A composition for use in investment casting includes a pattern material. The pattern material has internal mold releasability. The composition is suitable for use in investment casting. The pattern material may include a wax, a resin, a filler, and/or a fluoroceramic. The pattern material may be capable of being injected numerous consecutive times without requiring the application of an external mold release agent (such as spraying silicone release agent) to a die used in the investment casting process. The pattern material would preferably have sufficient mold releasability to not adhere to the die, but sufficient adhesion to adhere to a shell-forming material, such as a ceramic slurry.
FIG. 2
MOLD RELEASABLE PATTERN MATERIAL FOR USE IN INVESTMENT CASTING

BACKGROUND

[0001] This application relates to the field of investment casting. Particularly, the application relates to a pattern material and its use in investment casting.

[0002] Investment casting, sometimes referred to as the ‘lost wax process’, requires the making of an original pattern typically of pattern material, investing or repeatedly dipping the patterns into a refractory slurry and drying to make a ceramic shell, and melting or burning the pattern material out of the shell leaving a shell suitable for pouring molten metal.

[0003] Initially, before the casting process begins, an injection die is constructed to produce precise wax patterns. This may be constructed of aluminum or some other material, and may be formed using CAD/CAM driven CNC milling and EDM machines. The injection die may be automated and may contain numerous controls and monitoring devices to provide dimensionally consistent patterns. For many applications, single cavity dies are used. Multi-cavity dies may also be used (e.g. for high production quantities).

[0004] A specially formulated pattern material may be injected into a die to produce the pattern for the part. Typically, one pattern is made for each finished part to be cast. This pattern is an exact replica of the metal part to be produced, generally with some allowances added to compensate for volumetric shrinkage during the process. The pattern also includes one or more gates to guide molten metal into the part during the solidification process.

[0005] In some processes, a system such as that described in U.S. Pat. Nos. 4,971,547 or 5,205,969, the disclosures of which are hereby incorporated by reference, may be used for automatically distributing a semi-solid wax-based pattern material to the injection presses. This system is unique in the industry in its general ability to control pattern material temperature within ±1 degree Fahrenheit at a relatively low temperature and high viscosity, which is beneficial for producing dimensional conformity between patterns.

[0006] Pattern material injection molding at this temperature may have several advantages. Since the pattern material, in this system, is in a semi-solid state when injected, the part undergoes less shrinkage through the freezing process. In turn, the pattern generally possesses better dimensional stability and may better resist flash and cavitation (or sink) when cooling.

[0007] The individual wax patterns may be assembled onto a wax sprue to form a mold, or tree. The number of patterns assembled per mold varies depending upon the size, weight, and configuration of a given part.

[0008] Ceramic molds may be created by dipping or “investing” the assembled patterns in liquid ceramic slurry, draining and then coating with a dry “stucco” sand. After drying, this process is repeated several times until a specified shell thickness results. The ceramic shell may range in thickness from 3/16” to 1/2” depending upon the size of the part being produced.

[0009] Robotics may be incorporated into this operation. Sophisticated shell drying technology may be used to reduce the total time to build a shell and improve quality related to drying defects. The ceramic shells may be dried by moving the molds through forced air drying. Stable, economical, environmentally safe water based slurries may be used to form the shell.

[0010] The pattern material may be melted out, leaving a hollow ceramic shell. The molds may be fired at 1600-2000 degrees Fahrenheit to fuse the ceramic particles together so that the mold can withstand the pressure and temperature of the molten metal being cast. This also tends to remove any residual wax in the mold.

[0011] Molten metal is poured into the pre-heated molds. Typical pouring temperatures are around 3000 degrees Fahrenheit for steel. Before casting, every melt may be analyzed spectrographically to assure compliance with the necessary specifications.

[0012] The ceramic shell may be removed from the metal mold with high-pressure jets of water, which may operate at 8000 to 9000 psi, and/or may be mechanically removed. Any ceramic material remaining in pockets or holes may be dissolved away in a caustic bath and/or may be mechanically removed to ensure part cleanliness.

[0013] The parts are removed from the mold and the material protrusion left from the gate, called the gate witness, may be ground to print specification using a fixture for repeatability and efficiency.

[0014] Parts may be cleaned and receive their final surface finish by either blasting with steel shot or abrasive grit. Surface finish ranges generally from 90-150 Ra.

[0015] In a modern investment casting the making of patterns is often the work of automatic injection presses where a pattern material as liquid or paste is injected into a die. The injected pattern material may be held, cooled and ejected from the die and may fall into a water bath to cool completely. To keep the wax from sticking in the die cavity, a mold release agent is typically sprayed onto the die.

[0016] The most common mold release agents is silicone, polydimethylsiloxane, either as a water emulsion or as 100% silicone oil. The use of such materials as mold releases greatly degrades the quality of the resulting patterns due to open knit lines and flow lines. The silicone prevents the wax pattern material from fusing together during the injection process resulting in open knit lines that reproduce during investing and pouring of metal. Closed knit lines that are greatly weakened by the presence of silicone mold release may be caused to open during the injection, assembly, and/or dipping process resulting in open knit lines that can be reproduced in the finish product.

[0017] The process is exacerbated due to the complex patterns that need to be formed. Because of the power of producing near net shape parts that require little if any machining, the parts requirements can be complex. Some dies may have multiple sliding cores, hidden passages, and/or deep slots demanding the wax pattern material conform to these intricate shapes and then cleanly remove from the die. Due to some of these die geometries, there are areas of some dies that can not be sprayed (or at least sprayed well) with mold release. The tendency is to over spray to
achieve good release and the over abundance of spray within the die is a problem resulting in open knit lines.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] FIG. 1 is a flow chart of a method for investment casting according to one embodiment; and

[0019] FIG. 2 is an illustrative diagram of an open knit line.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0020] A pattern material for use in investment casting may possess the ability to be released from a mold without the, or with a reduced need for, application/spraying of release agents on a die used to form a pattern from the pattern material (i.e. the pattern material may have internal mold releasability). The mold release agents which are sprayed on/applied to the die shall be referred to herein as external mold release agents (i.e. external to/separate from the pattern material).

[0021] In some embodiments, a pattern material includes an additive that contributes to the internal mold releasability of the pattern material and eliminates or reduces the need for spraying of mold release agents during the formation of the pattern. Exemplary additives of this type may include fluorochemicals, such as perfluorinated oils (e.g. perfluoropolyether) with and without functional groups and other fluorinated compounds. Some fluorochemicals available for use include Fluoroguard® polymer additive available from Dupont, Novec™ fluorosurfactants available from 3M (previously Fluorocraft fluorosurfactants), and Zonyl® fluorosurfactants from DuPont. According to some exemplary embodiments, the pattern material may include at least about 0.1 wt. % of the mold release additive. In other embodiments, the pattern material include at least about 0.2 wt % or about 0.3 wt. % of the mold release additive. According to some exemplary embodiments, the pattern material includes no more than about 1 wt. % of the mold release additive. In other embodiments, the pattern material may include no more than about 0.8 wt. % or up to about 0.6 wt. % of the mold release additive. In some embodiments, the pattern material comprises less than 5 wt. % of this additive. Alternatively (or additionally), a pattern material may be selected which inherently has a reduced need for spraying of mold release materials.

[0022] For pattern materials using internal mold release additives, the ability to eliminate or reduce the need for spraying may be determined by comparing the performance of the pattern material without the additive to the performance of the pattern material with the additive. A determination can be made as to how many consecutive quality patterns can be formed with each formulation. A quality pattern is any pattern which resembles the final part closely enough that it will not result in a rejected part when reproduced. In some embodiments, the pattern material formulation with the additive may be used to form at least twice as many consecutive quality parts as the pattern material formulation without the additive. In other embodiments, the pattern material formulation with the additive may be used to form at least ten times as many consecutive quality parts. In some of these embodiments, the pattern material formulation with the additive will be able to form a substantially unlimited number of consecutive quality parts, while the pattern material formulation without the additive will not be able to form a substantially unlimited number of consecutive quality parts.

[0023] According to many embodiments, the pattern material with the additive may be configured such that is has sufficient mold releasability that it is capable of demonstrating one or more of these properties in a die for a typical part used for investment casting. According to some embodiments, the pattern material with the additive may be configured such that is has sufficient mold releasability that it is capable of demonstrating one or more of these properties in a die for a complicated part (e.g. a part having at least three pins around which the pattern material must flow). According to some embodiments, the pattern material with the additive may be configured such that is has sufficient mold releasability that it is capable of demonstrating one or more of these properties in a die for a part having a deep draw (e.g. a wall ¼ inch across, 1.5 inches deep, and about 90 degrees to the parting line). According to still other embodiments, the pattern material with the additive may be configured such that is has sufficient mold releasability that it is capable of demonstrating one or more of these properties in a die for a part meeting a combination of two or more of these parameters. It should be noted that a pattern material may be used in a die meeting some or none of the above-mentioned parameters, but still be configured such that it is capable of demonstrating one or more of these properties in a die according to one or more of the above mentioned parameters.

[0024] Some exemplary pattern materials with internal mold releasability may allow a single die to be used for a large number of shots without requiring a mold release agent to be sprayed or otherwise applied to the die. According to some embodiments, the pattern material may be used at least 40 times without application of external mold release agents. In some embodiments, the pattern material may be used at least about 100 times without application of external mold release agents. In still other embodiments, the pattern material may be used at least about 500 times without application of external mold release agents. In an advantageous embodiment, the pattern material may be used a substantially unlimited number of times without application of external mold release agents.

[0025] According to many embodiments, the pattern material may be configured such that is has sufficient mold releasability that it is capable of being used in the above-listed number of consecutive shots without the application of external mold release in a die for a typical part used for investment casting. According to some embodiments, the pattern material may be configured such that is has sufficient mold releasability that it is capable of being used in the above-listed number of consecutive shots without the application of external mold release in a die for a complicated part (e.g. a part having at least three pins around which the pattern material must flow). According to some embodiments, the pattern material may be configured such that is has sufficient mold releasability that it is capable of being used in the above-listed number of consecutive shots without the application of external mold release in a die for a part having a deep draw (e.g. a wall ¼ inch across, 1.5 inches deep, and about 90 degrees to the parting line). According to some embodiments, the pattern material may be configured...
such that it has sufficient mold releasability that it is capable of being used in the above-listed number of consecutive shots without the application of external mold release in a die for a part meeting a combination of two or more of these parameters. It should be noted that a pattern material may be used in a die meeting some or none of the above-mentioned parameters, but still be configured such that it is capable of producing the above-mentioned number(s) of consecutive shots in a die according to one or more of the above-mentioned parameters.

According to embodiments, the pattern material may be selected to have a melting point of at least about 110°F. According to some embodiments, the pattern material is selected to have a melting point of at least about 120°F or at least about 130°F. According to some embodiments, the pattern material is selected to have a melting point of up to about 170°F. According to some embodiments, the pattern material is selected to have a congeal point of about 140°F. According to some embodiments, the pattern material has a modulus of rupture of up to about 20 pounds or up to about 16 pounds.

According to some embodiments, the pattern material may be selected to have a melting point of at least about 110°F. According to some embodiments, the pattern material is selected to have a congeal point of at least about 120°F or at least about 130°F. According to some embodiments, the pattern material is selected to have a congeal point of up to about 170°F. According to some embodiments, the pattern material is selected to have a congeal point of up to about 160°F. In one embodiment, the pattern material has a congeal point of about 138°F to about 146°F.

According to some embodiments, the pattern material may be selected to have a ring and ball softening point of at least about 110°F. According to some embodiments, the pattern material is selected to have a ring and ball softening point of at least about 120°F or at least about 130°F. According to some embodiments, the pattern material is selected to have a ring and ball softening point of up to about 170°F. In one embodiment, the pattern material has a ring and ball softening point of about 138°F to about 146°F.

According to some embodiments, the pattern material has a hardness such that it has a penetration (with a 450 gram load and ASTM D5 needle), of at least about 10 DMM (tenths of a millimeter). In some embodiments, the pattern material has a hardness such that it has a penetration (with a 450 gram load), of up to about 20 DMM. In some embodiments, the pattern material comprises a penetration of 11 DMM to 19 DMM.

According to some embodiments, the pattern material has a deflection of no more than about 0.5 inches. In other embodiments, the pattern material has a deflection of up to about 0.1 inches or up to about 0.08 inches. In some embodiments, the pattern material has a deflection of at least about 0.01 inches. According to some embodiments, the pattern material has a deflection of at least about 0.05 inches. Deflection can be measured by suspending a wax bar that is 0.25 inch thick by 1.5 inches wide 5.75 long and suspended 5 inches. The wax bar is weighted on the end with a 40 gram weight. The deflection is the amount bar has moved in a set amount of time say 4 hours.

According to some embodiments, the pattern material has a modulus of rupture of at least about 5 pounds. According to some embodiments, the pattern material has a modulus of rupture of at least about 10 pounds or at least about 14 pounds. According to some embodiments, the pattern material has a modulus of rupture of up to about 25 pounds. According to some embodiments, the pattern material has a modulus of rupture of up to about 20 pounds or up to about 16 pounds.
[0036] According to some embodiments, the pattern material has a brittleness of about 5 to 20 inches. According to some embodiments, the pattern material has a brittleness of no less than about 10 inches. According to some embodiments, the pattern material has a brittleness of no more than about 15 inches.

[0037] In common embodiments, the pattern material is a wax-based material. The wax-based material may comprise one or more mineral waxes, natural waxes, and/or other waxes. The pattern material according to these embodiments may comprise about 1 wt. % to about 99 wt. % wax. In some embodiments, the pattern material comprises at least about 15 wt. % wax or at least about 30 wt. % wax. In some embodiments, the pattern material comprises no more than about 50 wt. % or no more than about 40 wt. % wax. In one embodiment, the pattern material comprises about 25 wt. % wax.

[0038] Some examples of mineral waxes include mineral waxes such as montan wax, petrolatum, paraffin wax, ozokerite, and cerasin waxes. Petroleum wax is a commonly used mineral wax. Petroleum wax can be a by-product of the petroleum refining process. The quality and quantity of the wax obtained from the refining process is dependent upon the source of the crude oil and the extent of the refining. The petroleum wax component of the wax composition may include, for example, a paraffin wax, including medium paraffin wax, microcrystalline paraffin wax or a combination thereof. However, petroleum wax obtained from crude oil refined to other degrees may also be used.

[0039] Although the exact chemical compositions of these waxes are not known as the nature of these by-products vary from one distillation process to the next, these waxes tend to be composed of various types of hydrocarbons. For example, medium paraffin wax is generally composed primarily of straight chain hydrocarbons having carbon chain lengths ranging from about 20 to about 40, with the remainder typically comprising isomeric and cyclo-alkanes. The melting point of medium paraffin wax is typically about 65°C. Microcrystalline paraffin wax is generally composed of branched and cyclic hydrocarbons having carbon chain lengths of about 30 to about 100 and the melting point of the wax is typically about 75°C to about 85°C. Further descriptions of the petroleum wax that may be used may be found in Kirk-Othmer, Encyclopedia of Chemical Technology, 3rd Edition, Volume 24, pages 473-76, which is hereby incorporated by reference.

[0040] Natural waxes and synthetic waxes may also be used to form the wax-based pattern material. For instance, many creatures (such as insects and animals) and plants form wax substances that are generally solid at room temperature. Some example of the various types of creature waxes are beams wax, lanolin, shellac wax, Chinese insect wax, and spermatica. Some of the examples of the various types of plant waxes are camden, candelilla, japan wax, ouricury wax, rice bran wax, jojoba wax, castor wax, bayberry wax, sugar cane wax, and maize wax. Additionally, synthetic waxes may be used. For instance, waxes such as polyethylene wax, Fischer-Tropsch wax, chlorinated naphthalene wax, chemically modified wax, substituted amide wax, alpha olefins and polymerized alpha olefin wax may be used. Waxes may also include waxes formed from chemically modified fatty acid esters, such as dehydrogenated palm oil and/or soybean oil. The wax may also comprise free fatty acids.

[0041] In some exemplary pattern materials, particular wax-based pattern materials, the pattern material comprise fillers. Fillers may be particles and may be used to control an amount of shrinkage of the pattern material. Exemplary fillers that may be used include acidic fillers (e.g. Terephthalic acid), acrylic fillers, polystyrene (e.g. cross-linked polystyrene), water, and bisphenol-A. In some embodiments, the pattern material may comprise at least about 10 wt. % filler. In other embodiments, the pattern material may comprise at least about 15 wt. % or at least about 20 wt. % filler. In some embodiments, the pattern material may comprise no more than about 50 wt. % or about 30 wt. % filler. In some embodiments, fillers may be used to reduce linear or volumetric contraction, increase viscosity, and/or control dimensions.

[0042] In some exemplary pattern materials, particularly wax-based pattern materials, the pattern material may comprise resin. Exemplary resins that may be used include ethylene vinyl acetate, hydrocarbon resins (e.g. C5 or C9 hydrocarbon resins), terpene resins, coal tar derived resins, and rosins. In some embodiments, the pattern material may comprise at least about 10 wt. % resins. In other embodiments, the pattern material may comprise at least about 20 wt. % or at least about 30 wt. % resins. In some embodiments, the pattern material may comprise no more than about 60 wt. % resins. In other embodiments, the pattern material may comprise no more than about 50 wt. % or up to about 40 wt. % resins. In some embodiments, resins may be used to reduce shrinkage and/or impart strength, rigidity, and/or hardness to a pattern formed by the pattern material.

[0043] In some exemplary pattern materials, the pattern material may include a dye or a pigment, which may be used to help identify one formulation of wax from a different formulation of wax.

[0044] A suitable wax-based material for use in investment casting may be purchased from Angueso under the trade name Cerita Pattern Waxes. Other suitable waxes may be obtained from Westech Products, J.F. McCaughlin, Blayson Olefines, and Blended Waxes, Inc.

[0045] Referring to FIG. 1, a method for performing investment casting includes forming the pattern material at block 10. The pattern material may be configured as described above. In some embodiments, the pattern material is wax-based. As discussed above, the wax-based pattern material may include an additive, such as a fluoroochemical, to give the pattern material better internal mold release. In the case of a wax-based pattern material comprising a fluoroochemical additive, the additive can be added directly to the wax at time of blending the melt or high shear mixed into the final melted pattern wax with aid of a high shear mixer. This can produce a pattern wax with very few droplets of the fluoroochemical dispersed in a pattern wax.

[0046] Once the pattern material is formed, the pattern itself may be formed at block 20. This may comprise injecting pattern material in a fluid state (e.g. liquid or paste) into a die (e.g. using an injection press), allowing the pattern material to enter a solid state, ejecting the solid pattern from
the die, and/or further cooling the pattern (e.g. using a water bath). U.S. Pat. No. 4,971,547 describes one exemplary method and system for forming a pattern from a pattern material, the disclosure of which is hereby incorporated by reference.

In some embodiments, the pattern material injection pressure may be about 240 to about 590 psi. In some embodiments, the pattern material injection pressure may be less than about 510 psi. In other embodiments, the pattern material injection pressure may be less than 300 psi.

In embodiments where an additive is used to increase the internal mold releasability of the pattern material, the pattern material with the additive may require less injection pressure than the same composition excluding the additive. In some embodiments, the pattern material with the additive requires a pattern material injection pressure that is less than 90% of the pattern material injection pressure required for the same pattern material composition without the additive. In some embodiments, the pattern material with the additive requires less than about 85%, or less than about 80% of a pattern material injection pressure than without the additive.

In embodiments where an additive is used to increase the internal mold releasability of the pattern material, an additive may be selected which tends to migrate to the surface of the pattern. In other words, the additive would tend to have a higher concentration on the surfaces of the pattern than in the center of the pattern.

Each pattern may include one or more gates, potentially located at the heaviest (thickest) portion of the pattern. Gates may be wax projections which may be used to attach the pattern to a sprue. A sprue is a connector (generally comprising a non-filled pattern material) used to fasten patterns together to form a mold. Sprues may vary in size and shape and may accommodate as few as one pattern. In some embodiments, a sprue is connected to at least about 30 patterns or at least about 100 patterns (and potentially several hundred). A pouring cup may be secured to the central sprue of the mold.

According to some embodiments, a pattern has a weight of about 3 to about 15 grams. According to some embodiments, the pattern has a weight of about 10 to about 40 grams. According to some embodiments, the pattern has a weight of about 35 to about 100 grams. According to some embodiments, the pattern has a weight of about 100 grams to 1000 grams. According to some embodiments, the pattern has a weight of more than 1000 grams. Some patterns may even weigh over 30,000 grams.

Once the pattern is formed, a shell is formed at block 30. The pattern may be dipped in or otherwise coated with one or more ceramic slurries. While it is advantageous to pick a pattern material with good mold releasability, it is also important to pick a pattern material which has sufficient adhesion with the shell forming material so that the shape of the pattern will be accurately reproduced. Excess slurry may be drained off and the cluster may be coated with a fine ceramic sand and dried. The coating process may be repeated, and may use progressively coarser grades of ceramic material. The shell may have a thickness of at least about 0.25 inches. In some embodiments, the shell has a thickness of about 0.2 inches to about 0.5 inches.

An exemplary process for forming a shell may include dipping a mold in a slurry consisting of either zircon or silica powder with colloidal silica as binder, styrene butadiene polymer, wetting aids, and biocide, followed by a sand such as zircon or fused silica. The shell is dried. This may be followed by a slurry consisting of fused silica, colloidal silica, polymer wetting aids, and biocide, followed by a sand such as fused silica. The shell is then dried and the process may be repeated until a desired shell thickness is achieved. This process allows for good adhesion of the prime layers to the exemplary patterns disclosed below. According to some exemplary embodiments, adhesion of the prime layer to the pattern material with the internal mold release additive is equal to or greater than the same pattern materials without an internal mold release additive which have been made using a silicon spray external mold release agent.

Once the shell is formed, the pattern material may be removed at block 40. The coated pattern may be placed in a furnace, steam autoclave, or other system where the pattern material, including any additives, melts and flows out of the mold through the pouring cup. The result should be a shell corresponding to the shape of the pattern. The shell may then be fired to burn out the last traces of pattern material and to preheat the mold in preparation for casting. The pattern material is generally configured to have little expansion when it is melted. This is generally done so that melting of the pattern does not cause cracking or other defects in the shell formed around the pattern. The pattern material is also generally configured to have a low viscosity at the conditions (temperature, etc.) at which the pattern material is removed from the shell.

Once the pattern material is removed from the shell, the shell is heated, and the finished item is cast at block 50. Molten metal is poured into the shell. When the metal is cooled, the shell may be removed (e.g. mechanically or by high pressure water jets).

The formed product may then be finished at block 60. Finishing may include treating the metal to impart desired properties, machining the product, painting the product, plating the product, and/or performing some other steps to finalize the product.

When the pattern material is removed at block 40, it may be recovered at block 70 for reuse in the investment casting process. Recovering may include removing (e.g. boiling off) any water that may be included in the pattern material. If water is removed and an additive is used to impart the internal mold releasability, the additive may be selected to have a higher boiling point than water and/or is otherwise selected to not be lost in significant amounts during the water removal process. Recovering may also include filtering, decanting, and/or performing some other process on the pattern material to remove particulate matter from the recovered pattern material.

The recovered pattern material may have components refreshed at block 80. This may be needed, for instance, if the filtering process would remove a filler or resin from the pattern material, and/or if significant amounts of a mold release additive is lost during the recovery process (such as during water removal).

Referring to FIG. 2, a ring-shaped pattern may be formed from pattern material by an exemplary molding
system 100. Pattern material flows from a source 102, through an injection runner 104 into a die cavity 120. Pattern material enters cavity 120 by way of casting gate 112. The pattern material is then split around pin 110 and flows left 106 and right 108 through cavity 120. In this embodiment, left 106 and right 108 flows reunite at junction 113 on the other side of pin 110 from gate 112. If something prevents left 106 and right 108 flows from joining properly, a knit line may be created in the pattern formed from the mold. If the knit line is capable of being reproduced in later steps of the investment casting process, the knit line may be referred to as an open knit line. Such open knit lines create visual defects and may be a source for structural weakness as well.

[0060] According to many exemplary pattern materials described herein, the pattern material may be configured to avoid the formation of open knit lines. According to some embodiments, the pattern material may be used to form at least about 100 patterns without open knit lines. According to some embodiments, the pattern material may be used to form at least about 1000 patterns without open knit lines.

[0061] According to many embodiments, the pattern material may be configured such that it is capable of avoiding lines as discussed in the previous paragraph in a die for a typical part used for investment casting. According to some embodiments, the pattern material may be configured such that it is capable of avoiding lines as discussed in the previous paragraph in a die for a complicated part (e.g., a part having at least three pins around which the pattern material must flow). According to some embodiments, the pattern material may be configured such that it is capable of avoiding lines as discussed in the previous paragraph in a die for a part having a deep draw (e.g., a wall 1/2 inch across, 1.5 inches deep, and about 90 degrees to the parting line). According to some embodiments, the pattern material may be configured such that it is capable of avoiding lines as discussed in the previous paragraph in a die for a part meeting a combination of two or more of these parameters. It should be noted that a pattern material may be used in a die meeting some or none of the above-mentioned parameters, but still be configured such that it is capable of demonstrating one or more of these properties in a die according to one or more of the above mentioned parameters.

[0064] In some embodiments, the pattern material may be used such that substantially no flow or knit lines are present in the resulting series of patterns. Substantially no flow lines or knit lines can be determined by comparison to a pattern wax configured as follows:

<table>
<thead>
<tr>
<th>Component</th>
<th>Percent Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bis-phenol A</td>
<td>10-20</td>
</tr>
<tr>
<td>Terephthalic acid</td>
<td>3-7</td>
</tr>
<tr>
<td>Cross-linked polystyrene</td>
<td>10-30</td>
</tr>
<tr>
<td>Paraffin wax</td>
<td>15-25</td>
</tr>
<tr>
<td>Microcrystalline Wax</td>
<td>5-10</td>
</tr>
<tr>
<td>Natural Wax (Candelilla)</td>
<td>1-5</td>
</tr>
<tr>
<td>Polyolefin/polyethylene</td>
<td>0.5-1.5</td>
</tr>
<tr>
<td>Carboxylic acid/Stearic Acid</td>
<td>1-5</td>
</tr>
<tr>
<td>Modified oxidized hydrocarbon 637501-75-2</td>
<td>1-5</td>
</tr>
<tr>
<td>Hydrocarbon Resin 69430-35-9</td>
<td>10-20</td>
</tr>
<tr>
<td>Hydrocarbon Resin 62255-49-5</td>
<td>15-30</td>
</tr>
<tr>
<td>Hydrocarbon Resin 69430-39-9</td>
<td>5-10</td>
</tr>
<tr>
<td>Resin Ethylene Vinyl Acetate</td>
<td>0.5</td>
</tr>
</tbody>
</table>

[0065] Substantially no flow lines or knit lines exist when the total number of flow lines or knit lines is less than or equal to half the number of flow lines formed by a same pattern using the above-listed pattern wax.

[0066] Determining whether flow lines or knit exist is limited to dies which are susceptible to flow lines and knit lines. In many exemplary embodiments, the die used to form the pattern comprises at least one pin around which the pattern material must flow. In some exemplary embodiments, the die used to form the pattern is used to form a complicated part (e.g., a part having three pins around which the pattern material must flow).

[0067] The following examples are presented to illustrate some embodiments and to assist one of ordinary skill in making and using the same. The examples are not intended in any way to otherwise limit the scope of the invention claimed in the claims.

EXAMPLE 1

[0068] 12.4 gram (0.35%) of Fluoroguard™ PCA (DuPont) was added to 3555 grams of molten pattern wax (Cerita™ F2010 from Argusco) at 185 deg F. This was mixed well for 10 minutes with a high speed mixer. It was cooled to 165 deg F, poured into a water jacketed shot chamber and conditioned 16 hours at 118 Deg F.

[0069] This composition was placed into an injection press and injected into an aluminum die to make solid and hollow cylinders. Over thirty-six consecutive injections were conducted with no external mold release being added (e.g.
sprayed). The 4-inch sliding core operated well with no sticking and no deformation of the part. An excellent pattern resulted with no open knit or flow lines.

EXAMPLE 2

A control wax as described above in Example 1 with no Fluoroguard additive was handled as discussed above in example 1. The control wax stuck in the die by fourth injection. The sliding core could not be retracted without deformation of part.

EXAMPLE 3

The same as example 2, except that silicone was sprayed on the aluminum die prior to injection every other pattern. Open knit lines resulted in patterns after spraying the silicone.

EXAMPLE 4

Handled in the same manner as Example 1 except added 17.5 grams (0.5%) of Fluoroguard™ PRO (DuPont) to 3500 grams of molten pattern wax (Cerita™ F2010 from Argueso). An excellent pattern resulted with over eighteen consecutive patterns produced with no sticking.

EXAMPLE 5

Same as Example 1 except added 16.7 grams (0.5%) of Fluoroguard™ FSM (Dupont) to 3340 grams of molten pattern wax (Cerita™ F2010 from Argueso). An excellent pattern resulted with over twenty-four patterns with no core sticking and absence of open knit lines.

EXAMPLE 6

An exemplary wax-based pattern material may be formed by high shear mixing 0.1 to 1 wt. % Fluoroguard™ PCA with 99.0 to 99.9 wt. % wax-base pattern wax having the following composition:

<table>
<thead>
<tr>
<th>Component</th>
<th>Percent Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bis-phenol A</td>
<td>10-20</td>
</tr>
<tr>
<td>Terephthalic acid</td>
<td>3-7</td>
</tr>
<tr>
<td>Cross-linked polystyrene</td>
<td>10-30</td>
</tr>
<tr>
<td>Paraffin wax</td>
<td>15-25</td>
</tr>
<tr>
<td>Microcrystalline Wax</td>
<td>5-10</td>
</tr>
<tr>
<td>Natural Wax(Candelilla)</td>
<td>1-5</td>
</tr>
<tr>
<td>Polyurethane</td>
<td>0.5-1.5</td>
</tr>
<tr>
<td>Carboxylic acid(Succinic Acid)</td>
<td>1-5</td>
</tr>
<tr>
<td>Modified oxidized hydrocarbon 637891-75-2</td>
<td>1-5</td>
</tr>
<tr>
<td>Hydrocarbon Resin 69430-35-9</td>
<td>10-20</td>
</tr>
<tr>
<td>Hydrocarbon Resin 62258-49-5</td>
<td>15-30</td>
</tr>
<tr>
<td>Hydrocarbon Resin 69430-35-9</td>
<td>5-10</td>
</tr>
<tr>
<td>Resin Ethylene Vinyl Acetate</td>
<td>&lt;0.5</td>
</tr>
</tbody>
</table>

EXAMPLE 7

Similar to Example 1, except 0.3 wt. % Fluorad™ FC4430 (3M) (now Novect™ FC-4432) was added instead of Fluoroguard™ PCA. The solid and hollow cylinders could be injected 5 times before core sticking and pattern distortion began to occur.

EXAMPLE 8

Similar to Example 6, except 0.5 wt. % of Zonyl® PF500 (DuPont) was added instead of Fluoroguard™ PCA. The solid and hollow cylinders could be injected up to 8 times before core sticking and pattern distortion began to occur.

EXAMPLE 9

Similar to Example 6, except that 0.4 wt. % Fluorad™ FC4432 (3M) (now Novect™ FC-4432) was added instead of Fluoroguard™ PCA. The solid and hollow cylinders could be injected up to 8 times before core sticking and pattern distortion began to occur.

EXAMPLE 10

Similar to Example 1, except that 0.6 wt. % Fluoroguard™ PRO (DuPont) was added instead of Fluoroguard™ PCA. The wax was melted and conditioned with a heat exchanger, similar to that described in U.S. Pat. No. 4,971,547, prior to being injected into dies by an automatic press. High quality patterns resulted showing no open knit lines nor open flow lines. Forty-six different dies were tested using this pattern material. Of these, six dies continued to require spraying of a silicone mold release agent, but were able to form 3 to 5 times as many patterns between spraying. Many of the tested dies were used to form multiple hundreds of consecutive quality parts without the need for an external mold release agent.

What is claimed is:

1. A wax-based pattern material for use in investment casting, comprising:
   a wax; and
   a fluorochemical;
   wherein the pattern material is suitable for use in investment casting.

2. The pattern material of claim 1, further comprising a filler.

3. The pattern material of claim 2, wherein the filler comprises at least two different types of filler.

4. The pattern material of claim 1, further comprising a resin.

5. The pattern material of claim 4, further comprising a filler.

6. The pattern material of claim 1, further comprising an ash content of less than about 0.02%.

7. The pattern material of claim 1, further comprising a shrinkage of no more than about 0.01 inch per inch.

8. A wax-based pattern material for use in investment casting, comprising:
   about 15 wt. % to about 50 wt. % wax;
   about 10 wt. % to about 60 wt. % resins; and
   a fluorochemical, fluorochemicals comprising less than about 5 wt. %.

9. The pattern material of claim 8, further comprising an ash content of less than about 0.02%.

10. The pattern material of claim 8, further comprising about 10 wt. % to about 50 wt. % filler.

11. The pattern material of claim 8, comprising about 20 wt. % to about 50 wt. % resins.

12. The pattern material of claim 8, comprising less than about 1 wt. % fluorochemicals.
13. A composition for use in investment casting, comprising:
   a pattern material, the pattern material comprising internal mold releasability; and
   wherein the composition is suitable for use in investment casting.
14. The composition of claim 13, wherein the pattern material comprises a wax, an additive that contributes to the internal mold releasability, and a resin.
15. The composition of claim 13, wherein the pattern material is configured to have sufficient internal mold releasability such that a die can use the pattern material at least about 20 times without requiring application of an external mold release agent.
16. The composition of claim 15, wherein the pattern material is configured to have sufficient internal mold releasability such that a die comprising a deep draw can use the pattern material at least about 20 times without requiring application of an external mold release agent.
17. The composition of claim 15, wherein the pattern material comprises sufficient adhesion to a ceramic slurry to form a shell.
18. The composition of claim 13, wherein the pattern material comprises an additive that contributes to the internal mold releasability, the additive selected such that the additive has a higher concentration on surfaces of a pattern molded using the composition than in an interior of the pattern.
19. The composition of claim 13, further comprising a fluorochemical which contributes to the internal mold releasability of the pattern material.
20. The composition of claim 13, wherein the pattern material comprises a shrinkage of no more than about 0.01 inch per inch.
21. The composition of claim 13, further comprising an ash content of less than about 0.02%.
22. The composition of claim 13, wherein the composition is solid at room temperature.
23. The composition of claim 13, wherein the composition comprises an additive that contributes to the internal mold releasability of the pattern material, wherein the additive contributes to the internal mold releasability of the pattern material such that the pattern material with the additive may be used to make at least about three times as many consecutive quality parts as the same pattern material without the additive.
24. A method of investment casting, comprising:
   forming a pattern using a pattern material, the pattern material comprising internal mold releasability;
   forming a shell using the pattern;
   removing the pattern material from the shell; and
   casting a product using the shell.
25. The method of claim 24, wherein the pattern material comprises a wax and a resin.
26. The method of claim 24, wherein the pattern material comprises a fluorochemical.
27. The method of claim 24, further comprising recovering the pattern material removed from the shell.
28. The method of claim 24, wherein the pattern material is solid at room temperature.
29. The method of claim 24, wherein forming a pattern using a pattern material does not comprise applying an external mold release agent to a die used to form the pattern.
30. The method of claim 24, wherein the pattern material is configured to have sufficient internal mold releasability such that a die can use the pattern material at least about 40 times without requiring application of an external mold release agent.
31. A method of investment casting, comprising:
   forming a pattern using a pattern material, forming a pattern using a pattern material not comprising applying an external mold release agent to a die used to form the pattern more than once every 100 shots;
   forming a shell using the pattern;
   removing the pattern material from the shell; and
   casting a product using the shell.
32. The method of claim 31, wherein the pattern material comprises a wax and a resin.
33. The method of claim 32, wherein the pattern material further comprises a filler.
34. The method of claim 32, wherein the pattern material comprises a fluorochemical.
35. The method of claim 31, further comprising recovering the pattern material removed from the shell.
36. The method of claim 31, wherein the pattern material is solid at room temperature.
37. The method of claim 31, wherein forming a pattern using a pattern material does not comprise applying an external mold release agent to a die used to form the pattern.
38. A method of investment casting, comprising:
   forming a pattern using a pattern material,
   forming a shell using the pattern;
   removing the pattern material from the shell; and
   casting a product using the shell;
   wherein substantially no flow or open knit lines are formed in the pattern.
39. The method of claim 38, wherein a die is used to form the pattern and the die comprises at least one pin around which the pattern material must flow.
40. The method of claim 38, wherein the product cast using the shell comprises a complicated part.
41. The method of claim 38, wherein forming a pattern using a pattern material not comprising applying an external mold release agent to a die used to form the pattern more than once every 100 shots.
42. The method of claim 38, wherein the pattern material comprises internal mold releasability.
43. The method of claim 38, wherein the pattern material comprises a wax and a resin.
44. The method of claim 38, wherein the pattern material comprises a fluorochemical.
45. The method of claim 38, wherein the pattern material comprises an additive that contributes to internal mold releasability of the pattern material, the additive selected such that the additive has a higher concentration on surfaces of a pattern molded using the composition than in an interior of the pattern.