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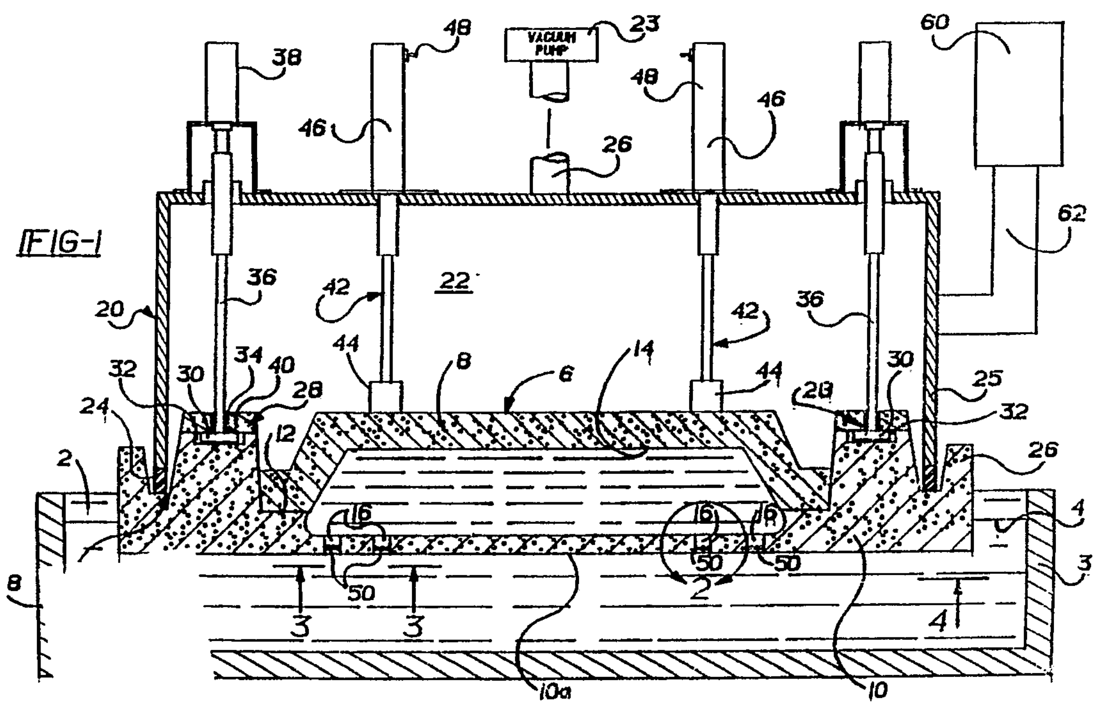
(71) Applicant: GENERAL MOTORS CORPORATION
New Center 1 Building 3031 W. Grand Boulevard
Detroit Michigan 48202(US)

(72) Inventor: Sabraw, Richard J.
1322 Andrew
Saginaw, Michigan 48603(US)

(74) Representative: Hoeger, Stellrecht & Partner
Uhlandstrasse 14 c
W-7000 Stuttgart 1(DE)

(54) Differential pressure, countergravity casting with selective alloyant introduction.

(57) A source of alloyant is disposed at (i.e., within or in close proximity to) one or more ingates of a casting mold so as to selectively introduce the alloyant into the melt stream drawn upwardly from a casting vessel through the ingate(s) during the differential pressure, countergravity casting process. Castings having different compositions, microstructures and mechanical properties can thereby be produced from a common base melt in the casting vessel.



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Field of The Invention

This invention relates to an improved apparatus and method for the differential pressure, countergravity casting of a melt in such a manner as to selectively introduce one or more alloyants into the melt as it is cast into the mold to tailor the metallurgical characteristics of the resultant casting, or local regions thereof.

Background Of The Invention

A vacuum countergravity casting process using a gas permeable mold sealingly received in a vacuum housing is described in such patents as the Chandley et al U.S. Patents 3,900,064; 4,340,108 and 4,606,396. That countergravity process involves providing a mold having a porous, gas permeable upper mold member (cope) and a lower mold member (drag) sealingly engaged at a parting plane, sealing the mouth of a vacuum housing to a surface of the mold such that a vacuum chamber formed in the housing confronts the gas permeable upper mold member, submerging the under side of the lower mold member in an underlying melt and evacuating the vacuum chamber to draw the melt through one or more narrow ingates (pin gates) in the lower mold member and into one or more mold cavities formed between the upper and lower mold members.

In practicing the vacuum countergravity process to produce nodular iron castings, the melt is typically prepared in a melting vessel (e.g., a cupola) using a charge of pig iron to which additions of alloyants are made to provide the desired base melt chemistry. For example, in casting nodular iron, ferromanganese (Fe-Mn), ferrosilicon (Fe-Si) and other additions are made to the base pig iron charge to provide a desired base melt chemistry.

Once the desired base melt composition is achieved, the melt is transferred from the melting vessel to a ladle where a nodularizing treating agent (e.g., Fe-Si-Mg) is added to spherodize the carbon. The treated base melt is then transferred from the ladle to a casting vessel to provide a melt pool from which a plurality of molds are successively vacuum countergravity cast. The nodular iron castings produced in this manner exhibit an as-cast ferritic/pearlitic microstructure depending upon the melt composition and solidification rate. The composition of the castings corresponds to that of the melt in the casting vessel.

In order to produce nodular iron castings having different compositions and microstructures (e.g., corresponding to the known ferritic grade 4010 or pearlitic grade 5203), the practice has been to prepare separate base melts of the desired different compositions using pig iron charges to which appropriate alloy additions are made in the melting vessel and then ladling and casting the separate base melts as described above. This practice amounts to producing castings of one composition/microstructure in one batch and castings of another different composition/micro-structure in a separate batch with preparation as well as subsequent handling, treatment and casting of different base melts for each batch.

Moreover, since the castings are produced by countergravity filling successive molds from a more or less homogenous underlying melt pool in the casting vessel, the vacuum countergravity casting process as currently practiced has not had the capability of purposefully and controllably producing castings having different metallurgical characteristics at different locations in the casting so as to alter or enhance certain properties (e.g., mechanical properties) at localized regions of the casting as may be desired in certain service applications.

It is an object of the present invention to provide an improved apparatus and method for the differential pressure, countergravity casting of a melt wherein an alloyant is positioned at one or more ingates (e.g., pin gates) of the mold drag so as to be introduced into the melt as the melt is drawn upwardly through the ingates into the mold cavity to produce a casting having a composition different from that of the underlying melt.

It is another object of the present invention to provide such an improved apparatus and method for differential pressure, countergravity casting wherein castings having different compositions tailored for different intended uses can be countergravity cast from a common melt to avoid the need to prepare, handle, treat and cast separate base melts.

It is another object of the present invention to provide such an improved apparatus and method for differential pressure, countergravity casting wherein an alloyant is positioned at one or more of the mold ingates so as to be introduced into the melt as it is drawn upwardly into the mold cavity to produce a microstructure in the casting that is not obtainable by solidification of the underlying melt composition.

It is another object of the present invention to provide such an improved apparatus and method for differential pressure, countergravity casting wherein the melt composition is selectively altered during casting in such a manner as to produce a casting having different metallurgical characteristics at different locations or regions of the casting to provide different or enhanced properties where needed in the casting.

It is another object of the present invention to provide such an improved apparatus and method for differential pressure, countergravity casting wherein melt contamination and slag potential are reduced by reducing alloy additions and treating agent additions (e.g., nodularizing agent additions) heretofore made to the base melt in the melting vessel and/or in the ladle.

It is another object of the present invention to provide a mold cavity fill analysis method for determining molten metal flow paths from the ingates into the mold cavity during differential pressure, countergravity casting.

Summary Of The Invention

The present invention contemplates an improved apparatus and method for the differential pressure, countergravity casting of a melt wherein an alloyant is disposed on the mold at (i.e., within or in close proximity to) one or more of the ingates (e.g., narrow pin gates) to the mold cavity so as to contact the molten metal stream drawn upwardly through the ingate(s) into the mold cavity and selectively introduce the alloyant therein. The composition of the melt is thereby altered as it is countergravity cast into the mold.

In one embodiment of the invention, an expendable source of the alloyant is disposed at each of a plurality of the ingates such that the alloyant is introduced (e.g., dissolved) into the molten metal stream drawn upwardly through the ingate into the mold cavity to produce a casting having a different composition from that of the melt. The alloyant introduced to the melt can be selected to provide a casting having different overall mechanical properties/microstructure from that obtainable from the melt. For example, copper can be introduced to a ferritic cast iron melt as it is drawn from the casting vessel upwardly into the mold cavity to produce a casting having a microstructure and substantially improved tensile and yield strength corresponding to a pearlitic cast iron grade.

In another embodiment of the invention, a fugitive nodularizing agent (e.g., Fe-Si-Mg) is disposed at each of a plurality of ingates so as to treat the melt as it is drawn upwardly from the casting vessel into the mold cavity for carbon nodularizing purposes.

In still another embodiment of the invention, the alloyant is disposed at some of the ingates to the mold cavity but not others so as to produce a casting having different compositions and resultant different metallurgical characteristics (e.g., different mechanical properties/microstructures) at different locations of the casting. For example, copper can be selectively introduced to the melt stream drawn upwardly into local regions of the mold cavity that form casting features requiring increased strength while other regions of the mold cavity that form casting features not requiring such strength receive untreated melt (i.e., melt devoid of copper).

Similarly, a first alloyant source can be disposed at some ingates while a second alloyant source is disposed at other ingates to produce a casting having different metallurgical characteristics at different locations.

In still another embodiment of the invention, molds configured to produce a particular cast part include a source of alloyant at one or more mold ingates while other molds configured to produce a different cast part are without such alloyant sources or perhaps include a source of a different alloyant at one or more ingates. The molds are successively countergravity cast from the same underlying melt to produce the different cast parts having different compositions tailored for different end uses from the common underlying melt. For example, molds configured to produce a particular part (e.g., an exhaust manifold) can be countergravity cast from an underlying ferritic nodular iron grade melt with no alloyant disposed on the molds while other molds configured to produce a different part (e.g., a connecting rod) can be countergravity cast from the same melt with a suitable alloyant disposed at the ingates to alter the composition of the ferritic nodular iron melt drawn into the mold cavity to produce a microstructure and improved mechanical properties corresponding to a pearlitic cast iron grade as desired for connecting rods.

The present invention also contemplates a mold cavity fill analysis method for determining molten metal flow paths from the ingates into the mold cavity during differential pressure, countergravity casting from an underlying melt. In accordance with the mold cavity fill analysis method, a source of alloyant that affects a metallurgical characteristic of the casting is disposed at a particular ingate such that the alloyant is selectively introduced into the melt drawn upwardly through the particular ingate and is not introduced into the melt drawn upwardly through other adjacent ingates. After the molten metal is solidified in the mold cavity, the resulting casting is examined (e.g., metallographically) to observe the distribution of the metallurgical characteristic in the casting attributable to introduction of the alloyant to the melt at the particular ingate. In this way the molten metal flow path from the particular ingate into the mold cavity can be determined. This procedure can be repeated for each ingate to determine melt flow paths from the ingates into the mold cavity. The results of such analysis can be used to improve mold ingating designs and eliminate casting defects resulting from inadequate ingating, thus providing higher quality castings.

The aforementioned objects and advantages of the present invention set forth hereinabove will become more readily apparent from the detailed description and drawings which follow.

Brief Description Of The Drawings

Figure 1 is a sectioned, side view of a vacuum countergravity casting apparatus in accordance with the invention.

Figure 2 is an enlarged sectional view of the ingate encircled in Fig. 1.

Figure 3 is a bottom elevation of the ingate shown in Fig. 2.

Figure 4 is a bottom elevation of the mold drag taken in the direction of arrows 4-4 of Fig. 1.

Figure 5 is a bottom elevation of the mold drag of another embodiment of the invention.

Figure 6 is a bottom elevation of a particular ingate wherein alloyant needles are disposed in the ingate.

Figure 7 is a bottom elevation of a particular ingate wherein alloyant plates or vanes are disposed in the ingate.

Figure 8 is a bottom elevation of a particular ingate wherein a tubular alloyant pellet is embedded in the underside of the mold drag coaxially about the ingate.

Figure 9 is a bottom elevation of a particular ingate wherein a solid alloyant disc is disposed in the ingate.

Figure 10 is a sectional view of a particular ingate wherein the alloyant source is disposed adjacent the outlet of the ingate.

Figure 11 is a sectional view of a particular ingate wherein the alloyant source is disposed in a pocket formed in the ingate of a two-part mold drag.

Figures 12, 13 and 14 are top elevational views of similar cast exhaust manifolds shaded to illustrate the presence of primary carbides bounding localized carbide-free regions resulting from positioning a Fe-Si inoculant pellet at ingate 1 in Fig. 12, at ingate 4 in Fig. 13 and at ingate 6 in Fig. 14.

Figure 15 is a longitudinal sectional view along lines 15-15 of Fig. 14.

Detailed Description Of Specific Embodiments

Figure 1 depicts a pool 2 of melt 4 which is to be drawn up into a mold 6 having a gas-permeable upper mold portion 8 (cope) and a lower mold portion 10 (drag) joined at a parting line 12 and defining a molding cavity 14 therebetween. The melt 4 is contained in a casting furnace or vessel 3 heated by one or more induction coils (not shown) to maintain the melt 4 at a desired casting temperature.

The lower mold portion 10 includes a plurality of narrow ingates 16 (i.e., pin gates) communicating the underside 10a thereof with the mold cavity 14 for admitting the melt 4 to the mold cavity 14 when it is evacuated through the upper mold portion 8 with the underside 10a immersed in the melt 4. The ingates (pin gates) 16 preferably have a major dimension (e.g., diameter for cylindrical ingates) not exceeding about 0.50 inch, preferably not exceeding 0.25 inch (e.g., .1875 inch) for purposes set forth in U.S. Patent 4,340,108 and hereinafter described.

The lower mold portion 10 of the mold 6 is sealed to the mouth 18 of a vacuum box 20 defining a vacuum chamber 22 via a seal 24 (e.g., high temperature rubber, ceramic rope, etc.). The seal 24 is affixed to the lower peripheral edge of the depending peripheral side 25 of the vacuum box 20. The vacuum chamber 22 encompasses the upper mold portion 8 and communicates with a vacuum source 23 (e.g., a vacuum pump) via conduit 26.

The upper mold portion 8 comprises a gas-permeable material (e.g., resin-bonded sand) which permits gases to be withdrawn from the casting cavity 14 therethrough when a vacuum is drawn in the chamber 22. The lower mold portion 10 may conveniently comprise the same material as the upper mold portion 8 or other materials, permeable or impermeable, which are compatible with the material of the upper mold portion 8. The lower mold portion 10 includes an upstanding levee 26 surrounding the seal 24 and isolating it from the melt 4 as described in U.S. Patent 4,745,962 and assigned to the assignee of the present invention.

The lower mold portion 10 includes a plurality of anchoring sites 28 engaged by T-bar keepers 30 of the type described in commonly assigned U.S. patent application Serial No. 147,863, abandoned in favor of patent application Serial No. 286,051, providing means for mounting the mold 6 to the vacuum box 20. As described in those patent applications, the lower mold portion 10 includes a plurality of anchoring cavities 32 adapted to receive the T-bar keepers 30 via slots 34 in the shelves 40 overlying the anchoring cavities 32 and attached to the lower mold portion 10. A 90° rotation of the T-bar carrying shafts 36 (e.g., by air motors 38) causes the T-bar keepers 30 to engage the underside of the attached shelves 40 overhanging the cavities 32 to secure the mold 6 to the box 20. Other known mold to vacuum box mounting means can also be employed in practicing the invention (e.g., U.S. Patent 4,658,880).

The upper mold portion 8 is pressed into sealing engagement with the lower mold portion 10 (i.e., at the parting line 12) by means of a plurality of plungers 42 so as to eliminate the need to glue the upper mold portion 8 and the lower mold portion 10 at the parting plane 12. Feet 44 on the ends of the plungers 42 distribute the force of the plungers 42 more widely across the top of the upper mold portion 8 to prevent penetration/puncture thereof by the ends of the plungers 42. Pneumatic springs 46 bias the plungers 42 downwardly to resiliently press the upper mold portion 8 against the lower mold portion 10 as the mold 6 is being positioned in the mouth 18 of the vacuum box 22. Schrader valves 48 on the air springs 46 permit varying the pressure in the springs 46 as needed to apply sufficient force to press the upper mold portion 8 into sealing engagement with the lower mold portion 10, and, as needed, to prevent destructive inward flexure of the mold 6 when the casting vacuum is drawn. The force applied by the plungers 42, however, will not be so great as to overpower and damage the anchoring sites 28, dislodge the mold 6 from the mouth 13 of the box 20, or break the seal formed thereat.

Countergravity casting of each casting mold 6 is effected by relatively moving each mold 6 and the pool 2 to immerse the underside 10a of the lower mold portion 10 in the melt 4 and evacuating the mold cavity 14 to draw the melt 4 upwardly through the ingates 16 into the mold cavity 14. Typically, the casting mold 6 is lowered toward the pool 2 using a hydraulic power cylinder 60 (shown schematically) actuating a movable support arm 62 (shown schematically) that is connected to the vacuum box 20. After filling of each mold cavity 14 with the melt 4 and initial solidification of the melt in the ingates 16, each casting mold 6 is raised by hydraulic power cylinder 60 to withdraw the underside 10a of the lower mold portion 10 out of the pool 2. The number and size of the ingates 16 to achieve metal solidification initially at the ingates 16 can be selected in accordance with the teachings of U.S. Patent 4,340,108. Alternatively, the molten iron can be allowed to solidify in both the ingates 16 and the mold cavity 14 before raising the casting mold.

Referring to Figs. 1-4, a first embodiment of the invention is illustrated for altering the composition of a ferritic nodular iron grade melt 4 as it is drawn upwardly through the narrow ingates (pin gates) 16 into the mold cavity 14 during the vacuum countergravity casting process described hereinabove. In particular, this embodiment involves altering the melt composition to produce a casting having not only a different composition (e.g., by inclusion of copper in the melt) but also a different microstructure (e.g., a pearlitic cast iron grade microstructure) from that obtainable by solidification of the ferritic nodular iron melt 4.

The melt 4 is prepared initially as a ferritic iron base melt in a melting vessel, such as for example a cupola (not shown), by the addition of suitable alloyants to a pig iron charge in the melting vessel. For example, additions of 49 lbs. of 50% Fe-Si, 50 lbs. of steel, 2.5 lbs. of Fe-Mn and 1 lb. of graphite are made to 1150 lbs. of pig iron in the melting vessel to provide a ferritic iron base melt having a composition corresponding to the known ferritic iron grade 4010 (e.g., total carbon = 3.60 to 4.10 w/o, Mn = .25 to .90 w/o, P = .05 w/o max, S = .02 w/o max, Si = 2.20 to 2.70 w/o, Cr = .10 w/o max, Cu less than .04 w/o and balance iron).

A portion (e.g., 300 lbs.) of the ferritic iron base melt is transferred to a ladle (not shown) where the melt is treated with a nodularizing treating agent (e.g., Fe-Si-Mg having a nominal composition of about 5 w/o Mg and balance Fe and Si in equal amounts) to spherodize the carbon. A Mg content of about 0.03-0.06 w/o is typically provided in the ferritic iron base melt for this purpose. Cut steel shavings are introduced as a cover layer over the treated base melt in the ladle to enhance recovery of magnesium.

The resulting ferritic nodular iron grade melt 4 (i.e., 300 lbs.) is then transferred from the ladle to the casting vessel 3 where the melt 4 is inoculated by the addition of 2 lbs. of Fe-Si alloyant and the melt temperature is maintained at about 2600°F during the vacuum countergravity casting of successive molds 6 therefrom.

In accordance with this embodiment of the invention, an expendable source 50 of copper alloyant is positioned at each ingate 16 so as to selectively introduce (e.g., dissolve) copper into the ferritic nodular iron grade melt 4 as a stream of the melt 4 is drawn upwardly through the ingates 16 into the molding cavity 14 during the vacuum, countergravity casting process.

In particular, the mold 6 includes the sources 50 of copper alloyant in each ingate (pin gate) 16 adjacent the inlet thereof (i.e., adjacent the underside 10a of the lower mold portion 10). Each source 50 of copper alloy comprises a spiral of copper electrical wire wedged in each ingate 16 adjacent the underside 10a with the axis of the spiral coaxial with the longitudinal axis or each ingate 16, see Figs. 2-3. It is apparent that the configuration and orientation of the spiral wire source 50 provides a plurality of upwardly extending passages 52 through which the ferritic nodular iron melt stream can be drawn upwardly from the pool 2 into the mold cavity 14 during the vacuum countergravity casting process.

As the stream of melt 4 is drawn upwardly through each ingate 16, the melt 4 passes through the passages 52 in the spiral wire source 50 for intimate contact therewith and introduction (e.g., dissolution) of copper selectively into the melt 4 flowing through each respective ingate 16.

In this embodiment of the invention, the amount of copper introduced into the melt 4 is selected (e.g., about .4 w/o minimum to about .5 w/o maximum) to provide a microstructure upon solidification of the melt 4 in the mold cavity 14 (during air cooling of the metal-filled mold 6) and improved tensile and yield strength properties at least comparable to the known as-cast pearlitic nodular iron grade 5203.

For example, in casting trials, eight castings (in the shape of tensile specimens each weighing between about 1.5 lbs. to 1.6 lbs.) were vacuum countergravity cast from the ferritic nodular iron melt 4. Each tensile specimen-shaped mold cavity 14 received the melt 4 via a pair of pin gates 16 with each pin gate having a spiral copper source 50 weighing about three (3) grams therein. A copper concentration of about .4 w/o was measured in the resultant castings (tensile specimens). Upon examination and testing, the castings (tensile specimens) were found to exhibit an as-cast microstructure corresponding to the known as-cast pearlitic nodular iron grade 5203 (e.g., 50 v/o ferrite max., 50 v/o pearlite min., 10 v/o carbide max.) and mechanical properties more than comparable (see Table I below) to the as-cast pearlitic nodular iron grade 5203.

TABLE I

Cast Specimen Number	Yield Strength* (ksi)	Ultimate Strength (ksi)	Elongation (%) From Extension	Reduction In Area (%)
(a)1	61.47	84.61	3.0	2.7
2	57.61	80.28	3.5	7.3
3	60.48	84.27	3.6	4.2
4	60.37	86.27	3.4	8.4
5	66.75	92.70	3.0	3.7
6	58.27	81.83	4.8	7.3
7	55.29	79.40	3.8	5.8
8	70.44	97.09	2.9	3.7
Mean	61.34	85.81	3.5	5.4
Standard Deviation	4.66	5.77	0.6	2.0
(b) Grade 5203	52	80	3	—

*.2 percent offset method

As is apparent, the embodiment of the invention described hereinabove with respect to Figs. 1-4 was effective in producing pearlitic nodular iron grade castings having significantly enhanced mechanical properties from the ferritic nodular iron melt 4 (corresponding to ferritic nodular iron grade 4010) as a result of the selective introduction of copper into the melt 4 as it was drawn upwardly through the narrow ingates (pin gates) 16 of the mold 6 during the vacuum-assisted countergravity casting process. Moreover, each source 50 of copper can be positioned in the conventionally shaped/sized narrow ingates (pin gates) 16 without having to make substantial modifications to the ingates 16. In particular, the ingates 16 can be configured sufficiently narrow (e.g., .1875 inch in diameter for the cylindrical ingates 16 shown) to effect initial freeze-off of the melt 4 in the ingates 16 in accordance with U.S. Patent 4,340,108 and yet still achieve desired introduction of the alloyant (Cu) in the melt 4 during casting.

Referring now to Fig. 5, a somewhat different embodiment of the invention is illustrated and involves positioning the sources 50 of copper (or other) alloyant soluble in the melt 4 at some ingates 16 but not other ingates 16' to produce a casting having different metallurgical characteristics (e.g., different microstructures/mechanical properties) at different locations of the casting. In particular, the sources 50 of copper alloyant are placed at some ingates 16 to feed a certain region R of the mold cavity 14 with the copper-modified melt 4 described hereinabove (i.e., a melt 4 containing copper in desired amount) to produce a pearlitic cast iron grade microstructure and improved mechanical properties upon solidification in the region R of the mold cavity 14.

On the other hand, other region L of the mold cavity 14 receives the ferritic nodular iron melt 4 substantially devoid of copper from the ingates 16' (where there are no sources 50 of copper alloyant) so as to produce a microstructure (e.g., 40 v/o ferrite min., 60 v/o pearlite max., 10 v/o carbide max.) and reduced mechanical properties (e.g., nominal tensile strength of 60,000 psi, nominal yield strength of 40,000 psi and nominal elongation of 10%) corresponding to the known as-cast ferritic nodular iron grade 4010 upon solidification of the melt 4 in the region L of the mold cavity 14.

Region R of the mold cavity 14 would correspond to a location of the casting requiring increased strength while region L would correspond to a location of the casting not requiring the higher strength but perhaps requiring more ductility. Dual property, vacuum-assisted countergravity castings can thereby be produced.

Referring again to Fig. 5, those skilled in the art will appreciate that an expendable source (not shown) of a second alloyant (i.e., an alloyant other than copper that is soluble in the melt 4) may be positioned at one or more of the ingates 16' while the copper alloyant sources 50 are positioned at the ingates 16 such that a first alloyant (i.e., copper) is introduced into the melt 4 drawn upwardly through one or more of the narrow ingates (pin gates) 16 while the second alloyant is introduced into the melt 4 drawn upwardly through one or more of the ingates 16'. A casting having different metallurgical characteristics at different locations can also be produced in this manner in accordance with the present invention.

Moreover, castings having different metallurgical characteristics at different locations can also be cast in accordance with the invention by introducing a first amount of an alloyant into the melt 4 drawn upwardly through one or more ingates 16 while a different amount of the same alloyant is introduced into the melt 4 drawn upwardly through one or more of the other ingates 16'. The position (i.e., proximity) of the sources 50 relative to the ingates 16,16' as well as the size and configuration of the alloyant sources 50 can be varied to achieve introduction of different amounts of the same alloyant into the melt 4 drawn through different ingates 16,16' during the vacuum-assisted countergravity casting process.

In accordance with still another embodiment of the invention, different cast parts having different metallurgical characteristics for different intended uses can be vacuum countergravity cast from a common melt using the apparatus shown in Fig. 1. For example, a plurality of the molds 6 having one or more connecting rod-shaped mold cavities 14 and copper alloyant sources 50 at each of the ingates 16 can be vacuum countergravity cast in succession from the ferritic nodular iron melt 4 as described hereinabove to produce cast connecting rods having an as-cast microstructure and mechanical properties at least equivalent to as-cast pearlitic nodular iron grade 5203.

Then, a plurality of other molds 6 having one or more exhaust manifold-shaped mold cavities 14 but without copper alloyant sources 50 at any of the ingates 16 can be vacuum countergravity cast in succession from the same (common) ferritic nodular iron melt 4 to produce exhaust manifolds having an as-cast microstructure and mechanical properties corresponding to as-cast ferritic nodular iron grade 4010.

Of course, the molds for casting the connecting rods and the molds for casting the exhaust manifolds can be cast in any sequence desired since both types of molds are cast from the common ferritic nodular iron melt 4.

This embodiment of the invention eliminates the need to prepare and handle different base melts in one or more melting vessels/ladles. Thus, a "universal" cupola melt can be used to produce different cast parts having different compositions and/or microstructures and resultant mechanical properties. The manufacture of different cast parts for different intended uses is thus simplified. Moreover, the flexibility of the vacuum countergravity casting process in meeting ever changing production schedule variations is tremendously improved. Furthermore, since at least some of the alloyant additions are made as the melt 4 is drawn upwardly through one or more ingates 16 and not to the base melt in the melting vessel or ladle, the potential for contamination and slagging is reduced.

Although Figs. 1-5 illustrate the sources 50 as spiral wound wire disposed in the ingates 16 adjacent the underside 10a of the lower mold portion 10, the invention is not so limited. For example, the sources 50 may assume other configurations as illustrated in Figs. 6, 7, 8 and 9. In Fig. 6, the alloyant source 50' comprises a plurality of circumferentially spaced alloyant needles 51' extending toward the center of the ingate (pin gate) 16'. Fig. 7 illustrates the alloyant source 50" as comprising a plurality of spaced apart alloyant plates 53" disposed in the ingate (pin gate) 16" for contact with the melt drawn upwardly therethrough. In Fig. 8, the source 50"' is illustrated as a solid, cylindrical, tubular alloyant pellet 54"' disposed about the ingate (pin gate) 16"' coaxial therewith for communicating directly with the ingate. In Fig. 9, the alloyant source 50"" comprises a solid disc 52"" of the alloyant positioned across the ingate 16"". In practicing the invention using solid disc 52"" in the ingate 16"", the underside of the mold 6 is immersed in the melt 4 (see Fig. 1) until the disc 52"" melts and then the vacuum is drawn in mold cavity to urge the melt upwardly through the ingate (pin gate) 16'''' past the melted disc 52'''' in such a manner that the alloyant is introduced into the melt as it is drawn upwardly through the ingate.

The sources 50, 50', etc. can be held in the respective ingates (pin gates) 16, 16', etc. using sodium silicate or other suitable adhesive. Alternately, the sources 50, 50', etc. can be embedded in the lower mold portion 10 in such a position as to extend in the desired manner into the ingate 16, 16', etc. as shown in Figs. 6-9. Typically, the alloyant source is embedded in the lower mold portion 10 while the sand-resin mixture thereof is compliant. Then, the sand-resin mixture of the lower mold portion 10 is cured or hardened to retain the alloyant sources in position.

Moreover, although Figs. 1-9 illustrate each alloyant source 50, 50', etc. as being disposed adjacent the inlet of the respective ingates 16, 16', etc., the invention is not so limited. Referring to Figs. 10, the cylindrical, tubular alloyant source 150 (in the form of the cylindrical, tubular alloyant pellet 154) can be disposed adjacent the outlet 116a of the respective ingate 115 in the lower mold portion 110 and in the mold cavity 114 formed between the upper and lower mold portions 108,110. Alternatively, as shown in Fig. 11, the alloyant source 250 can be disposed in a small pocket 217 formed in the narrow pin gate 216 at a parting plane P of a two-part lower mold portion (drag) 210. The pocket 217 is located in the upper portion 210 of the two-part lower mold portion (drag) 210 intermediate the inlet 216a and outlet 216b of the narrow pin gate 216. The pin gate 216 is of the type described hereinabove sized to effect initial, rapid solidification of a plug of metal therein after the mold cavity 214 is filled with molten metal. The pin gate 216 supplies the treated molten metal stream drawn therethrough to the mold cavity 214 formed in the upper mold portion (cope) 208. The outer periphery of the source alloyant 250 includes slots 250a to provide a molten metal flow path through the pin gate 216.

In general, the alloyant source 50, 50', etc. need not communicate directly with the ingate 16, 16', etc. so long as the alloyant source is in sufficiently close proximity to the ingate to contact the melt 4 drawn upwardly through the ingate 16 and selectively introduce the alloyant into the melt 4 drawn upwardly therethrough. For example, the source 50, 50', etc. can be embedded in the underside 10a of the lower mold portion 10 in the manner described in the copending application (attorney docket no. P-309 GM-Plant) spaced from the inlet of the ingate 16,16', etc. and yet sufficiently close to the inlet of the ingate 16, 16', etc. as to introduce the alloyant into the stream of melt 4 drawn upwardly into that particular ingate 16, 16', etc.

Although the embodiments of the invention are illustrated hereinabove with respect to the introduction of copper into the ferritic nodular iron melt 4, those skilled in the art will appreciate that the invention is not so limited. For example, other alloyants such as chromium, manganese, molybdenum, magnesium, silicon as well as others that are soluble in the melt 4 may be introduced therein in accordance with the invention. In one specific example, each alloyant source 50, Fig. 1, may comprise an iron-silicon-magnesium nodularizing agent (having a composition of about 5 w/o Mg and balance Fe and Si in equal amounts) to introduce magnesium into a stream of ferritic iron melt 4 as it is drawn upwardly through the ingates 16 to nodularize the carbon of the melt that fills the mold cavity 14. This method of introducing the nodularizing agent into the melt 4 as it is drawn upwardly through the ingates 16 can be used in lieu of or in addition to the method disclosed in the aforementioned copending application (attorney docket no. P-309 GM-Plant) of common assignee herewith for maintaining the magnesium content of the melt 4 at the required level (e.g., about 0.03 w/o-0.06 w/o) for nodularizing the carbon of the melt 4 filling the mold cavity 14 of successively cast molds 6. Loss or "fade" of the magnesium content of the melt 4 over time can be thereby countered.

In another specific example of another alloyant that can be introduced into the melt in accordance with the invention, the sources 50 may comprise a Fe-Si inoculant (comprising 1 w/o Ca, 75 w/o Si and balance Fe) for promoting nucleation of graphite in the ferritic (or pearlitic) nodular iron grade melt 4 during solidification. In particular, in certain casting trials, a source 50 of Fe-Si inoculant (in the form of a tubular solid pellet as shown in Fig. 8) was positioned about each ingate 16 adjacent the underside 10a of the lower mold portion 10 prior to vacuum countergravity casting of a ferritic nodular iron melt 4. The inoculant sources 50 were effective to introduce inoculant into the melt 4 drawn upwardly through the ingates 16 into the mold cavity 14 in such a quantity as to significantly increase the graphite nodule count in the casting; e.g., to 161.3 nodules per square millimeter.

Moreover, the present invention is not limited to the vacuum countergravity casting of cast irons and instead may be used in the vacuum countergravity casting of other metals/alloys where selective introduction of one or more alloyants is desired for some purpose. For illustrative purposes only, the present invention may be used to dissolve known degassing, desulfurizing, deslagging and similar treating agents into aluminum or steel during the vacuum countergravity casting thereof.

In addition to the improved differential pressure, countergravity casting method and apparatus described hereinabove, the invention also envisions a mold cavity fill analysis method for determining melt flow paths into the mold cavity 14 from the ingates 16 during the countergravity casting process. For example, referring to Fig. 1, an alloyant source 50 is disposed in close proximity to a selected one of the ingates 16 (instead of all the ingates 16 as shown) so as to introduce the alloyant only into the melt 4 drawn upwardly through that particular ingate. The alloyant is selected to impart a particular metallurgical characteristic to the casting which metallurgical characteristic will be localized to a region of the mold cavity 14 that is supplied melt 4 by the particular ingate 16 where the source 50 is placed. Regions of the casting receiving melt 4 from the other ingates 16 where there are no alloyant sources will not exhibit this metallurgical characteristic. As a result, the contribution of a particular ingate 16 (where the alloyant source is placed) to the filling of the mold cavity 14 can be determined based on an analysis of the solidified casting; i.e., to determine where the particular metallurgical characteristic appears in the casting. This procedure can be repeated for each ingate 16 (or multiple ingates 16 when they are sufficiently remote from one another) to determine melt flow paths into the mold cavity 14 from each ingate.

Figs. 12-15 illustrate application of this method to the vacuum countergravity casting of automobile engine exhaust manifolds 100, 100', 100" (schematically shown) using an apparatus similar to that shown in Fig. 1 with the exception that a single alloyant source 50 is disposed in proximity to one, but not others, of the ingates 16. The locations of the ingates on the cast exhaust manifolds 100, 100', 100" are numbered from #1 to #15 in Figs. 12-14 for identification purposes.

In Fig. 12, the exhaust manifold 100 was vacuum countergravity cast with a solid tubular Fe-Si inoculant pellet embedded in the underside 10a of the lower mold portion 10 about the inlet of ingate #1, e.g., as shown in Fig. 8. A nodular iron melt 4 depleted of its graphite nucleating ability was then vacuum countergravity cast into the mold cavity 14 and solidified.

The nodular iron melt 4 drawn upwardly through ingate #1 contacted the Fe-Si inoculant pellet embedded in proximity to the ingate #1 such that the inoculant was introduced therein. The quantity of inoculant introduced into the melt 16 at the ingate #1 was sufficient to promote formation of graphite nodules and inhibit formation of primary carbides during solidification of the melt 4 in those regions of mold cavity 14 receiving the melt 4 from ingate #1. Those regions of the mold cavity 14 filled through the other ingates 16 received melt which was substantially devoid of inoculant and which, as a result, solidified as "white" cast iron with primary carbide precipitation and little or no graphite nodule formation. Thus, a noticeable metallurgical characteristic was associated with selective introduction of the inoculant into the melt passing through the ingate #1. The resultant exhaust manifold 100 was then sectioned at various locations for metallographic examination.

Fig. 12 includes shaded areas A where primary carbides of the varying percentages shown were found upon sectioning of the casting. The shaded areas A indicate those regions of the casting (or mold cavity 14) that are not fed by the ingate #1. These shaded areas A bound or enclose those regions of the casting that are fed with the melt containing inoculant from ingate #1. From Fig. 12, it is apparent that the ingate #1 feeds only a portion of flange area F1 of the cast exhaust manifold 100.

Fig. 13 includes shaded areas A' where carbides of the varying percentages shown were observed in the cast exhaust manifold 100' when the Fe-Si inoculant pellet was disposed at only the ingate #4 to selectively introduce silicon into the melt drawn upwardly through that ingate #4. It is apparent that the ingate #4 feeds the melt primarily to the flange area F2 of the cast exhaust manifold 100'. Fig. 13 also reveals that the ingates #3, #8 and/or #9 also supply melt to this same flange area F2. The flow of melt to the flange area F2 from ingates #3, #8 and/or #9 was not planned or expected during the design of the gating system for the particular mold involved.

Fig. 14 includes shaded areas A" where primary carbides of the varying percentages shown were observed in the cast exhaust manifold 100" when the Fe-Si inoculant pellet was disposed at only ingate #6 to selectively introduce the inoculant into the melt drawn upwardly through the ingate #6.

A comparison of Figs. 12 and 14 reveals that the ingate #6 feeds a much larger area of the cast exhaust manifold 100" than the ingate #1. Moreover, melt flow through the ingate #6 is effective enough to blend with melt entering the flange area F1 through the ingate #1.

Fig. 15 is a longitudinal sectional view through the flange area F1 of the cast exhaust manifold 100" and reveals massive carbides at the back side of the flange area F1. The presence of these massive carbides suggests that the ingate #1 feeds melt to the flange area F1 prior to ingate #6 and that solidification in that local region (where massive carbides are observed) began prior to arrival of the melt from the ingate #6.

The mold cavity fill analysis method of the invention illustrated hereinabove with reference to Figs. 12-15 provides to the casting engineer a tool for determining melt flow patterns from particular ingates 16 into the mold cavity 14 during vacuum-assisted countergravity casting of molten metal. This method will help the casting engineer to improve and optimize mold gating systems for a particular casting to be produced. This method also will help reduce the development and lead times required to design a particular casting mold and thus facilitate meeting scheduling demands for production castings. The prospect of producing quality castings on a production basis should be improved as a result.

While the invention has been described in terms of specific embodiments thereof, it is not intended to be limited thereto but rather only to the extent set forth hereafter in the claims which follow.

Claims

1. Apparatus for the differential pressure, countergravity casting of molten metal, comprising:
(a) a mold having a mold cavity, a lower mold portion adapted to engage an underlying source of said molten metal and an ingate communicating the mold cavity with the lower mold portion for supplying molten metal drawn from said source into said cavity,
(b) means for applying a suffioient differential pressure between the mold cavity and the source while the lower mold portion is engaged with the source to urge the molten metal upwardly through the ingate into the mold cavity, and
(c) an alloyant disposed on the mold at the ingate so as to selectively contact the molten metal stream drawn upwardly through said ingate into the mold cavity and substantially selectively introduce the alloyant into such stream.

2. The apparatus of claim 1 wherein said source comprises a pool of molten metal and said lower mold portion is adapted for immersion in said pool.

3. The apparatus of claim 1 wherein the alloyant is disposed adjacent an inlet of the ingate.

4. The apparatus of claim 3 wherein the alloyant is secured to the lower mold portion.

5. The apparatus of claim 1 wherein the alloyant is disposed adjacent an outlet of the ingate.

6. The apparatus of claim 5 wherein the alloyant is disposed in the mold cavity.

7. The apparatus of claim 1 wherein the alloyant is disposed in the ingate.

8. The apparatus of claim 1 wherein the mold includes a plurality of ingates and alloyant is positioned at each ingate.

9. Apparatus for the differential pressure, countergravity casting of molten metal to form a casting having different metallurgical characteristics at different locations, comprising:
(a) a mold having a mold cavity and a first ingate and a second ingate communicating a respective first location and second location of the mold cavity with a lower mold portion adapted to engage an underlying source of said molten metal,
(b) alloyant disposed on the mold at the first ingate to so contact the molten metal drawn upwardly through said first ingate as to substantially selectively introduce the alloyant therein remote from the second ingate, and
(c) means for applying a sufficient differential pressure between the mold cavity and the source while the lower mold portion is engaged with the source to urge the molten metal upwardly through the first ingate to supply the first location of the mold cavity with the molten metal having the alloyant introduced therein and through the second ingate to supply the second location of the mold cavity with the molten metal substantially devoid of the alloyant.

10. Apparatus for the differential pressure, countergravity casting of molten metal to form a casting having different metallurgical characteristics at different locations, comprising:
(a) a mold having a mold cavity and a first ingate and a second ingate communicating a respective first location and second location of the mold cavity with a lower mold portion adapted to engage an underlying source of said molten metal,
(b) first alloyant disposed on the mold at the first ingate to so contact the molten metal drawn upwardly through the first ingate as to substantially selectively introduce the first alloyant therein,
(c) second alloyant disposed on the mold at the second ingate to so contact the molten metal drawn upwardly through the second ingate as to substantially selectively introduce the second alloyant therein, and

(d) means for applying a sufficient differential pressure between the mold cavity and the source while the lower mold portion is engaged with the source to urge the molten metal upwardly through the first ingate to supply the first location of the mold cavity with the molten metal having the first alloyant introduced therein and through the second ingate to supply the second location of the mold cavity with the molten metal having the second alloyant introduced therein.

11. Apparatus for the differential pressure, countergravity casting of molten metal to form a casting having different metallurgical characteristics at different locations, comprising:

(a) a mold having a mold cavity and a first ingate and a second ingate communicating a respective first location and second location of the mold cavity with a lower mold portion adapted to engage an underlying source of said molten metal,

(b) alloyant disposed on the mold at the first ingate to so contact the molten metal drawn upwardly through said first ingate as to introduce a first amount of the alloyant therein,

(c) alloyant disposed on the mold at the second ingate to so contact the molten metal drawn upwardly through said second ingate as to introduce a second amount of the alloyant therein, and

(d) means for applying a sufficient differential pressure between the mold cavity and the source while the lower mold portion is engaged with the source to urge the molten metal upwardly through the first ingate to supply the first location of the mold cavity with the molten metal having said first amount of the alloyant therein and through the second ingate to supply the second location of the mold cavity with the molten metal having said second amount of the alloyant therein.

12. Apparatus for the differential pressure, countergravity casting of molten metal to form a casting having different metallurgical characteristics at different locations, comprising:

(a) a mold having a mold cavity and a plurality of ingates communicating different locations of the mold cavity with an underside of the mold adapted to engage an underlying source of said molten metal,

(b) alloyant disposed on the underside at at least one of said ingates to so contact the molten metal drawn upwardly through said one ingate as to substantially selectively introduce said alloyant therein remote from another of said ingates, and

(c) means for applying a sufficient differential pressure between the mold cavity and the source while the underside is engaged with the source to urge the molten metal upwardly through said one ingate to supply one location of the mold cavity with the molten metal having the alloyant introduced therein and through said another of the ingates to supply another location of the mold cavity with the molten metal substantially devoid of said alloyant.

13. A method of differential pressure, countergravity casting of molten metal, comprising:

(a) forming a mold having a mold cavity and an ingate communicating the mold cavity with a lower mold portion adapted to engage an underlying source of the molten metal, including disposing a source of an alloyant on the mold in such relation to the ingate that the molten metal drawn upwardly through the ingate contacts the alloyant,

(b) relatively moving the mold and the source to engage the lower mold portion and the source,

(c) applying a sufficient differential pressure between the mold cavity and the source while the lower mold portion is engaged with the source to urge the molten metal upwardly through the ingate into the mold cavity, including so contacting the molten metal and the alloyant as to substantially selectively introduce said alloyant into the molten metal drawn upwardly through the ingate into the mold cavity, and

(d) solidifying the molten metal in the mold cavity.

14. The method of claim 13 including disposing the alloyant on the lower mold portion in close proximity to an inlet of the ingate.

15. The method of claim 13 including disposing the alloyant in close proximity to an outlet of the ingate.

16. The method of claim 13 including disposing the alloyant in the ingate.

17. The method of claim 13 wherein the mold includes a plurality of ingates and a source of the alloyant is disposed in close proximity to each ingate.

18. A method of differential pressure, countergravity casting of molten metal to form a casting having different metallurgical characteristics at different locations, comprising:
(a) forming a mold having a mold cavity and a first ingate and a second ingate communicating a respective first location and second location of the mold cavity with a lower mold portion adapted to engage an underlying source of said molten metal,
(b) disposing an alloyant at the first ingate to so contact the molten metal drawn upwardly through said first ingate as to substantially selectively introduce said alloyant therein remote from the second ingate,
(c) relatively moving the mold and the source to engage the lower mold portion and the source,
(d) applying a sufficient differential pressure between the mold cavity and the source while the lower mold portion is engaged with the source to urge the molten metal upwardly through said first ingate to supply one location of the mold cavity with the molten metal having the alloyant introduced therein and through said second ingate to supply said second location of the mold cavity with the molten metal substantially devoid of the alloyant, and
(e) solidifying the molten metal in the mold cavity.

19. A method of differential pressure, countergravity casting of molten metal to form a casting having different metallurgical characteristics at different locations, comprising:
(a) forming a mold having a mold cavity and a first ingate and a second ingate communicating a respective first location and second location of the mold cavity with a lower mold portion adapted to engage an underlying source of said molten metal,
(b) disposing a first alloyant at the first ingate and a second alloyant at the second ingate to so contact the molten metal drawn upwardly through said first ingate and the second ingate as to substantially selectively introduce the respective first alloyant and second alloyant therein,
(c) relatively moving the mold and the source to engage the lower mold portion and the source,
(d) applying a sufficient differential pressure between the mold cavity and the source while the lower mold portion is engaged with the source to urge the molten metal upwardly through said first ingate to supply said first location of the mold cavity with the molten metal having the first alloyant introduced therein and through said second ingate to supply said second location of the mold cavity with the molten metal having the second alloyant introduced therein, and
(e) solidifying the molten metal in the mold cavity.

20. A method of differential pressure, countergravity casting of molten metal to form a casting having different metallurgical characteristics at different locations, comprising:
(a) forming a mold having a mold cavity and a first ingate and a second ingate communicating a respective first location and second location of the mold cavity with a lower mold portion adapted to engage an underlying source of said molten metal,
(b) disposing a first source of an alloyant at the first ingate and a second source of the alloyant at the second ingate to selectively contact the molten metal drawn upwardly through said first ingate and second ingate,
(c) relatively moving the mold and the source to engage the lower mold portion and the source,
(d) applying a sufficient differential pressure between the mold cavity and the source while the lower mold portion is engaged with the source to urge the molten metal upwardly through the first ingate and the second ingate, including so contacting the first source of said alloyant and the molten metal drawn upwardly through said first ingate as to supply one location of the mold cavity with the molten metal having an amount of the alloyant introduced therein and so contacting the second source of said alloyant and the molten metal drawn upwardly through said second ingate as to supply said second location of the mold cavity with the molten metal having a different amount of the alloyant introduced therein, and
(e) solidifying the molten metal in the mold cavity.

21. A method of differential pressure, countergravity casting of molten metal to form a casting having different metallurgical characteristics at different locations, comprising:
(a) forming a mold having a mold cavity and a plurality of ingates communicating different locations of the mold cavity with an underside of said mold adapted to engage an underlying source of said molten metal,
(b) disposing an alloyant on the underside at at least one of the ingates to so contact the molten metal drawn upwardly through said at least one of the ingates as to introduce said alloyant therein

remote from another of the ingates,
(c) relatively moving the mold and the source to engage the underside and the source,
(d) applying a sufficient differential pressure between the mold cavity and the source while the underside is engaged with the source to urge the molten metal upwardly through said at least one of the ingates to supply one location of the mold cavity with the molten metal having the alloyant introduced therein and through said other of the ingates to supply another location of the mold cavity with the molten metal substantially devoid of the alloyant, and
(e) solidifying the molten metal in the mold cavity.

22. A method of differential pressure, countergravity casting a first part and a second part having different compositions, comprising:
(a) forming a first mold for casting the first part,
(b) forming a second mold for casting the second part,
(c) providing a common source of molten metal from which the first mold and the second mold will be cast,
(d) disposing a source of an alloyant on one of said first mold or second mold in such relation to an ingate thereof that the alloyant is introduced into the molten metal drawn upwardly through the ingate during casting,
(e) drawing the molten metal of the common source upwardly through the ingate and into a mold cavity of the first mold while the first mold is engaged with the common source, and
(f) drawing the molten metal of the common source upwardly through the ingate and into a mold cavity of the second mold while the second mold is engaged with the common source,

whereby the molten metal drawn upwardly into the mold cavity of said one of the first mold or second mold will contain said alloyant and the molten metal drawn upwardly into the mold cavity of the other of the first mold or second mold will be devoid of said alloyant.

23. A mold cavity fill analysis method, comprising:
(a) forming a mold having a mold cavity and a plurality of ingates communicating different locations of the mold cavity with a lower mold portion adapted to engage an underlying source of molten metal,
(b) disposing an alloyant on the mold at one of the ingates to so contact the molten metal drawn upwardly through said one of the ingates as to introduce said alloyant therein in a sufficient quantity to affect a metallurgical characteristic of said molten metal upon solidification,
(c) countergravity casting the molten metal into the mold cavity by drawing the molten metal upwardly through the ingates and into the mold cavity while the lower mold portion is engaged with said source,
(d) solidifying the molten metal in the mold cavity to form a casting, and
(e) examining the casting to locate any region thereof exhibiting the metallurgical characteristic attributable to the presence of the alloyant in the solidified metal.

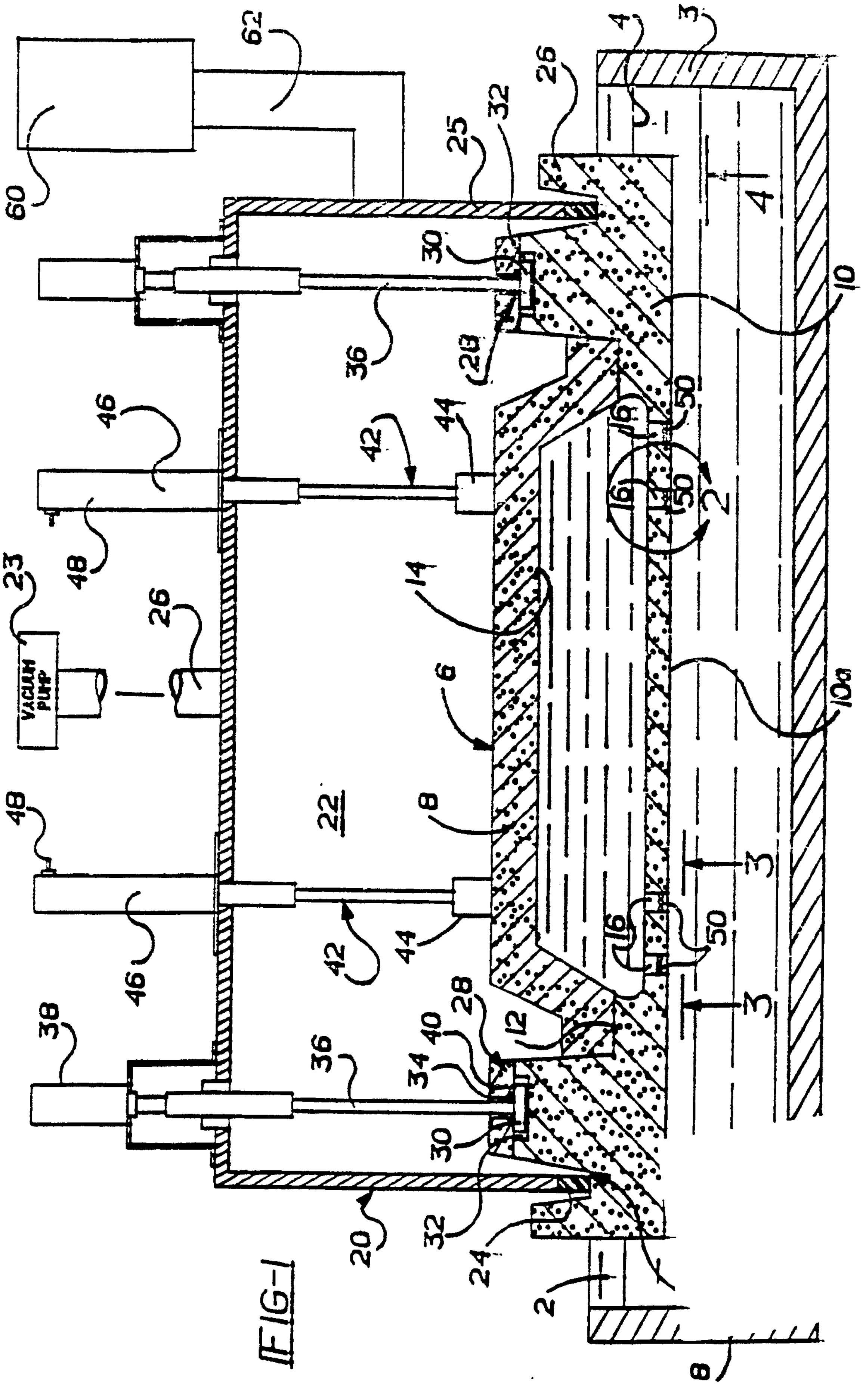


FIG-1

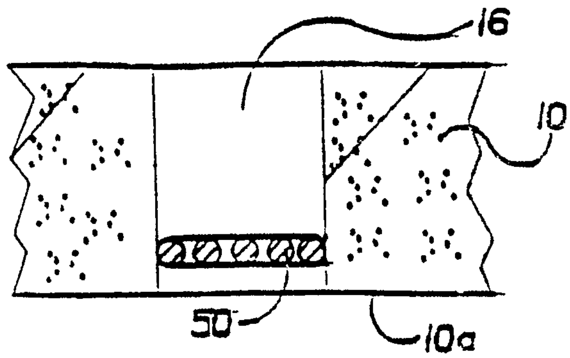


FIG-2

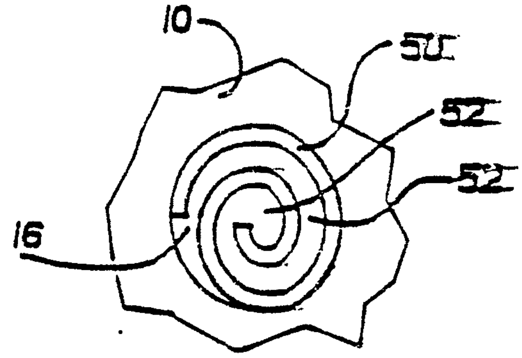


FIG-3

FIG-4

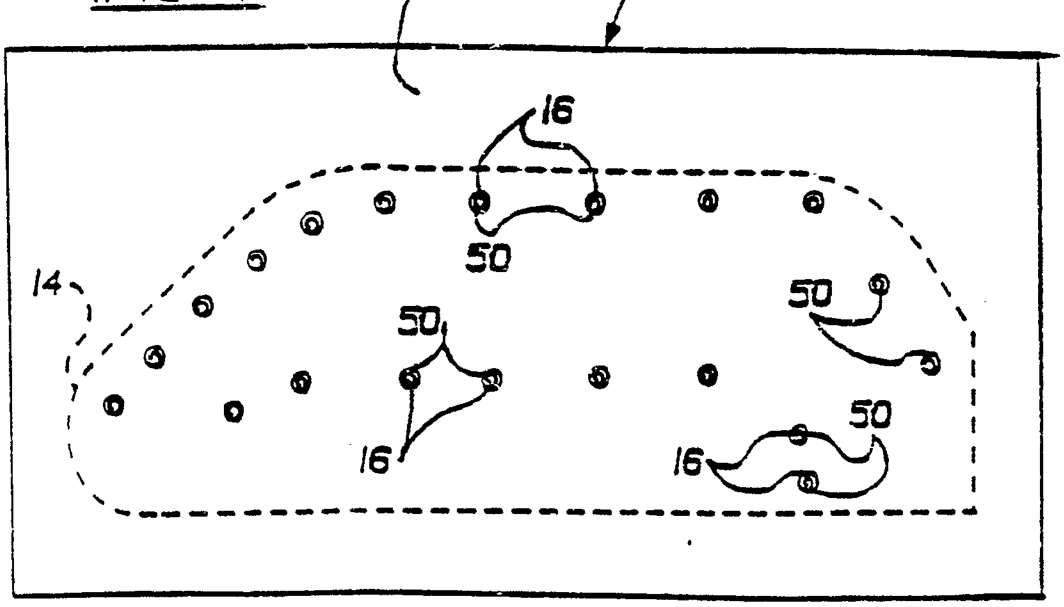
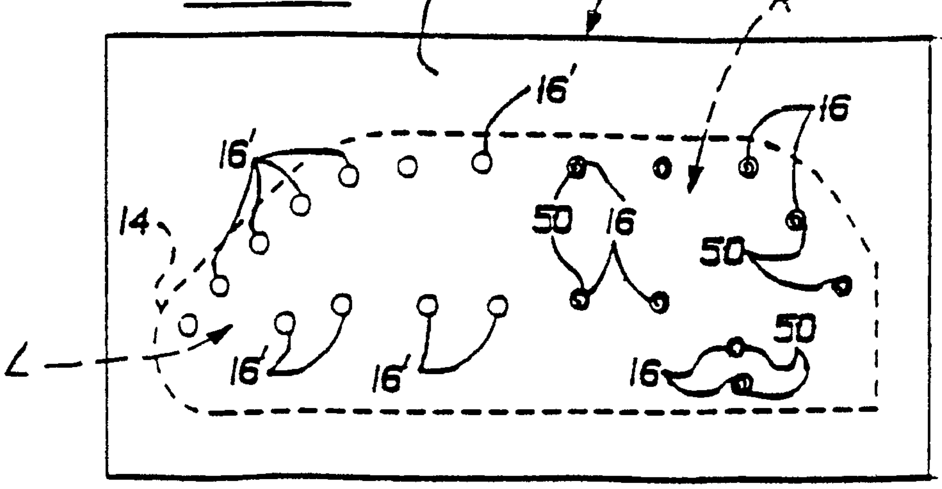


FIG-5



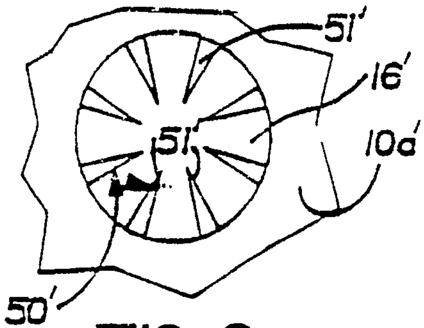


FIG-6

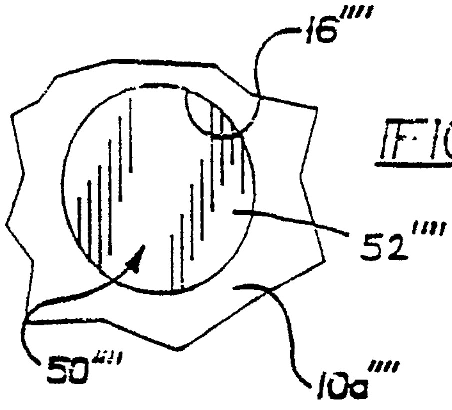


FIG-9

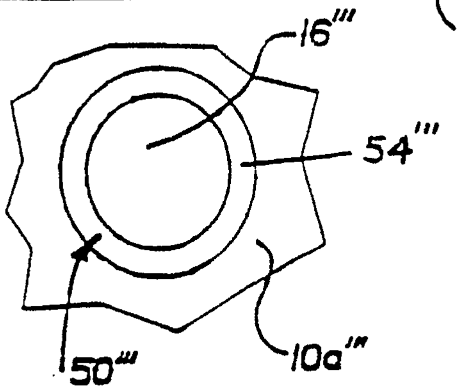
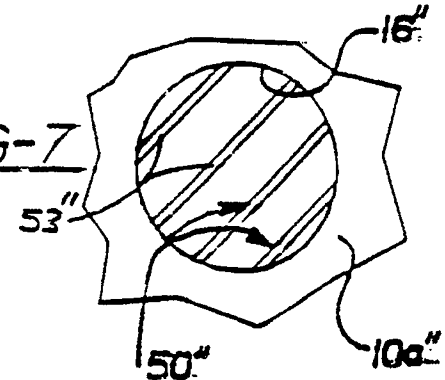


FIG-8

FIG-7



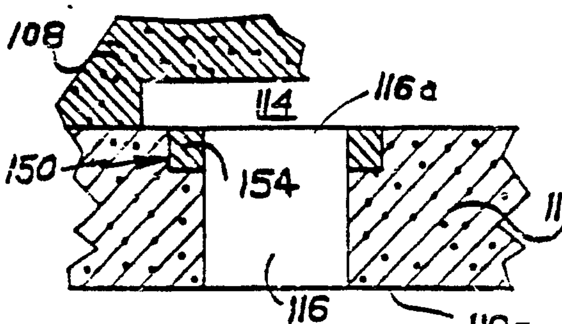


FIG-10

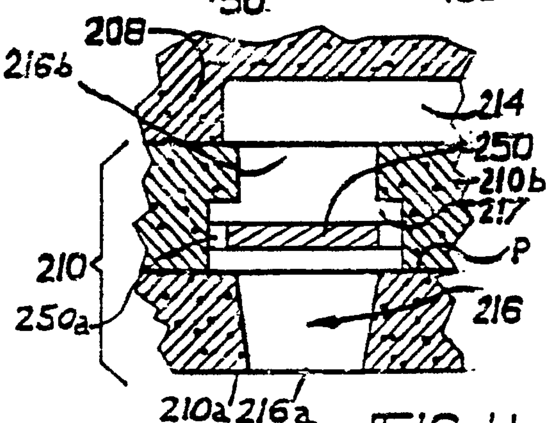


FIG-11

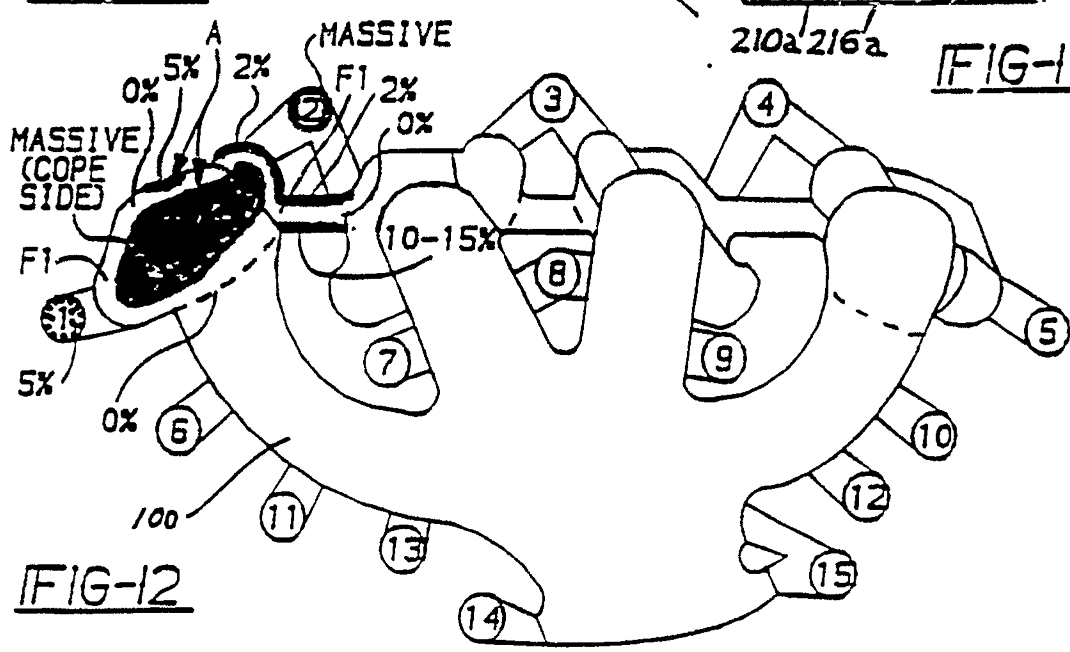
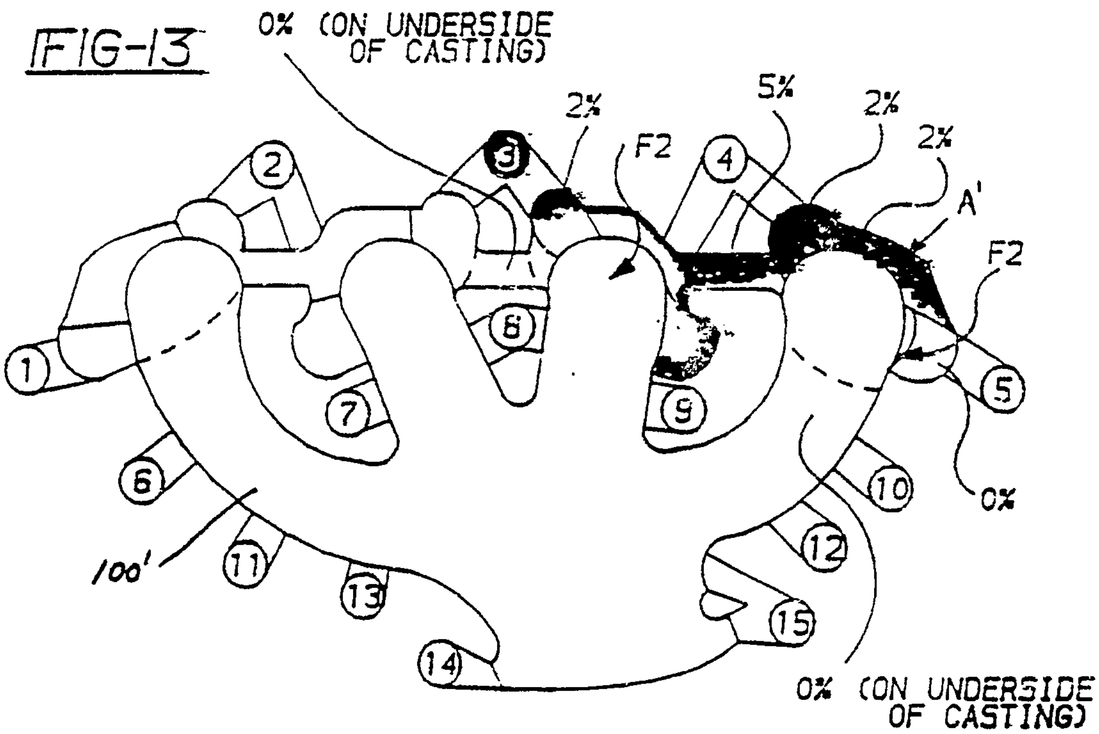


FIG-12

FIG-13



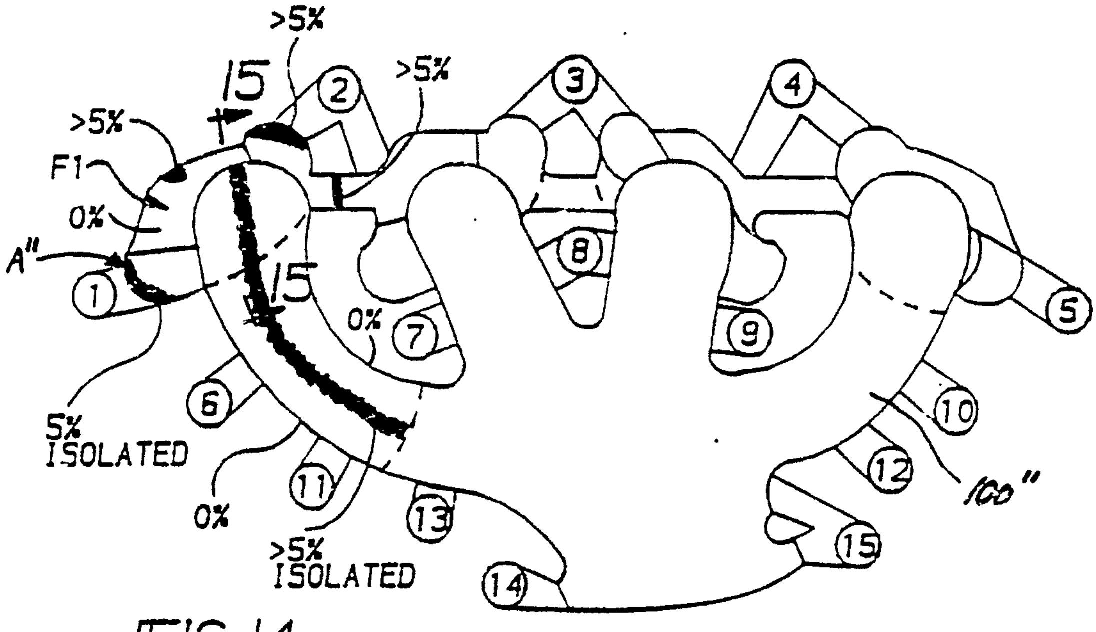


FIG-14

FIG-15