The disclosure comprises a shell and a cavity formed by the shell. The shell comprises a plurality of layers additively formed using a shell material. The cavity is filled with a filler material. The shell comprises a parting surface, where the parting surface includes a molding structure in conformation with a surface of the apparatus.

Title: 3D PRINTED INJECTION MOLDS WITH HEAT TRANSFER FILLER MATERIALS

Abstract: At least some aspects of the present disclosure direct to an injection mold used for manufacturing an apparatus. The injection mold comprises a shell and a cavity formed by the shell. The shell comprises a plurality of layers additively formed using a shell material. The cavity is filled with a filler material. The shell comprises a parting surface, where the parting surface includes a molding structure in conformation with a surface of the apparatus.
3D PRINTED INJECTION MOLDS WITH HEAT TRANSFER FILLER MATERIALS

Technical Field

[0001] The present disclosure relates to 3D printed injection molds, cooling and temperature management structures, systems and methods making the molds, and other relevant components.

Summary

[0002] At least some aspects of the present disclosure direct to an injection mold used for manufacturing an apparatus. The injection mold comprises a shell and a cavity formed by the shell. The shell comprises a plurality of layers additively formed using a shell material. The cavity is filled with a filler material. The shell comprises a parting surface, where the parting surface includes a molding structure in conformation with a surface of the apparatus. The shell material has a thermal conductivity lower than a thermal conductivity of the filler material.

[0003] At least some aspects of the present disclosure direct to a method of forming an injection mold used for manufacturing an apparatus. The method includes the steps of: receiving, by a manufacturing device having one or more processors, a digital object comprising data specifying a plurality of layers to form a shell of the injection mold, the shell having a parting surface and forming a cavity; generating, with the manufacturing device by an additive manufacturing process using a shell material, the shell of the injection mold based on the digital object; pouring a filler material into the cavity of the shell, the filler comprising a filler material, wherein the filler is filled in the cavity of the shell, wherein the parting surface comprises a molding structure in conformation with a surface of the apparatus, wherein the shell material has a thermal conductivity lower than a thermal conductivity of the filler material.

Brief Description of Drawings

[0004] The accompanying drawings are incorporated in and constitute a part of this specification and, together with the description, explain the advantages and principles of the invention. In the drawings,

[0005] Figure 1A illustrates a cross-section view of one embodiment of an injection mold;

[0006] Figure 1B illustrates a perspective view of the mold illustrated in Figure 1A;

[0007] Figure 1C illustrates another example of an injection mold;
Figure 2A is a perspective view of one example of an injection mold; Figure 2B is a bottom view of the injection mold illustrated in Figure 2A; and Figure 2C is a cross-sectional view of the injection mold illustrated in Figure 2A;

Figure 2D is a cutaway view of one example of an injection mold;

Figures 3A-3H illustrate various examples of fluid flow structures;

Figure 4A-4K illustrate various examples of nozzles;

Figure 5A and 5B illustrate some examples and configurations of mating structures;

Figures 6A and 6B illustrate one example of an injection mold having a filler material;

Figure 6C illustrates an example of an injection mold having a shell forming four compartments;

Figure 7A is a cross-section view of one illustrative example of a 3D printed injection mold with filler material;

Figure 7B shows an example of the temperature field in the mold and the filler material;

Figure 7C the mold temperatures at 3 mm below the mold surface with or without filler material;

Figure 8A illustrates a cross-section schematic of one example of an injection mold;

Figure 8B is a perspective view of the injection mold from the bottom; Figure 8C is a perspective view of the injection mold illustrated in Figure 8B from the top; and Figure 8D is a section view of the injection mold illustrated in Figure 8B;

Figure 9A illustrates a flowchart of one example process of making injection molds using 3D printing technology;

Figure 9B illustrates a flowchart of another example process of making injection molds using 3D printing technology;

Figure 9C is a system diagram for one example of a 3D printing system to make or manufacture an injection mold;

Figure 10A shows the result of a numerical simulation of the air flowing out of the air slot nozzle and impinging on the top surface of the mold;

Figure 10B shows the magnitude of the air velocity leaving the air slot nozzle;

Figure 10C shows the distribution of the predicted heat transfer coefficient on the surface of the injection mold;

Figure 10D shows the results for the heat transfer distribution;

Figures 11A-1 ID are numerical modeling results showing the effectiveness of front-side cooling in reducing the thermal loading on an injection mold; and
[0028] Figure 12A and Figure 12B show the relationship between predicted and measured temperature at several locations in the example two-piece injection molds during a series of typical injection cycles.

[0029] In the drawings, like reference numerals indicate like elements. While the above-identified drawings, which may not be drawn to scale, set forth various embodiments of the present disclosure, other embodiments are also contemplated, as noted in the Detailed Description. In all cases, this disclosure describes the presently disclosed disclosure by way of representation of exemplary embodiments and not by express limitations. It should be understood that numerous other modifications and embodiments can be devised by those skilled in the art, which fall within the scope and spirit of this disclosure.

**Detailed Description**

[0030] Unless otherwise indicated, all numbers expressing feature sizes, amounts, and physical properties used in the specification and claims are to be understood as being modified in all instances by the term "about." Accordingly, unless indicated to the contrary, the numerical parameters set forth in the foregoing specification and attached claims are approximations that can vary depending upon the desired properties sought to be obtained by those skilled in the art utilizing the teachings disclosed herein. The use of numerical ranges by endpoints includes all numbers within that range (e.g. 1 to 5 includes 1, 1.5, 2, 2.75, 3, 3.80, 4, and 5) and any range within that range.

[0031] As used in this specification and the appended claims, the singular forms "a," "an," and "the" encompass embodiments having plural referents, unless the content clearly dictates otherwise. As used in this specification and the appended claims, the term "or" is generally employed in its sense including "and/or" unless the content clearly dictates otherwise.

[0032] Spatially related terms, including but not limited to, "lower," "upper," "beneath," "below," "above," and "on top," if used herein, are utilized for ease of description to describe spatial relationships of an element(s) to another. Such spatially related terms encompass different orientations of the device in use or operation in addition to the particular orientations depicted in the figures and described herein. For example, if an object depicted in the figures is turned over or flipped over, portions previously described as below or beneath other elements would then be above those other elements.

[0033] As used herein, when an element, component or layer for example is described as being "on" "connected to," "coupled to" or "in contact with" another element, component or layer, it can be directly on, directly connected to, directly coupled with, in direct contact with, or intervening elements, components or layers may be on, connected, coupled or in contact with the particular
element, component or layer, for example. When an element, component or layer for example is referred to as being "directly on," "directly connected to," "directly coupled to," or "directly in contact with" another element, there are no intervening elements, components or layers for example.

[0034] 3D printing processes, or referred to as additive manufacturing processes, can be used to improve mold design and its fabrication process. A typical development process of designing, fabricating and testing a mold for injection molding requires significant investment in time and capital. 3D printing process makes it possible to prototype molds and test them rapidly and cost effectively. It helps determine the limits of the process and optimize it. This technique has the potential to significantly improve development of injection molding processes by reducing cost and development time. Also it can be used to produce production quality articles in relative large quantities, for example, such as several hundreds of articles.

[0035] 3D printing material is often polymer-based and can be degraded by heats in the injection molding process, while conventional metal molds do not have the same degradation issues. At least some embodiments of the present disclosure describe designs and methods of heat management for injection molds, such as 3D printed molds. In one embodiment, the 3D printed injection molds are to cooling 3D printed molds with controlled airflow. Polymer-based 3D printed materials often have low thermal conductivity, which makes managing heat flow in the molds challenging. At least some embodiments of the present disclosure describe an integrated systems to distribute and manage fluid flow over the hot surfaces of the molds. Fluids refer to materials in liquid or gas states. Accumulation of heat in 3D printed molds leads to degradation of the mold itself and the quality of the produced articles. In some embodiments, fluid flow structures are included in the injection molds in the additive manufacturing process. The fluid flow structures may be designed to allow efficient heat transfer. In some cases, the fluid flow structures may include a lattice structure on the supporting part of a mold. In some cases, the fluid flow structures may have one or more opening above the molding structure of a mold to allow fluid flowing on the surface. A molding structure refers to a part of the mold having conformation surface with the article to be made.

[0036] At least some embodiments of the present disclosure describe apparatus and methods of a 3D printed molds with molding materials having relative high thermal conductivities with a heat transfer structure having filler materials having relative low thermal conductivities. A polymer-based 3D printed material has low thermal conductivity typically in the range of 0.1 to 0.3 W/m-K, which may hinder heat flow out of the mold. In some embodiments, an injection mold with 3D printed shell structure having a cavity and a filler material in the cavity using a higher thermal
conductivity material and a method of making such injection mold are described. The filler material is typically used to enhance heat flow through the mold.

[0037] At least some embodiments of the present disclosure describe a method of cooling 3D printed molds with air or other fluid by integrating fluid flow structures in the mold, controlling air or fluid speed and distribution over the molding structures, and potentially taking advantage of the air or fluid flow to cool the interior of the mold. Such integrated system involves fluid flow structures, internal structures, manifolds, and nozzles, all integrated in the mold. In some cases, 3D printing technology makes it possible to include this system in the injection molds at low cost. One of the benefits of 3D Printing or additive manufacturing is the ability to fabricate complicated structures that cannot be fabricated with more traditional subtractive processes such as CNC milling, electro-discharge machining, etc. The internal structures and fluid flow structures can be designed to distribute air or other fluid in the interior of the mold. This may serve two purposes: 1) it removes some of the heat that builds up in the interior of the mold, and 2) it brings the air from the source (normally compressed air line that is available in the molding shop) to a location to discharge it over the hot surfaces. Additionally, in some embodiments, manifolds and nozzles are designed to control the air or fluid discharge to the hot surface. In some cases, nozzles are designed to optimize the air or fluid speed and its discharge angle, which allows the desired heat transfer rate. In some cases, manifolds are designed to have uniform and/or controlled discharge of fluid from the nozzles. In some cases, manifolds are designed to have low pressure drops.

[0038] At least some embodiments of the present disclosure allow to control temperature of 3D printed molds. This feature enables the extension of the life of a 3D printed mold and the improvement of dimensional stability and quality of the part, extension of process temperature range, and achievement of faster cycle times. In addition, with this feature, it may be possible to produce hundreds of high quality articles in contrast to tens of them with one mold.

[0039] In some cases, thermal management of 3D printed molds may be a challenge. The base material normally is a polymer which has a low thermal conductivity, typically about one hundred to one thousand times less than of aluminum and steel, where these two metals are commonly used to make molds for injection molding. In this process, the resin temperature could be in the range of 300°F to 550°F. As articles are molded, heat flows from the resin into the mold. Low thermal conductivity of the molds leads to heat build-up in the mold after a few cycles. This heat build-up, manifested as higher mold structure temperatures, causes tool wear which shortens the life of the mold and its dimensional stability.

[0040] In some embodiments, injection molds are used to make thermal curable articles. In some cases, a generally constant temperature, for example, in the range of 120°C to 180°C, is needed to speed up the curing process. At least some embodiments of the present disclosure direct to
injection molds with heaters or heating structure(s), to allow faster curing process. Figure 1A illustrates a cross-section view of one embodiment of an injection mold 100 and Figure 1B illustrates a prospective view of the mold 100. The injection mold 100, formed by a plurality of layers 105 additively manufactured, includes a parting surface 110 and a supporting body 120. In some embodiments, the parting surface 110 refers to part surfaces facing each other when the mold is in use. The supporting body 120 has a plurality of fluid flow structures, including front fluid flow structures 130 and back fluid flow structures 140. The plurality of fluid flow structures 130 and 140 are configured to receive fluid and allow the fluid flow through. The parting surface 110 includes a molding structure 150 is in conformation with a surface of the apparatus to be produced.

In some embodiments, at least one of fluid flow structures 130 has an opening 133 above or on the parting surface. In some cases, at least one of fluid flow structures 130 is designed to allow fluid in gas state to blow on the parting surface, such that the mold 100 can be cooled down.

[0041] In some embodiments, the plurality of layers 105 are additively formed by a polymer material. The polymer material can be generic, epoxy aerylate photopolymers, or the like. In some cases, the polymer material has a thermal conductivity less than 50 W/mK. As used herein, thermal conductivity refers to the property of a material to conduct heat, which is Watt per meter Kelvin. The thermal conductivity can be measure using the test criteria described in ASTM C518 - Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus. In some cases, the plurality of layers are additively formed by a polymer material infused with metal particles. The metal particles may be Al, Cu, Mg, Be, silver, gold, tungsten, diamond, and the like. The plurality of layers are additively formed a polymer material infused with some particles, for example, ceramics, nitride, glass bubbles, oxides, graphene, or the like.

[0042] In some embodiments, the front fluid flow structures 130 and back fluid flow structures 140 can have various designs. The front fluid flow structures 130 are typically designed to allow air or fluid to flow through the mold structure. In some embodiments, the front fluid flow structures 130 include fluid inlets 135 to be connected with a fluid source. In some cases, one of fluid flow structures 130 comprises an engineered nozzle. In some embodiments, the engineered nozzles are designed to emit fluid in a controlled fashion. In some cases, the engineered nozzles are designed to control fluid flow directions, flow rate, and the link. In some cases, the fluid flow can be controlled by varying fluid temperatures, gas composition, and the like.

[0043] In some embodiments, as illustrated in Figure 1C, an injection mold 100C includes a first piece 160 and a second piece 170. Each of the first piece 160 and the second piece 170 can use any of the embodiments as described for the injection mold 100. In some cases, each of the first and second pieces 160 and 170 comprises a mating structure, 165 and 175 respectively, where the
surface of the mating structure is a part of the parting surface. In some embodiments, the mating structure of the first piece is mated with the mating structure of the second piece. In some embodiments, the mating structure 165 comprises a protruded portion 162 and a recessed portion 164. Similarly, in some embodiments, the mating structure 175 comprises a protruded portion 172 and a recessed portion 174. In some cases, one or more of the front fluid flow structures have an opening on the surface of the mating structure 165 and/or 175 of the first piece or the second piece. In some cases, one or more of the front fluid flow structures have an opening on the surface of protruded portions (162 and/or 172). In some cases, one or more of the front fluid flow structures have an opening the surface of the recessed portion (164 and/or 174).

[0044] There are various arrangements and configurations of the mating structures, for example, having one or more pairs of posts and hosts. In some cases, the opening on the surface of the mating structure of the first piece is closed when the mating structure of the first piece is mated with the mating structure of the second piece. In some cases, the opening in the mating structure of the first piece remains opened when the mating structure of the first piece is mated with the mating structure of the second piece.

[0045] The back fluid flow structures may have different configurations and embodiments. In the examples illustrated in Figure 2A-2D, the back fluid flow structures includes a lattice structure of fluid flow structures. Figure 2A is a perspective view of one example of an injection mold 200; Figure 2B is a bottom view of the injection mold 200; and Figure 2C is a cross-sectional view of the injection mold 200. The injection mold 200 includes back fluid flow structures 240, front fluid flow structures 130, fluid inlets 135, and a parting surface 110. The parting surface 110 includes a molding structure 150. The components having the same numbers as components in Figures 1A-1C have same configurations and options as the components in Figures 1A-1C. In some embodiments, a portion or all of the fluid flow structures 240 has a regular pattern. In the example illustrated in Figure 2A, the fluid flow structures 240 has a lattice structure. In some cases, the fluid flow structures 240 have cross-channel holes between adjacent channels, to direct fluid flow through the channels 240. Figure 2C illustrates one example of fluid flow directions in the injection mold 200. In this example, there are cross-channel holes allowing fluid flowing through channels in a direction generally perpendicular to a line of fluid inlets to a channel farthest away from the respectively fluid inlet. Additionally, there are cross-channel holes between adjacent channels along the line generally parallel to the line of fluid inlets. Figure 2D is a cutaway view of one example of an injection mold 200 illustrating cross-channel holes 245 between adjacent fluid flow structures 240. The fluid flow structures 240 has a honeycomb structure. The 3D printing technology is capable to produce such complex geometry structures with one manufacturing step.
In some embodiments, injection molds include fluid flow structures with geometries that have both mechanical structures for injection mold load bearing purposes as well as a reduction in thermal mass. These fluid flow structures may include channels, vias, and matrices of mechanical load bearing structures, such as honeycomb shapes. These structures can be of repeating or random order and may have a plurality of multidirectional channels for the purposes of liquid or gas fluid thermal transport distribution, separation, and flow. Additionally, these structures may have different density and structures in selected areas to achieve desirable thermal coupling.

The fluid injected into the fluid flow structure can be selected based on its thermal transport properties. In the case of the selected fluid being air, the air after going through the fluid flow structures can be vented to atmosphere. In the case of the selected fluid being a liquid, it can be routed to an accumulator for temperature reconditioning and recirculated back into the injection molding system. The fluid can be altered by temperature and flow rate to manipulate the temperature of the fluid flow structures, though more localized temperatures could be controlled with more sophisticated channeling that might include valves, manifolds, or gating of conduits having differing temperature and flow rates. Again, 3D printing technology makes this easier to do and at a significantly lower cost than most traditional solid metal tooling method.

Figures 3A-3H illustrate various examples of fluid flow structures. Figure 3A is a cut-away view of one example of a fluid flow structure 300A in an injection mold 310A. The fluid flow structure 300A is in a shape of a serpentine line. The fluid flow structure 300A has two openings 320A, where one is to allow fluid to enter and the other is to allow fluid to exit. Figure 3B is perspective view of a schematic illustration of a fluid flow structure 300B; and Figure 3C is a cutaway view of the fluid flow structure 300B in an injection mold 310B. The fluid flow structure 300B is in a shape of serpentine line and has two openings 320B. In the embodiment illustrated, the injection mold 310B includes a 3D printed shell 305B, which includes the fluid flow structure 300B, and a filler material 320B, which fills into the shell 305B.

Figures 3D and 3E illustrate a couple of example fluid flow structures, where a portion or all of the fluid flow structure has a randomized pattern. Figure 3D illustrates a schematic view of a fluid flow structure 300D that is part of an injection mold 310D. The fluid flow structure 300D is a random fiber-like structure, which provides fluid channels. In some embodiments, the injection mold 310D can be generated using an additive manufacturing process. Figure 3E illustrates another schematic view of a fluid flow structure 300E that is part of an injection mold 310E. The injection mold 310E may include a shell 305E. In one embodiment, the fluid flow structure 300E may include bubbles with various sizes. In some cases, the injection mold 310E can be generated using an additive manufacturing process.
[0050] Figures 3F-3H illustrate another example of a fluid flow structure 300F that is within an injection mold 310F having two pieces, 301F and 302F. In this example, the injection mold 310F has a honeycomb shape. Figure 3G is a section view of the injection mold 310F. Figure 3H is a perspective view of the injection mold piece 302F showing the fluid flow structure 300F therein. In this example, the fluid flow structure 300F has closely contouring circular channels. In some embodiments, the fluid flow structure provides conformal cooling.

[0051] Figure 4A-4K illustrate various examples of nozzles. Figure 4A illustrates one example of a nozzle 400A undulating along the length. Figure 4B illustrates a nozzle 400B twisted and spiraled. Figure 4C illustrates a nozzle 400C tapered along the length. Figure 4D illustrates a nozzle 400D that is uniform along the length. Any of the nozzles 400A, 400B, 400C, 400D may have various cross-section shapes, while in the illustrations, each of the nozzles (400A-400D) has a star shape.

[0052] Figure 4E illustrates a nozzle 400E has a cross-section in a shape of triangle. Figure 4F illustrates a nozzle 400F has a cross-section in a shape of a rectangle. Figure 4G illustrates a nozzle 400G has a cross-section in a shape of a new moon. Figure 4H illustrates a nozzle 400H has a cross-section in a shape of a circle. Figure 4I illustrates a nozzle 400I has a cross-section in a shape of an ellipse. Figure 4J illustrates a nozzle 400J has a cross-section in a shape of a polygon, for example, a pentagon. Figure 4K illustrates a nozzle 400K has a cross-section in a shape of a polygon, for example, a hexagon.

[0053] Figure 5A and 5B illustrate some examples and configurations of mating structures. Figure 5A illustrates a section view of an injection mold 500 having two pieces, 501 and 502; and Figure 5B illustrates a perspective view of the piece of injection mold 501. As illustrated, the injection mold piece 501 has a set of mating structures 510 which are paired with a set of mating structures 520 in the injection mold piece 502. The injection mold piece 501 has fluid flow structures 530 partially inside the mating structures 510. The fluid flow structures 530 have outlet ports 540 opening on the mating structures 510, which extends from the parting surface 511. In this example, the mating structures 510 are posts. In some embodiments, the injection mold piece 501 may include other mating structures, such as 512 that is protruded from a general plane of the injection mold piece 501 and 514 that is recessed from a general plane of the injection mold piece 501.

[0054] In some embodiments, injection molds can have a cavity which contains relative high thermal conductivity filler materials in the cavity to transfer heat. Figures 6A and 6B illustrate one example of an injection mold 600 having a filler material. The injection mold 600 includes a shell 610 and a cavity 620. In some cases, the shell 610 can be 3D printed using a shell material. The shell 610 has a parting surface 612. The parting surface 612 includes a molding structure 630
conformed to the surface of the article to be made by the injection mold 600. In this embodiment, the cavity 620 is filled with the filler material 640. In some cases, the shell material has a thermal conductivity lower than the thermal conductivity of the filler material 640. In some cases, the shell material is selected such that the thermal conductivity of the shell material is a function of the thermal conductivity of the filler material. In some cases, the filler material is selected such that the thermal conductivity of the filler material is a function of the thermal conductivity of the shell material. In some cases, the thermal conductivity of the filler material is at least ten (10) times the thermal conductivity of the shell material. In some cases, the thermal conductivity of the filler material is at least five (5) times the thermal conductivity of the shell material.

[0055] In some cases, the shell material can be a polymer material, for example, such as generic, epoxy aerylte photopolymers, or the like. In some cases, the polymer material has a thermal conductivity less than 50 W/mK. In some cases, the plurality of layers are additively formed by a polymer material infused with metal particles. The metal particles may be Al, Cu, Mg, Be, silver, gold, tungsten, diamond, and the like. The plurality of layers are additively formed a polymer material infused with some particles, for example, ceramics, nitride, glass bubbles, oxides, graphene, or the like.

[0056] In some embodiments, the filler material can be an epoxy-based material. In some cases, the filler material has a thermal conductivity no lower than 2 W/mK. In one example, the filler material is an epoxy with a thermal conductivity of about 8.0 W/m-K. In some cases, the filler material comprises a metal-filled epoxy. In some cases, the metal comprises at least one of aluminum, cooper, thermal interface material, ceramics, boron nitride, and nitride. In some cases, the filler material is a porous material. In some cases, the filler material can be composite material such as, for example, epoxy filled with conductive particles or fibers, urethane filled with thermally conductive particles and/or fibers.

[0057] In some cases, the shell 610 has a thickness of at least two millimeters, which can provide a sufficiently strong mechanical structure. The thickness of a shell refers to the distance between the parting surface and the filler material. The thickness of a cavity refers to the height of the cavity space formed by the shell. In some cases, the shell may form one or more compartments. In some embodiments, the shell includes more than one compartments and at least two of the compartments contain a different filler material from each other. In some cases, the different filler materials have different thermal conductivities. In some cases, the shell 610 is designed to have a thickness no greater than a threshold that is a function of the thermal conductivity of the filler material. In some cases, if the shell thickness is greater than a threshold value, the heat transfer function of the filler material is affected. In some cases, the shell 610 is designed to have a
thickness no greater than a threshold that is a function of the thermal conductivity of the filler material. In some cases, the shell 610 is designed to have

[0058] Figure 6C illustrates an example of an injection mold 600C having a shell 610C forming four compartments, 611C, 612C, 613C, and 614C. In some cases, each compartment (611C, 612C, 613C, and 614C) is filled with a material with specific thermal conductivity. In some cases, at least two of the compartments are filled with filler materials with different thermal conductivities.

[0059] The effectiveness of using fillers to manage heat flow in the mold is demonstrated by constructing a model of a mold and simulating heat flow in it. Figure 7A is a cross-section view of one illustrative example of a 3D printed injection mold with filler material 700. The mold 700 includes a shell 710 and a cavity 720 filled with the filler material. The shell 710 has a thickness of d, the mold 700 has a thickness D, and the cavity 720 has a thickness of (D-d). In the cases of the shell having variable thickness across the mold, the shell thickness refers to the average thickness of the shell. In one example, the mold is made of a 4 mm thick shell fabricated by 3D printing process. The cavity 720 is filled with an epoxy. The overall mold thickness D on the sides is one inch. The average mold surface temperature is calculated for epoxies with various thermal conductivities. The results of these simulations are shown in Table 1.

<table>
<thead>
<tr>
<th>Thermal Conductivity (W/m-K)</th>
<th>Maximum Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>52.2</td>
</tr>
<tr>
<td>20</td>
<td>52.6</td>
</tr>
<tr>
<td>4.5</td>
<td>58.6</td>
</tr>
<tr>
<td>3.5</td>
<td>60.3</td>
</tr>
<tr>
<td>2</td>
<td>67.3</td>
</tr>
<tr>
<td>1.0</td>
<td>83.3</td>
</tr>
<tr>
<td>0.5</td>
<td>115</td>
</tr>
</tbody>
</table>

[0060] The thermal conductivity of the epoxy (filler) is varied from 0.2 to 200 W/m-K. The low value may represent a material suitable for 3D printing, and this simulates the case where the whole mold is made by the 3D printing process. The high value represent a case where the filler is some metal with a very high thermal conductivity. In these simulations the heat flux on the surface of the mold is set at 1000 W/m² which is typical of the heat fluxes encountered in the molding polycarbonate. Figure 7B shows an example of the temperature field in the mold and the filler material. As is demonstrated in Table 1, using an epoxy with a thermal conductivity of 4.5
W/m-K can reduce average mold surface temperature by about 71%. Heat conduction equation that describes heat transfer in the mold is linear, as provided below.

\[
\frac{d^2T}{dx^2} - \frac{1}{\alpha} \frac{d^2T}{dy^2} - \frac{1}{\alpha} \frac{d^2T}{dz^2} = \frac{dT}{dt}
\]

[0061] This indicates that the temperature values show in Table 1 scale with the heat flux applied to surface of the mold, and the relative values of these temperature holds at higher heat fluxes. For the same cooling conditions, the mold temperatures at 3 mm below the mold surface for the two molds shown in Figure 6A and 6B with and without filler materials are shown in Figure 7C, where the mold is closed for 60 seconds and open for 60 seconds. For the mold without the filler material the temperature is increasing with the number of cycles. However, for the one with the filler material, that temperature stabilizes after a few cycles at a much lower temperature. This is another indication that the molds filled with relative high thermal conductivity materials are much more effective at dissipating heat.

[0062] In one embodiment, the 3D printed mold can be printed on a specially designed structure, for example, such as a structure having vertical plates and/or pins mounted on the structure. Figure 8A illustrates a cross-section schematic of one example of an injection mold 800A. The injection mold 800A includes a shell 810A, a cavity 820A, plates and pins 830A, and a base plate 840A. The heights of the plates and pins 830A can be adjusted to match the dimensions of the article to be manufactured. The plates and pins 830A can be prefabricated and mounted on the base plate before print the shell 830A. The plates and the pins 830A conduct the heat away from the surface of the mold to the base plate 840A. Due to their higher thermal conductivity, compare to that of the shell material, the plates and pins 830A can carry the heat away more effectively which leads to a lower mold surface temperatures.

[0063] In some embodiments, as illustrated in Figures 8B-8D, an injection mold 800B can include a 3D printed shell having front fluid flow structures. Figure 8B is a perspective view of the injection mold 800B from the bottom; Figure 8C is a perspective view of the injection mold 800B from the top; and Figure 8D is a section view of the injection mold 800B. The injection mold 800B includes a shell 810B having a parting surface 812B and a cavity 820B. The shell 810B includes a molding structure 850B on its parting surface 812B. The shell 810B includes front fluid flow structures 830B. The front fluid flow structures 830B may use any embodiments and configurations described herein. The front fluid flow structures 830B may have inlet pots 832B, air channel(s) 833B, and outlet port(s) 835B. The cavity 820B can be filled with a filler material 825B with desired thermal conductivity. The shell 810B, the cavity 820B, and the filler material 825B may use any embodiments and configurations described herein. In some cases, the injection mold 800B may have one or more mating structures 840B. In some implementations, the
injection mold 800B may have a mating structure 840B protruded from the general surface of the shell 810B. In some implementations, the injection mold 800B may have a mating structure 840B regressed from the general surface of the shell 810B.

[0064] Figure 9A illustrates a flowchart of one example process of making injection molds using 3D printing technology. Initially, the manufacturing device receives a digital object comprising data specifying a plurality of layers to form an injection mold (step 910A). The injection mold can be any one of the configurations and embodiments described herein. The injection mold comprises a parting surface, a supporting body, and a plurality of fluid flow structures in the supporting body. The parting surface includes a molding structure in conformation with a surface of the article to be manufactured. In some embodiments, at least one of fluid flow structures has an opening on the parting surface. The manufacturing device generates the injection mold based on the digital object using an additive manufacturing process (step 920A).

[0065] Figure 9B illustrates a flowchart of another example process of making injection molds using 3D printing technology. Initially, the manufacturing device receives a digital object comprising data specifying a plurality of layers to form a shell of an injection mold (step 910B). The shell includes a parting surface and forms a cavity. The parting surface includes a molding structure in conformation with a surface of the article to be manufactured. The manufacturing device generates the shell of the injection mold based on the digital object using an additive manufacturing process (step 920B). The shell is made with a shell material. Next, pour a filler material into the cavity (step 930B). In some cases, the shell material has a thermal conductivity lower than a thermal conductivity of the filler material.

[0066] Figure 9C is a system diagram for one example of a 3D printing system 900C to make or manufacture an injection mold 910C. The injection mold 910C may use any embodiments and configurations described herein. In the embodiment illustrated, the 3D printing system 900C includes a computing device 930C and a 3D printer 940C. The 3D printer can be any feasible 3D printer, for example, such as Stratasys Connex, Stratasys EDEN, 3D Systems VIPER, 3D Systems Projet 7000, and the like. The computing device 930C can be a computer, a processor, a processing unit, a microprocessor, a tablet computer, a microprocessor, a microcontroller, a computing unit on cloud servers, or the like. In some cases, the computing device 930C is an integrated component in the 3D printer 940C. The computing device 930C receives a digital object 920C. The digital object 920C can be a digital object representing the injection mold 910C, for example, a 3D model of the injection mold 910C, data comprising a plurality of layers to form the injection mold 910C, data comprising printing instructions for the injection mold 910C, or the like. The computing device 930C is configured to generate printing instructions based on the digital object 920C. The 3D printer 940C is configured to generate the injection mold 910C.
according to the printing instructions. In some embodiments, only a part of the injection mold 910C is generated by the 3D printing process, or referred to as additive manufacturing process. In some cases, only the shell of the injection mold 910C is formed by the 3D printing process, and later filled with one or more filler materials.

Examples

[0067] Example 1

[0068] A two-piece injection mold, as illustrated in Figure 1B and 1C, was designed and fabricated from a methacrylate resin Digital ABS available from Stratasys, Ltd., Eden Prairie, Minnesota, USA, using a stereolithography Projet 7000HD available from 3D Systems, Rock Hill, South Carolina, USA. The two-piece mold design incorporates an exemplary air cooling system. The air cooling system had a front cooling system design created using a numerical modeling tool ANSYS Fluent available from ANSYS Corp, Canonsburg, Pennsylvania, USA.

[0069] Figure 10A shows the result of a numerical simulation of the air flowing out of the air slot nozzle and impinging on the top surface of the mold. The size of the cooling structures are of a slot aperture in nature with a height of 0.1 inch (0.254 cm) and a length of 2.7 inches (6.858 cm). The top surface of the mold is generally exposed to the cooling air after the two parts of the mold are separated after an injection molding operation. Figure 10A further shows the design of the internal air flow passages that deliver air uniformly across the slot nozzle while also minimizing the pressure drop through the passages.

[0070] Figure 10B shows the magnitude of the air velocity leaving the air slot nozzle. The cooling air flows downward and along the length-wise of injection mold. The impinging flow absorbs heat from the hot surface of the mold. Figure 10C shows the distribution of the predicted heat transfer coefficient on the surface of the injection mold when air is flowing from the air slot nozzle. The simulation results show that heat transfer coefficients are significantly higher than typically found on low-cost polymer injection molds.

[0071] Figure 10D shows the results for the heat transfer distribution on the mid-line surface of the top surface of a mold piece from numerical simulations at air flow nozzle exit flow velocities of 2 (m/s), 20 (m/s) and 50 (m/s). An exit flow velocity greater than 20 (m/s) produces high heat transfer coefficients along the surface of the mold to provide significantly improved cooling of the injection mold surface. In the example illustrated in Figure 10D, the air slot nozzle flow rate should be appropriately designed and controlled to achieve a beneficial cooling effect.

[0072] Figures 11A-1 ID are numerical modeling results showing the effectiveness of front-side cooling in reducing the thermal loading on an injection mold during a typical molding process. After about 10 molding cycles, the mold temperature reached a steady state cyclic variation.
Figures 11A-11D compare the predicted temperature distribution of the mold at three cross-sections after 14 molding cycles. Figure 11A and Figure 11C show the effect of front side cooling when the mold is open for 10 seconds and 30 seconds per cycle, respectively. Figure 11B and Figure 11D show the results without front side air cooling. The overall mold temperature is higher in the case without front side air cooling.

[0073] Figure 12A and Figure 12B show the relationship between predicted and measured temperature at several locations in the example two-piece injection molds during a series of typical injection cycles. Figure 12A shows a good correlation between measured and predicted temperature at most locations when the front-side air slot cooling is enabled. Figure 12A also shows that the topmost measuring location (T1) reaches a steady-state average temperature of 68°C after about 15 cycles. Figure 12B also shows good agreement between measured and predicted temperatures during several injection cycles. In contrast to Figure 12A, however, the average temperature at the topmost measuring location (T1) continues to increase after 15 cycles and approaches 88°C as a result of the lack of front-side air cooling.

[0074] Example 2

[0075] A two-piece injection mold was designed and fabricated from a methacrylate resin ABS-Like available from Stratasys, Ltd., Eden Prairie, Minnesota, USA, MN using a Polyjet additive manufacturing process or a stereolithography additive manufacturing process. The two-piece mold design incorporates a cross-flowing honeycomb structure as shown in Figure 2D. In one example, distances between adjacent fluid flow structures are in the range of 0.20-0.40 inches (0.50-1.2 cm). In one example, fluid flow structures occupy 50-85% of the total cross-sectional area. This honeycomb structure may serve the dual purpose of reducing the total weight/cost of the injection mold and providing cooling air access to the back side of the mold.

[0076] Example 3

[0077] Two-piece injection mold was designed using standard CAD tools. The mold was designed as a conformable shell structure with a filling variable of thermal conductivity as shown in Figure 6A. The shell was fabricated from a methacrylate resin Digital ABS available from Stratasys, Ltd., Eden Prairie, Minnesota, USA, using a stereolithography Projet 7000HD available from 3D Systems, Rock Hill, South Carolina, USA. The conformable shell structure had a wall thickness of 4 (mm). Experimental temperature measurements were made during a series of injection molding cycles for molds with low and high thermal conductivity epoxy filler. Figure 7C shows the measured temperature at a location 3 millimeters below the cavity structure. The mold with the high thermal conductivity epoxy maintained an average temperature around 20°C below the average temperature of the mold with the low thermal conductivity epoxy.
Exemplary Embodiments

[0078] Item A1. An injection mold used for manufacturing an apparatus, comprising: a plurality of layers additively formed to comprise: a parting surface, a supporting body, and a plurality of fluid flow structures in the supporting body, wherein the parting surface comprises a molding structure in conformation with a surface of the apparatus, wherein at least one of fluid flow structures has an opening on the parting surface, and wherein the plurality of fluid flow structures are configured to receive fluid.

[0079] Item A2. The injection mold of Item A1, wherein the plurality of layers are additively formed by a polymer material.

[0080] Item A3. The injection mold of Item A1 or A2, wherein the plurality of layers are additively formed by a polymer material infused with metal particles.

[0081] Item A4. The injection mold of any one of Items A1-A3, wherein the plurality of layers are additively formed by a composite material.

[0082] Item A5. The injection mold of any one of Items A1-A4, wherein the fluid comprises gas or liquid.

[0083] Item A6. The injection mold of any one of Items A1-A5, wherein one of the at least one fluid flow structures comprises an engineered nozzle.

[0084] Item A7. The injection mold of Item A6, wherein the engineered nozzle emits fluid in a controlled fashion.

[0085] Item A8. The injection mold of any one of Items A1-A7, wherein the injection mold comprises a first piece and a second piece.

[0086] Item A9. The injection mold of Item A8, wherein each of the first and second pieces comprises a mating structure, and wherein the mating structure of the first piece is mated with the mating structure of the second piece.

[0087] Item A10. The injection mold of Item A8, wherein one of the at least one of fluid flow structures has an opening in the mating structure of the first piece or the second piece.

[0088] Item A11. The injection mold of Item A10, wherein the opening in the mating structure of the first piece or second piece is closed when the mating structure of the first piece is mated with the mating structure of the second piece.

[0089] Item A12. The injection mold of Item A10, wherein the opening in the mating structure of the first piece or second piece remains opened when the mating structure of the first piece is mated with the mating structure of the second piece.

[0090] Item A13. The injection mold of Item A10, wherein the mating structure of the first piece is protruded from a general surface of the first piece, and wherein the opening in the mating structure of the first piece is above the molding structure.
Item A14. The injection mold of any one of Items A1-A13, wherein the plurality of fluid flow structures comprises a lattice structure of fluid flow structures.

Item A15. The injection mold of Item A14, wherein a portion or all of the lattice structure has a regular pattern.

Item A16. The injection mold of Item A14, wherein a portion or all of the lattice structure has a randomized pattern.

Item A17. The injection mold of Item A2, wherein the polymer material has a thermal conductivity less than 50 W/mK.

Item B1. A method of forming an injection mold used for manufacturing an apparatus, the method comprising: receiving, by a manufacturing device having one or more processors, a digital object comprising data specifying a plurality of layers to form the injection mold, wherein the injection mold comprises a parting surface, a supporting body, and a plurality of fluid flow structures in the supporting body; generating, with the manufacturing device by an additive manufacturing process, the injection mold based on the digital object, wherein the parting surface comprises a molding structure in conformation with a surface of the apparatus, wherein at least one of fluid flow structures has an opening on the parting surface, and wherein the plurality of fluid flow structures are configured to receive fluid.

Item B2. The method of Item B1, wherein the plurality of layers are additively formed by a polymer material.

Item B3. The method of Item B1 or B2, wherein the plurality of layers are additively formed by a polymer material infused with metal particles.

Item B4. The method of any one of Items B1-B3, wherein the plurality of layers are additively formed by a composite material.

Item B5. The method of any one of Items B1-B4, wherein the fluid comprises gas or liquid.

Item B6. The method of any one of Items B1-B5, wherein one of the at least one of fluid flow structures comprises an engineered nozzle.

Item B7. The method of Item B6, wherein the engineered nozzle emits fluid in a controlled fashion.

Item B8. The method of any one of Items B1-B7, wherein the injection mold comprises a first piece and a second piece.

Item B9. The method of Item B8, wherein each of the first and second pieces comprises a mating structure, and wherein the mating structure of the first piece is mated with the mating structure of the second piece.
Item B10. The method of Item B8, wherein one of the at least one of fluid flow structures has an opening in the mating structure of the first piece or the second piece.

Item B11. The method of Item B10, wherein the opening in the mating structure of the first piece or second piece is closed when the mating structure of the first piece is mated with the mating structure of the second piece.

Item B12. The method of Item B10, wherein the opening in the mating structure of the first piece or second piece remains opened when the mating structure of the first piece is mated with the mating structure of the second piece.

Item B13. The method of Item B10, wherein the mating structure of the first piece is protruded from a general surface of the first piece, and wherein the opening in the mating structure of the first piece is above the molding structure.

Item B14. The method of any one of Items B1-B10, wherein the plurality of fluid flow structures comprises a lattice structure of fluid flow structures.

Item B15. The method of Item B14, wherein a portion or all of the lattice structure has a regular pattern.

Item B16. The method of Item B14, wherein a portion or all of the lattice structure has a randomized pattern.

Item B17. The method of Item B2, wherein the polymer material has a thermal conductivity less than 50 W/mK.

Item C1. A system, comprising: a computing device configured to receive a digital object comprising data specifying a plurality of layers to form an injection mold, wherein the injection mold comprises a parting surface, a supporting body, and a plurality of fluid flow structures in the supporting body, wherein the parting surface comprises a molding structure in conformation with a surface of the apparatus, wherein at least one of fluid flow structures has an opening on the parting surface, and wherein the plurality of fluid flow structures are configured to receive fluid, wherein the computing device is configured to generate printing instructions based on the digital object; and a 3D printer controlled by the computing device, configured to generate the injection mold according to the printing instructions.

Item C2. The system of Item C1, wherein the plurality of layers are additively formed by a polymer material.

Item C3. The system of Item C1 or C2, wherein the plurality of layers are additively formed by a polymer material infused with metal particles.

Item C4. The system of any one of Items C1-C3, wherein the plurality of layers are additively formed by a composite material.
[00116] Item C5. The system of any one of Items C1-C4, wherein the fluid comprises gas or liquid.

[00117] Item C6. The system of any one of Items C1-C5, wherein one of the at least one of fluid flow structures comprises an engineered nozzle.

[00118] Item C7. The system of Item C6, wherein the engineered nozzle emits fluid in a controlled fashion.

[00119] Item C8. The system of any one of Items C1-C7, wherein the injection mold comprises a first piece and a second piece.

[00120] Item C9. The system of Item C8, wherein each of the first and second pieces comprises a mating structure, and wherein the mating structure of the first piece is mated with the mating structure of the second piece.

[00121] Item C10. The system of Item C8, wherein one of the at least one of fluid flow structures has an opening in the mating structure of the first piece or the second piece.

[00122] Item C11. The system of Item C10, wherein the opening in the mating structure of the first piece or second piece is closed when the mating structure of the first piece is mated with the mating structure of the second piece.

[00123] Item C12. The system of Item C10, wherein the opening in the mating structure of the first piece or second piece remains opened when the mating structure of the first piece is mated with the mating structure of the second piece.

[00124] Item C13. The system of Item C10, wherein the mating structure of the first piece is protruded from the parting surface, and wherein the opening in the mating structure of the first piece is above the molding structure.

[00125] Item C14. The system of any one of Items C1-C13, wherein the plurality of fluid flow structures comprises a lattice structure of fluid flow structures.

[00126] Item C15. The system of Item C14, wherein a portion or all of the lattice structure has a regular pattern.

[00127] Item C16. The system of Item C14, wherein a portion or all of the lattice structure has a randomized pattern.

[00128] Item C17. The system of Item C2, wherein the polymer material has a thermal conductivity less than 50 W/mK.

[00129] Item D1. An injection mold used for manufacturing an apparatus, comprising: a parting surface, a supporting body, a plurality of fluid flow structures in the supporting body, wherein the parting surface comprises a molding structure in conformation with a surface of the apparatus, wherein at least one of fluid flow structures has an opening on the parting surface, and wherein the plurality of fluid flow structures are configured to receive fluid.
[00130] Item D2. The injection mold of Item D1, wherein the fluid comprises gas or liquid.

[00131] Item D3. The injection mold of Item D1 or D2, wherein one of the at least one of fluid flow structures comprises an engineered nozzle.

[00132] Item D4. The injection mold of Item D3, wherein the engineered nozzle emits fluid in a controlled fashion.

[00133] Item D5. The injection mold of any one of Items D1-D4, wherein the injection mold comprises a first piece and a second piece.

[00134] Item D6. The injection mold of Item D5, wherein each of the first and second pieces comprises a mating structure, and wherein the mating structure of the first piece is mated with the mating structure of the second piece.

[00135] Item D7. The injection mold of Item D5, wherein one of the at least one of fluid flow structures has an opening in the mating structure of the first piece or the second piece.

[00136] Item D8. The injection mold of Item D7, wherein the opening in the mating structure of the first piece or second piece is closed when the mating structure of the first piece is mated with the mating structure of the second piece.

[00137] Item D9. The injection mold of Item D7, wherein the opening in the mating structure of the first piece or second piece remains opened when the mating structure of the first piece is mated with the mating structure of the second piece.

[00138] Item D10. The injection mold of Item D7, wherein the mating structure of the first piece is protruded from the parting surface, and wherein the opening in the mating structure of the first piece is above the molding structure.

[00139] Item D11. The injection mold of any one of Items D1-D10, wherein the plurality of fluid flow structures comprises a lattice structure of fluid flow structures.

[00140] Item D12. The injection mold of Item D11, wherein a portion or all of the lattice structure has a regular pattern.

[00141] Item D13. The injection mold of Item D11, wherein a portion or all of the lattice structure has a randomized pattern.

[00142] Item D14. The injection mold of Item D2, wherein the polymer material has a thermal conductivity less than 50 W/mK.

[00143] Item E1. An injection mold used for manufacturing an apparatus, comprising: a shell comprising a plurality of layers additively formed using a shell material; a cavity formed by the shell, wherein the cavity is filled with a filler material, wherein the shell comprises a parting surface, wherein the parting surface comprises a molding structure in conformation with a surface of the apparatus, and wherein the shell material has a thermal conductivity lower than a thermal conductivity of the filler material.
Item E2. The injection mold of Item E1, wherein the filler material comprises epoxy.

Item E3. The injection mold of Item E1 or E2, wherein the filler material comprises an epoxy-based material.

Item E4. The injection mold of any one of Items E1-E3, wherein the plurality of layers are additively formed by a polymer material.

Item E5. The injection mold of any one of Items E1-E4, wherein the plurality of layers are additively formed by a polymer material infused with metal particles.

Item E6. The injection mold of any one of Items E1-E5, wherein the filler material has a thermal conductivity no lower than 2 W/mK.

Item E7. The injection mold of any one of Items E1-E6, wherein the filler material comprises a metal material.

Item E8. The injection mold of Item E7, wherein the metal material comprises at least one of aluminum, cooper, thermal interface material, ceramics, boron nitride, and nitride.

Item E9. The injection mold of any one of Items E1-E8, wherein the shell is designed to have a thickness no greater than a threshold that is a function of a thickness of the cavity.

Item E10. The injection mold of any one of Items E1-E9, wherein the shell is designed to have a thickness no greater than a threshold that is a function of a thermal conductivity of the shell material.

Item E11. The injection mold of any one of Items E1-E10, wherein the shell is designed to have a thickness no greater than a threshold that is a function of a thermal conductivity of the filler material.

Item E12. The injection mold of any one of Items E1-E11, wherein the cavity is designed to have a thickness no less than 10 times a thickness of the shell.

Item E13. The injection mold of any one of Items E1-E12, wherein the filler material comprises a material with porous structure.

Item E14. The injection mold of any one of Items E1-E13, wherein the shell forms a plurality of compartments.

Item E15. The injection mold of Item E14, wherein at least two of the plurality of compartments contain materials different from each other.

Item E16. The injection mold of Item E14, wherein at least two of the plurality of compartments contain materials having thermal conductivities different from each other.

Item E17. The injection mold of Item E14, wherein at least two of the plurality of compartments have geometry shapes different from each other.

Item E18. The injection mold of any one of Items E1-E17, wherein the shell has a thickness of at least two millimeters.
[00161] Item E19. The injection mold of any one of Items E1-E18, wherein the shell comprises a fluid flow structure, and wherein the fluid flow structure is configured to receive fluid.

[00162] Item E20. The injection mold of Item E19, wherein the fluid flow structures has an opening on the parting surface.

[00163] Item E21. The injection mold of Item E20, further comprising: a mating structure protruded from a general surface of the shell, wherein the opening of the fluid flow structures is in the mating structure.

[00164] Item F1. A method of forming an injection mold used for manufacturing an apparatus, the method comprising: receiving, by a manufacturing device having one or more processors, a digital object comprising data specifying a plurality of layers to form a shell of the injection mold, the shell having a parting surface and forming a cavity; generating, with the manufacturing device by an additive manufacturing process using a shell material, the shell of the injection mold based on the digital object; pouring a filler material into the cavity of the shell, wherein the filler material is filled in the cavity of the shell, wherein the parting surface comprises a molding structure in conformation with a surface of the apparatus, wherein the shell material has a thermal conductivity lower than a thermal conductivity of the filler material.

[00165] Item F2. The method of Item F1, wherein the filler material comprises epoxy.

[00166] Item F3. The method of Item F1 or F2, wherein the filler material comprises an epoxy-based material.

[00167] Item F4. The method of any one of Items F1-F3, wherein the plurality of layers are additively formed by a polymer material.

[00168] Item F5. The method of any one of Items F1-F4, wherein the plurality of layers are additively formed by a polymer material infused with metal particles.

[00169] Item F6. The method of any one of Items F1-F5, wherein the filler material has a thermal conductivity no lower than 2 W/mK.

[00170] Item F7. The method of any one of Items F1-F6, wherein the filler material comprises a metal material.

[00171] Item F8. The method of Item F7, wherein the metal material comprises at least one of aluminum, cooper, thermal interface material, ceramics, boron nitride, and nitride.

[00172] Item F9. The method of any one of Items F1-F8, wherein the shell is designed to have a thickness no greater than a threshold that is a function of a thickness of the cavity.

[00173] Item F10. The method of any one of Items F1-F9, wherein the shell is designed to have a thickness no greater than a threshold that is a function of a thermal conductivity of the shell material.
[00174] Item F1. The method of any one of Items F1-F10, wherein the shell is designed to have a thickness no greater than a threshold that is a function of a thermal conductivity of the filler material.

[00175] Item F12. The method of any one of Items F1-F11, wherein the cavity is designed to have a thickness no less than 10 times a thickness of the shell.

[00176] Item F13. The method of any one of Items F1-F12, wherein the filler material comprises a material with porous structure.

[00177] Item F14. The method of any one of Items F1-F13, wherein the shell forms a plurality of compartments.

[00178] Item F15. The method of Item F14, wherein at least two of the plurality of compartments contain materials different from each other.

[00179] Item F16. The method of Item F14, wherein at least two of the plurality of compartments contain materials having thermal conductivities different from each other.

[00180] Item F17. The method of Item F14, wherein at least two of the plurality of compartments have geometry shapes different from each other.

[00181] Item F18. The method of any one of Items F1-F17, wherein the shell has a thickness of at least two millimeters.

[00182] Item F19. The method of any one of Items F1-F18, wherein the shell comprises a fluid flow structure, and wherein the fluid flow structure is configured to receive fluid.

[00183] Item F20. The method of Item F19, wherein the fluid flow structures has an opening on the parting surface.

[00184] Item F21. The method of Item F20, wherein the shell further comprises a mating structure protruded from a general surface of the shell, wherein the opening of the fluid flow structures is in the mating structure.

[00185] The present invention should not be considered limited to the particular examples and embodiments described above, as such embodiments are described in detail to facilitate explanation of various aspects of the invention. Rather the present invention should be understood to cover all aspects of the invention, including various modifications, equivalent processes, and alternative devices falling within the spirit and scope of the invention as defined by the appended claims and their equivalents.

-23-
What is claimed is:

1. An injection mold used for manufacturing an apparatus, comprising:
   a shell comprising a plurality of layers additively formed using a shell material;
   a cavity formed by the shell,
wherein the cavity is filled with a filler material,
wherein the shell comprises a parting surface,
wherein the parting surface comprises a molding structure in conformation with a surface of the apparatus, and
wherein the shell material has a thermal conductivity lower than a thermal conductivity of the filler material.

2. The injection mold of claim 1, wherein the filler material comprises an epoxy-based material.

3. The injection mold of claim 1, wherein the plurality of layers are additively formed by a polymer material.

4. The injection mold of claim 1, wherein the filler material has a thermal conductivity no lower than 2 W/mK.

5. The injection mold of claim 1, wherein the filler material comprises a metal material.

6. The injection mold of claim 1, wherein the shell is designed to have a thickness no greater than a threshold that is a function of the thermal conductivity of the shell material and the thermal conductivity of the filler material.

7. The injection mold of claim 1, wherein the shell forms a plurality of compartments.

8. The injection mold of claim 7, wherein at least two of the plurality of compartments contains materials different from each other.

9. The injection mold of claim 1, wherein the shell comprises a fluid flow structure, and wherein the fluid flow structure is configured to receive fluid.
10. A method of forming an injection mold used for manufacturing an apparatus, the method comprising:

receiving, by a manufacturing device having one or more processors, a digital object comprising data specifying a plurality of layers to form a shell of the injection mold, the shell having a parting surface and forming a cavity;

generating, with the manufacturing device by an additive manufacturing process using a shell material, the shell of the injection mold based on the digital object;

pouring a filler material into the cavity of the shell, wherein the filler material is filled in the cavity of the shell,

wherein the parting surface comprises a molding structure in conformation with a surface of the apparatus,

wherein the shell material has a thermal conductivity lower than a thermal conductivity of the filler material.

11. The method of claim 1, wherein the filler material comprises an epoxy-based material.

12. The method of claim 1, wherein the filler material has a thermal conductivity no lower than 2 W/mK.

13. The method of claim 1, wherein the shell is designed to have a thickness no greater than a threshold that is a function of the thermal conductivity of the shell material and the thermal conductivity of the filler material.

14. The method of claim 1, wherein the shell forms a plurality of compartments, and wherein at least two of the plurality of compartments contains materials different from each other.

15. The method of claim 1, wherein the shell comprises a fluid flow structure, and wherein the fluid flow structure is configured to receive fluid.
FIG. 8D

910A
Receive a digital object comprising data specifying a plurality of layers to form an injection mold

920A
Generate the injection mold based on the digital object

FIG. 9A

910B
Receive a digital object comprising data specifying a plurality of layers to form a shell of an injection mold, the shell forms a cavity

920B
Generate the shell of the injection mold based on the digital object

930B
Pour a filler material into the cavity

FIG. 9B
FIG. 11D
Without Air Jet Face Cooling

Temperature (°C)

Time (Sec.)

FIG. 12B
### INTERNATIONAL SEARCH REPORT

**International application No**

PCT/US2018/034294

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#### A. CLASSIFICATION OF SUBJECT MATTER

INV. B29C33/38 B29C45/26 B29C45/44 B29C33/30 B29C33/44 B29C33/52 B33Y10/00

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#### B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B29C B33Y

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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

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#### C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>WO 2016/124432 Al (PHILIPS LIGHTING HOLDING BV [NL]) 11 August 2016 (2016-08-11) page 5, line 8; claim 1; figure 1 page 16, line 20 - line 22; claim 4 page 15, line 9 - line 11 claim 12 -----</td>
<td>1,6, 8-10, 13-15</td>
</tr>
</tbody>
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**X** Further documents are listed in the continuation of Box C.  
**X** See patent family annex.

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* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
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- "Z" document member of the same patent family

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**Date of the actual completion of the international search**

16 October 2018

**Date of mailing of the international search report**

25/10/2018

**Name and mailing address of the ISA**

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**Authorized officer**

Ferrer Santos, A
<table>
<thead>
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<th>Category</th>
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<th>Relevant to claim No.</th>
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<td>A</td>
<td>WO 2017/037713 A1 (STRATASYS LTD [IL]) 9 March 2017 (2017-03-09) page 3, line 4 - line 10; claims 1-3; figure 2</td>
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<td>A</td>
<td>US 2017/043506 A1 (KÖYANAGI TOMO [JP]) 16 February 2017 (2017-02-16) paragraphs [0026], [0027], [0054], [0055], [0061], [0076]; claim 11; figures 6-8</td>
<td>1-15</td>
</tr>
<tr>
<td>A</td>
<td>WO 2014/141276 A2 (STRATASYS LTD [IL]) 18 September 2014 (2014-09-18) paragraphs [0034], [0037]; claim 1; figures 3A-5</td>
<td>1-15</td>
</tr>
<tr>
<td>Patent document cited in search report</td>
<td>Publication date</td>
<td>Patent family member(s)</td>
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<tr>
<td>US 5439622 A 08-08-1995</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WO 2016124432 A1 11-08-2016</td>
<td>CN 106132654 A</td>
<td>16-11-2016</td>
</tr>
<tr>
<td></td>
<td>EP 3102391 A1</td>
<td>14-12-2016</td>
</tr>
<tr>
<td></td>
<td>JP 6178933 B2</td>
<td>09-08-2017</td>
</tr>
<tr>
<td></td>
<td>JP 2017514725 A</td>
<td>08-06-2017</td>
</tr>
<tr>
<td></td>
<td>RU 2642654 C1</td>
<td>25-01-2018</td>
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<tr>
<td></td>
<td>US 2018009134 A1</td>
<td>11-01-2018</td>
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<tr>
<td></td>
<td>WO 2016124432 A1</td>
<td>11-08-2016</td>
</tr>
<tr>
<td></td>
<td>US 2018243948 A1</td>
<td>30-08-2018</td>
</tr>
<tr>
<td></td>
<td>WO 2017037713 A1</td>
<td>09-03-2017</td>
</tr>
<tr>
<td></td>
<td>EP 3150348 A1</td>
<td>05-04-2017</td>
</tr>
<tr>
<td></td>
<td>JP 6253516 B2</td>
<td>27-12-2017</td>
</tr>
<tr>
<td></td>
<td>JP 2015223750 A</td>
<td>14-12-2015</td>
</tr>
<tr>
<td></td>
<td>US 2017043506 A1</td>
<td>16-02-2017</td>
</tr>
<tr>
<td></td>
<td>WO 20151824444 A1</td>
<td>03-12-2015</td>
</tr>
<tr>
<td>WO 20141176 A2 18-09-2014</td>
<td>CN 105209241 A</td>
<td>30-12-2015</td>
</tr>
<tr>
<td></td>
<td>EP 2969465 A2</td>
<td>20-01-2016</td>
</tr>
<tr>
<td></td>
<td>HK 1220425 A1</td>
<td>05-05-2017</td>
</tr>
<tr>
<td></td>
<td>JP 6348520 B2</td>
<td>27-06-2018</td>
</tr>
<tr>
<td></td>
<td>JP 2016509968 A</td>
<td>04-04-2016</td>
</tr>
<tr>
<td></td>
<td>JP 2018149816 A</td>
<td>27-09-2018</td>
</tr>
<tr>
<td></td>
<td>US 2016039120 A1</td>
<td>11-02-2016</td>
</tr>
<tr>
<td></td>
<td>US 2018154557 A1</td>
<td>07-06-2018</td>
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<tr>
<td></td>
<td>US 2018290342 A1</td>
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<td></td>
<td>WO 2014141276 A2</td>
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