure of the molten material (46) in the gate cavity (32) reaches a predefined pressure level, to allow fluid communication between the gate cavity (32) and the casting cavity (30). The molten material (46) is pushed through the gate cavity (32) and into the casting cavity (30) under pressure to form the article (28). A die casting system (20) is also disclosed. The method allows the vacuum system (34) to remove more air and gasses from the casting cavity (30), prior to the molten material (46) being introduced into the casting cavity (30), thereby reducing porosity in the final cast article (28).

# ULTRA-VACUUM HIGH PRESSURE DIE CASTING PROCESS, AND SYSTEM THEREFORE

## TECHNICAL FIELD

**[0001]** The disclosure generally relates to a die casting system, and a method of casting an article with the die casting system.

## BACKGROUND

**[0002]** Die cast articles, particularly those that are cast from aluminum or magnesium, may be cast with an ultra-vacuum, high pressure die casting process. The ultra-vacuum high casting process includes first forming a vacuum in a casting cavity to remove air and other gasses from the casting cavity, and then introducing molten material into the casting cavity under high pressure to form the article. However, timing and control of the vacuum system in a standard ultra-vacuum, high pressure die casting system is very complicated, and only allows for a very short pumping time to form the vacuum, which limits the pressure level of the vacuum.

## SUMMARY

**[0003]** A die casting system is provided. The die casting system includes a die set having a first die half and a second die half. The first die half and the second die half oppose each other, and cooperate together to define a casting cavity and a gate cavity therebetween. A vacuum system is disposed in fluid communication with the casting cavity. The vacuum system is operable to remove air from the casting cavity to form a vacuum in the casting cavity. A melt injection system is disposed in fluid communication with the gate cavity. The melt injection system is operable to introduce a molten material into the gate cavity. A pressure actuated valve interconnects the casting cavity and the gate cavity in fluid communication. The pressure actuated valve is normally biased into a closed position to block fluid communication between the gate cavity and the casting cavity. The pressure actuated valve is operable to move from the closed position into an open position in response to a fluid pressure in the gate cavity being equal to or greater than a predefined pressure level. The pressure actuated valve moves into the open

position to open fluid communication between the gate cavity and the casting cavity, to allow molten material to flow from the gate cavity into the casting cavity.

**[0004]** A method of casting an article is also provided. The method includes closing a die set. The die set includes a first die half and an opposing second die half, which cooperate together to define a casting cavity and a gate cavity therebetween. A pressure actuated valve is closed to block fluid communication between the casting cavity and the gate cavity. A vacuum system is engaged to remove air and form a vacuum in the casting cavity. A molten material is introduced into the gate cavity. The molten material is compressed in the gate cavity to increase a fluid pressure of the molten material. The pressure actuated valve is opened when the fluid pressure of the molten material in the gate cavity reaches a predefined pressure level. The pressure actuated valve opens to allow fluid communication between the gate cavity and the casting cavity.

**[0005]** Accordingly, the die casting system described above, using the pressure actuated valve to open fluid communication between the gate cavity and the casting cavity, permits the use of a much simplified vacuum system, and enables the vacuum system to pump from the casting cavity for an extended period of time, with the pressure actuated valve closed to block fluid communication between the gate cavity and the casting cavity. This allows the vacuum system to remove more air and gasses from the casting cavity, prior to the molten material being introduced into the casting cavity, thereby reducing porosity in the final, cast article.

**[0006]** The above features and advantages and other features and advantages of the present teachings are readily apparent from the following detailed description of the best modes for carrying out the teachings when taken in connection with the accompanying drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0007]** Figure 1 is a schematic cross sectional view of a die casting system, showing a pressure actuated valve in a closed position, and a quantity of a molten material injected into a shot sleeve of a melt injection system.

**[0008]** Figure 2 is a schematic cross sectional view of the die casting system, showing the pressure actuated valve in the closed position, with a plunger of the melt

injection system compressing the molten material within a gate cavity of the die casting system.

**[0009]** Figure 3 is a schematic cross sectional view of the die casting system, showing the pressure actuated valve in an open position, with the plunger of the melt injection system pushing the molten material through the gate cavity and into a casting cavity of the die casting system.

**[0010]** Figure 4 is a schematic cross sectional view of the die casting system, showing two halves of the die casting system separated to eject a formed article.

## DETAILED DESCRIPTION

**[0011]** Those having ordinary skill in the art will recognize that terms such as "above," "below," "upward," "downward," "top," "bottom," etc., are used descriptively for the figures, and do not represent limitations on the scope of the disclosure, as defined by the appended claims. Furthermore, the teachings may be described herein in terms of functional and/or logical block components and/or various processing steps. It should be realized that such block components may be comprised of any number of hardware, software, and/or firmware components configured to perform the specified functions.

**[0012]** Referring to the Figures, wherein like numerals indicate like parts throughout the several views, an ultra-vacuum, high pressure die casting system is schematically shown at 20. The die casting system 20 is used to cast an article 28, shown in Figure 3. While the die casting system 20 may be used with any suitable material, the die casting system 20 is particularly suited for casting an article 28 from steel, aluminum or magnesium.

**[0013]** Referring to Figures 1 through 3, the die casting system 20 includes a die set 22. The die set 22 includes a first die half 24 and a second die half 26 opposing each other. One of the first die half 24 and the second die half 26 may be referred to as a moving die, and the other may be referred to as a stationary die. As shown, the first die half 24 is the moving die, and the second die half 26 is the stationary die. However, it should be appreciated that the relative positions of each may be reversed, with the first die half 24 being the stationary die, and the second die half 26 being the moving die. The

moving die moves into and out of engagement with the stationary die during the casting process to release a formed article 28.

**[0014]** The first die half 24 and the second die half 26 cooperate together to define a casting cavity 30 and a gate cavity 32 therebetween. The casting cavity 30 forms the shape of the article 28. The gate cavity 32 forms a volume that is used to feed a molten material 46 into the casting cavity 30. The gate cavity 32 may be formed in any suitable manner to properly feed the molten material 46 into the casting cavity 30. Accordingly, the shape and orientation of both the casting cavity 30 and the gate cavity 32 will depend upon the particular shape of the article 28 to be cast.

**[0015]** The die casting system 20 further includes a vacuum system 34, and a melt injection system 36. The vacuum system 34 is disposed in fluid communication with the casting cavity 30. The vacuum system 34 is operable to remove air and other gasses from the casting cavity 30, to form a vacuum in the casting cavity 30, when the die set 22 is closed. The vacuum system 34 may include a vacuum pump 38, and may further include but is not limited to a vacuum tank 40.

**[0016]** A vacuum control valve 42 interconnects the vacuum system 34 and the casting cavity 30. The vacuum control valve 42 may be attached to either the first die half 24 or the second die half 26. As shown, the vacuum control valve 42 is attached to the second die half 26, i.e., the stationary die. The vacuum control valve 42 is operable to open and close fluid communication between the vacuum system 34 and the casting cavity 30. The vacuum control valve 42 may include any type and/or style of valve suitable for use in a casting system with molten metals, and capable of sealing the vacuum formed in the casting cavity 30. The vacuum control valve 42 may be connected to and controlled by a system controller 44, such as a computer or other similar device.

**[0017]** The melt injection system 36 is disposed in fluid communication with the gate cavity 32. The melt injection system 36 is operable to introduce the molten material 46 into the gate cavity 32, and thereby into the casting cavity 30. The melt injection system 36 may be configured in any suitable manner capable of introducing the molten material 46 into the gate cavity 32, and compressing the molten material 46 in the gate cavity 32 to increase the fluid pressure in the gate cavity 32 to at least the predefined pressure level. For example, the melt injection system 36 may include a shot sleeve 48

disposed in fluid communication with the gate cavity 32. The shot sleeve 48 defines a staging volume, and is operable to receive a quantity of molten material 46 into the staging volume through an opening 50 in the shot sleeve 48. A plunger 52 is moveable through the staging volume of the shot sleeve 48. The plunger 52 is operable to force the molten material 46 in the staging volume of the shot sleeve 48, into the gate cavity 32, and compress the molten material 46 in the gate cavity 32. The plunger 52 compresses the molten material 46 in the gate cavity 32 to increase the fluid pressure of the molten material 46 in the gate cavity 32 to at least the predefined pressure level. The plunger 52 may be connected to and powered by an actuator, such as but not limited to, a hydraulic ram or other similar linear actuator.

**[0018]** A pressure actuated valve 54 interconnects the casting cavity 30 and the gate cavity 32 in fluid communication, when the die set 22 is closed. The pressure actuated valve 54 may be attached to either the first die half 24 or the second die half 26. As shown, the pressure actuated valve 54 is attached to and supported by the second die half 26, i.e., the stationary die. However, it should be appreciated that the pressure actuated valve 54 may be attached to and supported by the first die half 24, i.e., the moveable die. The pressure actuated valve 54 is normally biased into a closed position. When disposed in the closed position, the pressure actuated valve 54 blocks or prevents fluid communication between the gate cavity 32 and the casting cavity 30. The pressure actuated valve 54 is operable to move from the closed position, into an open position, in response to a fluid pressure in the gate cavity 32 being equal to or greater than the predefined pressure level. The pressure actuated valve 54 opens fluid communication between the gate cavity 32 and the casting cavity 30, when the pressure actuated valve 54 moves into the open position, to allow the molten material 46 to flow from the gate cavity 32 into the casting cavity 30.

**[0019]** The pressure actuated valve 54 may include any type and/or style of valve capable of being normally biased into a closed position to prevent fluid flow between the gate cavity 32 and the casting cavity 30, and moving into the open position when the fluid pressure of the molten material 46 reaches the predefined pressure level. For example, the pressure actuated valve 54 may include, but is not limited to, a piston 56 that is slideably supported by one of the first die half 24 or the second die half 26. As shown in

the Figures, the piston 56 is shown supported in a bore 58 defined by the second die half 26. A biasing device 60 biases the piston 56 against one of the first die half 24 or the second die half 26 to define the closed position of the pressure actuated valve 54. As shown in the Figures, the biasing device 60 biases the piston 56 out of the bore 58, and against the first die half 24, to close fluid communication between the gate cavity 32 and the casting cavity 30. The biasing device 60 may include, but is not limited to, a spring, a linear actuator, or some other device capable of moving the piston 56 linearly into and out of engagement with the first die half 24.

**[0020]** The biasing device 60 may be a constant resistance device, or a variable resistance device. As used herein, a constant resistance device moves the piston 56 into a specific, single, open position, upon the fluid pressure in the gate cavity 32 reaching the predefined pressure level. As used herein, a variable resistance device may move the piston 56 a varying distance from the closed position, depending upon the fluid pressure of the molten material 46 in the gate cavity 32. Upon the fluid pressure reaching the predefined pressure level, the variable resistance device may move the piston 56 a little to open fluid communication. An increase in the fluid pressure of the molten material 46, to a pressure level that is greater than the predefined pressure level, causes the piston 56 to move farther and increase the flow area connecting the gate cavity 32 and the casting cavity 30, thereby allowing more material through. Accordingly, a variable resistance pressure actuated valve 54 may be moveable between an infinite number of positions, depending upon the fluid pressure of the molten material 46 in the gate cavity 32, with the distance the piston 56 is moved from the first die half 24 increasing as the fluid pressure of the molten material 46 in the gate cavity 32 increases.

**[0021]** The casting cavity 30 is disposed vertically above the gate cavity 32. Accordingly, relative to a ground surface, the casting cavity 30 is disposed at a higher elevation than the gate cavity 32. The vacuum system 34 connects to the casting cavity 30 at a vertically upper end of the casting cavity 30. As such, the vacuum control valve 42 is disposed vertically above the casting cavity 30, at a higher elevation than the casting cavity 30, relative to the ground surface. The pressure actuated valve 54 is disposed vertically below the casting cavity 30, and is disposed vertically above the gate cavity 32. Accordingly, the pressure actuated valve 54 is disposed at a lower elevation than the

casting cavity 30, relative to the ground surface, and the pressure actuated valve 54 is disposed at a higher elevation than the gate cavity 32, relative to the ground surface. The melt injection system 36 is disposed vertically below the gate cavity 32, at a lower elevation than the gate cavity 32, relative to the ground surface.

**[0022]** A method of casting the article 28 with the die casting system 20 described above, is described herein. Referring to Figure 1, the method includes closing the die set 22. As noted above, the die set 22 includes the first die half 24 and the opposing second die half 26, cooperating together to define the casting cavity 30 and the gate cavity 32 therebetween. Closing the die set 22 includes moving the first die half 24 into abutting engagement with the second die half 26. The first die half 24 may be moved in any suitable manner, such as with a hydraulic press, or some other similar system.

**[0023]** Once the die set 22 is closed, with the first die half 24 pressed against the second die half 26 to define the casting cavity 30 and the gate cavity 32, the pressure actuated valve 54 is closed to block fluid communication between the casting cavity 30 and the gate cavity 32, as is shown in Figure 1. As described above, the pressure actuated valve 54 is preferably automatically biased into the closed position with the biasing device 60. However, it should be appreciated that the pressure actuated valve 54 may be configured differently than the exemplary embodiment described herein and shown in the Figures, and as such, the pressure actuated valve 54 may be closed in some other manner, such as but not limited to closing the pressure actuated valve 54 with a linear actuator or other device controlled by the system controller 44.

**[0024]** As shown in Figure 1, once the pressure actuated valve 54 is closed to block fluid communication between the gate cavity 32 and the casting cavity 30, the vacuum system 34 is engaged to remove all gasses from the casting cavity 30 and thereby form a vacuum in the casting cavity 30. The vacuum system 34 may be engaged for any suitable duration of time, to form a vacuum of any desirable level. For example, an exemplary process may include applying the vacuum system 34 for a soak time of 10 seconds, to form a vacuum having an absolute pressure level equal to 1 mBar.

**[0025]** After the vacuum has been formed in the casting cavity 30 by removing the gasses contained therein, the molten material 46 is introduced into the gate cavity 32. As described above, introducing the molten material 46 into the gate cavity 32 may

include for example, pouring a quantity of the molten material 46 into the shot sleeve 48, such as shown in Figure 1. Referring to Figure 2, the molten material 46 is then pushed through the shot sleeve 48, and into the gate cavity 32, with the plunger 52. However, it should be appreciated that if the melt injection system 36 differs from the exemplary embodiment described herein, the process of introducing the molten material 46 into the gate cavity 32 may differ from the exemplary process described herein.

**[0026]** As the plunger 52 pushes the molten material 46 into the gate cavity 32, the fluid pressure within the gate cavity 32 increases. Once the gate cavity 32 is substantially filled with the molten material 46, the plunger 52 continues to press more of the molten material 46 into the gate cavity 32 to compress the molten material 46 in the gate cavity 32, thereby increasing the fluid pressure of the molten material 46. The plunger 52 continues to compress the molten material 46 until the fluid pressure of the molten material 46 in the gate cavity 32 increases to at least the predefined pressure level.

**[0027]** Referring to Figure 3, when the fluid pressure of the molten material 46 in the gate cavity 32 reaches the predefined pressure level, the pressure actuated valve 54 moves into the open position to open fluid communication between the gate cavity 32 and the casting cavity 30, thereby allowing the molten material 46 to flow from the gate cavity 32 into the casting cavity 30. At approximately the same time that the pressure actuated valve 54 is moved into its open position to open fluid communication between the gate cavity 32 and the casting cavity 30, the vacuum control valve 42 connecting the vacuum system 34 and the casting cavity 30 in fluid communication is closed to prevent the molten material 46 from being drawn into the vacuum system 34.

**[0028]** Once the fluid pressure from the molten material 46 in the gate cavity 32 has opened the pressure actuated valve 54, the molten material 46 is moved from the gate cavity 32 into the casting cavity 30 by forcing the molten material 46 through the gate cavity 32 and into the casting cavity 30 with the plunger 52. Accordingly, the plunger 52 keeps moving to force the molten material 46 into the gate cavity 32, and thereby through the pressure actuated valve 54 and into the casting cavity 30, until the casting cavity 30 is completely filled with the molten material 46.

**[0029]** The molten material 46 may be kept in the casting cavity 30 for a period of time to solidify, and form the finished article 28. As the molten material 46 solidifies, the

pressure actuated valve 54 may be moved further from the first die half 24, i.e., further opened, to increase a flow area connecting the gate cavity 32 and the casting cavity 30, to ensure that the casting cavity 30 is properly filled with the molten material 46, and that the pressure applied to the molten material 46 in the casting cavity 30 is sufficient to form the article 28 with minimal porosity.

**[0030]** Referring to Figure 4, after the article 28 has solidified, the die set 22 may be opened, and the article 28 may be ejected. The die set 22 is opened by moving the first die half 24 away from the second die half 26, thereby exposing the article 28. The article 28 may be ejected, for example, with a push pin or other similar device that detaches the article 28 from the first die half 24.

**[0031]** The detailed description and the drawings or figures are supportive and descriptive of the disclosure, but the scope of the disclosure is defined solely by the claims. While some of the best modes and other embodiments for carrying out the claimed teachings have been described in detail, various alternative designs and embodiments exist for practicing the disclosure defined in the appended claims.

## CLAIMS

1. A die casting system comprising:

a die set having a first die half and a second die half opposing each other, and cooperating together to define a casting cavity and a gate cavity therebetween;

a vacuum system in fluid communication with the casting cavity and operable to remove air from the casting cavity to form a vacuum in the casting cavity;

a melt injection system in fluid communication with the gate cavity and operable to introduce a molten material into the gate cavity;

a pressure actuated valve selectively interconnecting the casting cavity and the gate cavity in fluid communication;

wherein the pressure actuated valve is normally biased into a closed position to block fluid communication between the gate cavity and the casting cavity; and

wherein the pressure actuated valve is operable to move from the closed position into an open position in response to a fluid pressure in the gate cavity being equal to or greater than a predefined pressure level, to open fluid communication between the gate cavity and the casting cavity to allow molten material to flow from the gate cavity into the casting cavity.

2. The die casting system set forth in claim 1 further comprising a vacuum control valve interconnecting the casting cavity and the vacuum system, and operable to open and close fluid communication between the vacuum system and the casting cavity.

3. The die casting system set forth in claim 2 wherein the vacuum control valve is disposed vertically above the casting cavity.

4. The die casting system set forth in claim 1 wherein the pressure actuated valve includes a piston slideably supported by one of the first die half or the second die half.

5. The die casting system set forth in claim 4 wherein the pressure actuated valve includes a biasing device biasing the piston against one of the first die half or the second die half to define the closed position of the pressure actuated valve.

6. The die casting system set forth in claim 1 wherein the pressure actuated valve is disposed at a lower elevation relative to the casting cavity, and wherein the pressure actuated valve is disposed at a higher elevation relative to the gate cavity.

7. The die casting system set forth in claim 6 wherein the melt injection system is disposed at a lower elevation relative to the gate cavity.

8. The die casting system set forth in claim 7 wherein the vacuum system connects to the casting cavity at a vertically upper end of the casting cavity.

9. The die casting system set forth in claim 1 wherein the melt injection system includes a shot sleeve in fluid communication with the gate cavity, wherein the shot sleeve is operable to receive a quantity of molten material.

10. The die casting system set forth in claim 9 wherein the melt injection system includes a plunger moveable within the shot sleeve and operable to force molten material in the shot sleeve into the gate cavity, and compress molten material in the gate cavity to increase the fluid pressure in the gate cavity to at least the predefined pressure level.

11. A method of casting an article, the method comprising:

closing a die set, wherein the die set includes a first die half and an opposing second die half that cooperate together to define a casting cavity and a gate cavity therebetween;

closing a pressure actuated valve to block fluid communication between the casting cavity and the gate cavity;

engaging a vacuum system to form a vacuum in the casting cavity;

introducing a molten material into the gate cavity;

compressing the molten material in the gate cavity to increase a fluid pressure of the molten material; and

opening the pressure actuated valve when the fluid pressure of the molten material in the gate cavity reaches a predefined pressure level to open fluid communication between the gate cavity and the casting cavity.

12. The method set forth in claim 11 further comprising moving the molten material from the gate cavity into the casting cavity.

13. The method set forth in claim 11 further comprising closing a vacuum control valve connecting the vacuum system and the casting cavity in fluid communication when the pressure actuated valve is opened in response to the fluid pressure of the molten material reaching the predefined pressure level.

14. The method set forth in claim 11 further comprising solidifying the molten material for a period of time to form the article.

15. The method set forth in claim 14 further comprising further opening the pressure actuated valve to increase a flow area connecting the gate cavity and the casting cavity as the molten material solidifies.

16. The method set forth in claim 14 further comprising opening the die set and ejecting the article after the molten material has solidified to form the article.

17. The method set forth in claim 12 wherein introducing the molten material into the gate cavity includes pouring a quantity of the molten material into a shot sleeve.

18. The method set forth in claim 17 wherein introducing the molten material into the gate cavity includes pushing the molten material through the shot sleeve and into the gate cavity with a plunger.

19. The method set forth in claim 18 wherein compressing the molten material in the gate cavity includes compressing the molten material with the plunger.

20. The method set forth in claim 19 wherein moving the molten material from the gate cavity into the casting cavity includes forcing the molten material through the gate cavity and into the casting cavity with the plunger.

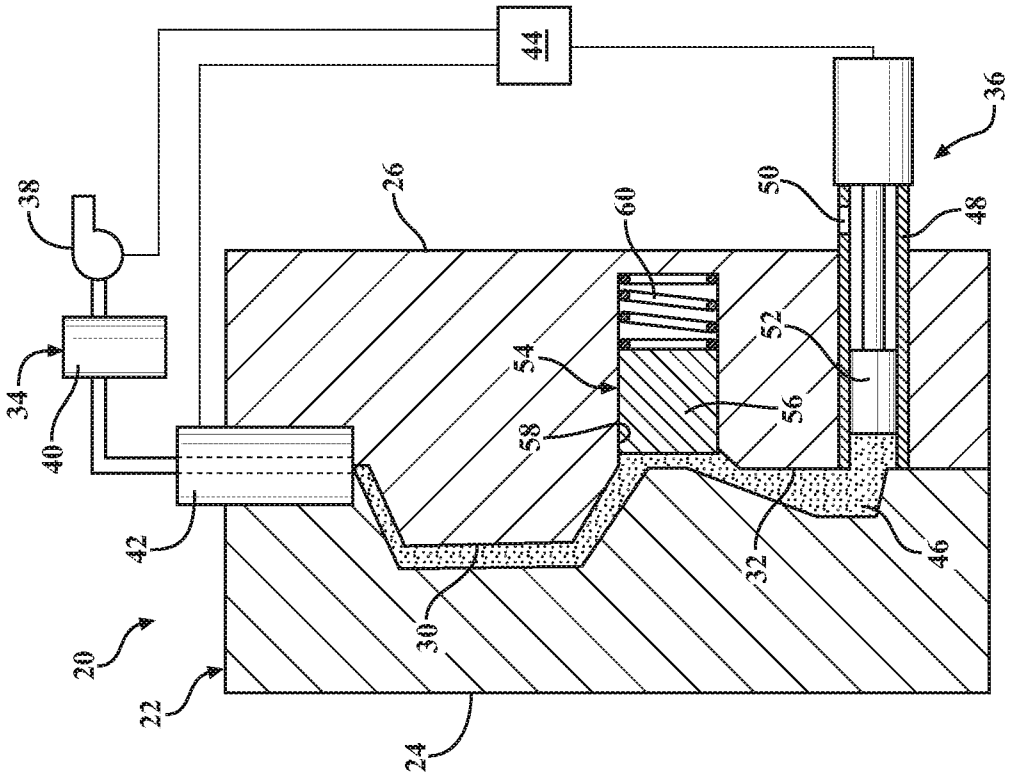
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FIG. 2

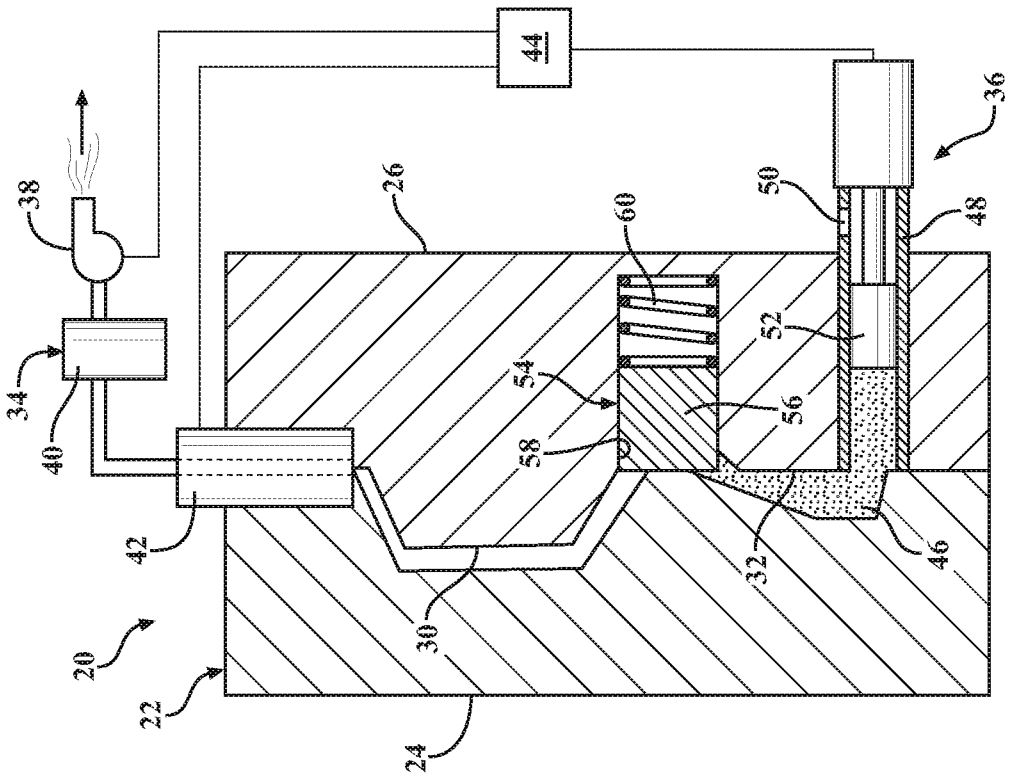
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FIG. 1

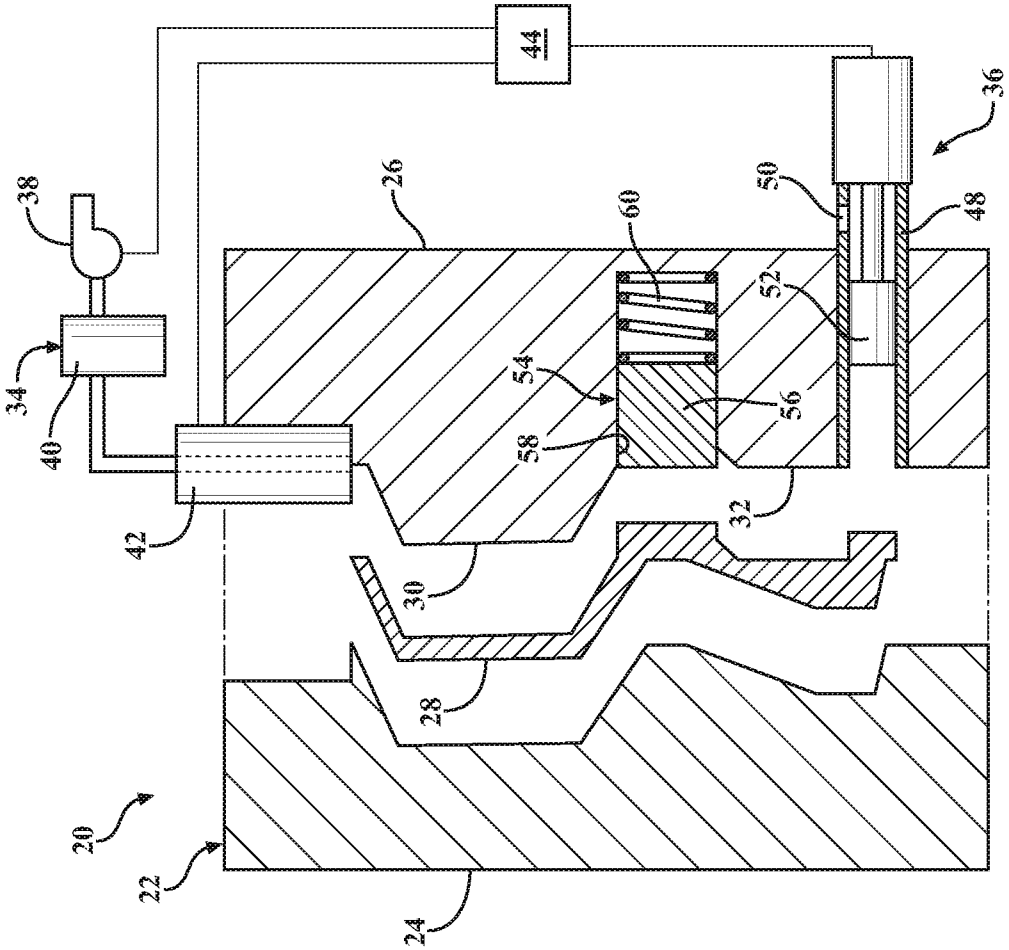
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FIG. 4

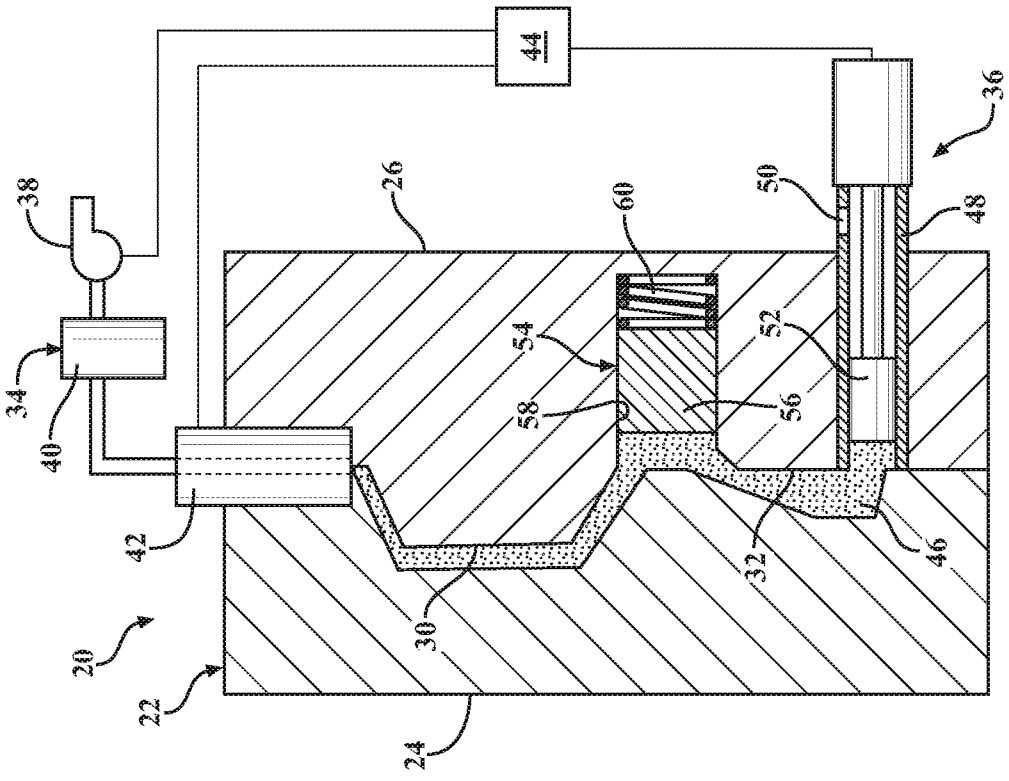
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FIG. 3

# INTERNATIONAL SEARCH REPORT

International application No.
**PCT/CN2015/092521**

## A. CLASSIFICATION OF SUBJECT MATTER

B22D 17/14(2006.01)i; B22D 17/20(2006.01)i

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)

B22D

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 practicable, search terms used)

CNABS, VEN, CNTXT, CNKI: die cast+, cast+, valve, vacuum, gate, sprue, cavity, air, gas, porosity

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | EP 0441289 A1 (YAMASAKI ENGINEERING CO LTD) 14 August 1991 (1991-08-14)<br>See description column 2 line 1 to column 4 line 54 and figures 1-3 | 1-20 |
| X | EP 1900456 A1 (ALUWAG AG) 19 March 2008 (2008-03-19)<br>See description paragraphs 0043 to 0050 and figures 1 to 5 | 1-20 |
| A | CN 87102218 A (DAIWA INDUSTRY CO LTD) 30 September 1987 (1987-09-30)<br>See the whole document | 1-20 |
| A | CN 1150921 A (TOSHIBA MACHINE CO LTD) 04 June 1997 (1997-06-04)<br>See the whole document | 1-20 |
| A | JP 2013099756 A (DIRECT 21 CORP) 23 May 2013 (2013-05-23)<br>See the whole document | 1-20 |

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