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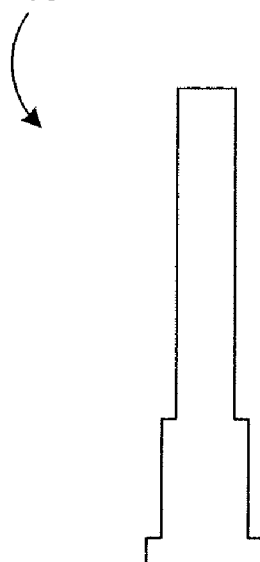
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(54) Title: SYSTEMS AND METHODS FOR MANUFACTURING HYBRID POLYMER MOLD TOOLING

100



(57) Abstract: A method of manufacturing an injection mold includes providing a build plate. A plurality of layers of a material are printed onto the build plate so as to form a near net shape of an injection mold component. The near net shape of the injection mold component defines a first volumetric part cavity. Material is removed from each of the build plate and the plurality of layers so as to form a net shape of the injection mold component. The net shape defines a second volumetric part cavity. The build plate at least partially defines the net shape of the injection mold component.

Fig. 1



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SYSTEMS AND METHODS FOR MANUFACTURING HYBRID POLYMER MOLD TOOLING

CROSS-REFERENCE TO RELATED PATENT APPLICATION

[0001] The present application claims the benefit of priority to U.S. Provisional Patent Application No. 62/323,370, filed April 15, 2016, the contents of which are incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] This disclosure relates to systems and methods for manufacturing injection mold tooling.

BACKGROUND

[0003] Injection molding is a manufacturing process for producing parts by injecting material into a mold. Material for the part is fed into a heated barrel, mixed, and forced into a mold cavity, where it cools and hardens to the configuration of the cavity. Manufacturing high volumes of an injection molded part requires a high quality mold. Producing mold tooling is typically labor intensive and highly technical, which results in high cost. Mold tooling is a fixed capital expenditure that is amortized over the expected life volume of a part produced using the mold tooling. Accordingly, producing injection molded parts can be cost prohibitive for low production volume parts. Further, the more complex the part, the more expensive the mold, and hence, the more expensive the part. Accordingly, it can be cost prohibitive to produce low volume and/or high complexity parts via injection molding.

[0004] Additive manufacturing is a manufacturing process in which successive layers of material are formed to create a part based on a three-dimensional model of the part. Additive manufacturing includes various different types of technologies and techniques. For example, powder bed technology involves selectively fusing materials in a powder bed. A thin layer of powdered material is spread onto a build plate. A laser selectively fuses a thin layer of the powdered material to form a cross-sectional layer of the part. The first layer is fused to the build plate, which provides structural integrity during the build. After forming

the first layer, the powder bed is lowered by one layer thickness, and a new layer of material is applied on top of the first layer. The process is repeated until the part is completely formed. The completed part is then removed from the build plate, for example, using wire electrical discharge machining ("wire EDM").

[0005] Additive manufacturing enables parts to be built without the need for expensive injection mold tooling. While injection mold tooling can typically be used to produce only a single part design, an additive manufacturing machine can be used to produce any number of different part designs. Accordingly, additive manufacturing is more cost effective than injection molding for producing low production volume parts.

[0006] One challenge associated with producing parts via additive manufacturing is achieving an acceptable surface finish on the parts. The surface finish is primarily defined by the resolution or step size (e.g., thickness) of each layer. In general, the higher the resolution (the smaller the step size between layers), the better the surface finish. However, resolution is directly tied to the time it takes to produce a part. The cost per part for additive manufacturing is primarily driven by amortization of the capital expenditure of the additive manufacturing machine. Accordingly, the higher the resolution, the longer it takes to produce a part, and thus, the higher the cost per part. It has therefore generally been economically infeasible to produce high quality, high volume parts using additive manufacturing techniques.

SUMMARY

[0007] Various embodiments relate to a method of manufacturing an injection mold. An example method includes providing a build plate. A plurality of layers of a material are printed onto the build plate so as to form a near net shape of an injection mold component. The near net shape of the injection mold component defines a first volumetric part cavity. Material is removed from each of the build plate and the plurality of layers so as to form a net shape of the injection mold component. The net shape of the injection mold component defines a second volumetric part cavity. The build plate at least partially defines the net shape of the injection mold component.

[0008] Various other embodiments relate to a method of manufacturing a part. An example method includes providing a build plate. A plurality of layers of a material are printed onto the build plate so as to form a near net shape of the mold component. Material is removed from each of the build plate and the plurality of layers so as to form a net shape of the mold component corresponding to a precise model of the mold component. The build plate at least partially defines the net shape of the mold component. A thermoplastic material is injected into a cavity defined by each of the build plate and the plurality of layers so as to form the part.

[0009] Various other embodiments relate to an injection mold. An example injection mold includes a first injection mold component. The first injection mold component includes a first build plate and a first plurality of layers printed onto the first build plate. Upon printing the first plurality of layers onto the first build plate, each of the first build plate and the first plurality of layers are machined so as to form a first net shape of the first injection mold component. The first net shape of the first injection mold component defines a first volumetric part cavity corresponding to a model of at least a portion of an injection molded part to be formed using the injection mold.

[0010] These and other features, together with the organization and manner of operation thereof, will become apparent from the following detailed description when taken in conjunction with the accompanying drawings, wherein like elements have like numerals throughout the several drawings described below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The details of one or more implementations are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages of the disclosure will become apparent from the description, the drawings, and the claims.

[0012] Fig. 1 is a side elevational view of an injection molded part, according to an embodiment.

[0013] Fig. 2A is a cross-sectional side view of an injection mold component used to produce the injection molded part of Fig. 1.

[0014] Fig. 2B is a detailed view A of a portion of the injection mold component of Fig. 2A in a partially formed state, according to an embodiment.

[0015] Fig. 2C illustrates the detailed view A of the injection mold component of Fig. 2A in a finished state, according to an embodiment.

[0016] Fig. 3 is a flow diagram illustrating a method of manufacturing an injection mold component, according to an embodiment.

[0017] It will be recognized that some or all of the figures are schematic representations for purposes of illustration. The figures are provided for the purpose of illustrating one or more implementations with the explicit understanding that they will not be used to limit the scope or the meaning of the claims.

DETAILED DESCRIPTION

[0018] Injection molding has relatively high tooling costs but relatively low per-part costs associated therewith. Conversely, additive manufacturing does not require tooling (other than the additive manufacturing apparatus) but has higher per-part costs. However, there are a number of challenges associated with constructing high-quality injection mold tooling using additive manufacturing. For example, tooling components produced using additive manufacturing may not have an acceptable surface finish. Instead, the resolution or step size of each layer used to produce the component may cause the finished component to have a rough surface. In general, the higher the resolution (the smaller the step size between layers), the longer it takes to construct the component. Because the per-part cost for parts produced using additive manufacturing is closely tied to manufacturing time, it may be cost prohibitive to produce high-quality mold tooling using additive manufacturing alone.

[0019] Additionally, injection mold tooling produced using additive manufacturing may be less durable than injection mold tooling produced using conventional subtractive manufacturing techniques (e.g., machining). One reason for this is that metals with wrought properties are conventionally used to manufacture mold tooling components using conventional subtractive manufacturing techniques. The term “wrought” means “to work.” Metals with wrought properties are metals that have been processed to alter the physical

properties of the metal. For example, metals with wrought properties may have been processed via work hardening (e.g., cold forming), heat treating, etc. Metals with wrought properties are conventionally used to produce injection mold tooling components so that the tooling components are sufficiently durable to operate over many thousands of cycles without exhibiting excessive wear. In contrast, the metals that may be used to manufacture components using additive manufacturing techniques do not exhibit wrought properties.

[0020] Referring to the figures generally, various embodiments relate to systems and methods for manufacturing injection mold tooling using a hybrid manufacturing process including both additive and subtractive manufacturing techniques. According to various embodiments, a mold component is formed using additive manufacturing in which a plurality of layers of a material are printed onto a wrought build plate. The plurality of layers are formed using a relatively large step-size. Unlike conventional systems in which the build plate is removed from the additive manufacturing portion, portions of the build plate are integrated into the final mold component. Upon completion of the additive manufacturing portion, both the build plate and the additive manufacturing portion are processed using subtractive manufacturing techniques to produce the final mold component. The final subtractive manufacturing process removes material from both the build plate and the additive manufacturing portion (e.g., its rough surfaces) so that the final mold component has precise dimensional tolerances and a high-quality surface finish.

[0021] By incorporating the build plate into the final mold component, the mold component includes wrought properties in particular areas while still leveraging the benefits of additive manufacturing in other areas. For example, in some embodiments, the build plate defines a high-stress area, such as a mating surface of the mold component. Accordingly, the mold component is produced using a hybrid of additive manufacturing and subtractive manufacturing using metal with wrought properties. As will be appreciated, the additive manufacturing portion of the mold component may generally be manufactured more quickly than using conventional subtractive manufacturing techniques because of the relatively large step-size utilized in accordance with various embodiments. As will be appreciated, the additive manufacturing portion exhibits other desirable characteristics, such as superior cooling features, among other things.

[0022] Fig. 1 is a side elevational view of an injection molded part 100, according to an embodiment. The injection molded part 100 may be formed using injection mold tooling, according to various example embodiments. The injection molded part 100 may be formed using various thermoplastic or thermosetting polymers, among other materials. In one embodiment, the injection molded part 100 is an engine piston cooling nozzle. However, the injection molded part 100 may be any type of component.

[0023] Fig. 2A is a cross-sectional side view of an injection mold component 200 used to produce the injection molded part 100 of Fig. 1, according to an embodiment. The injection mold component 200 includes a wrought portion 202 and an additive portion 204. The wrought portion 202 is formed from a build plate, and the additive portion 204 is formed via additive manufacturing. The wrought portion 202 may be formed using any of various materials having wrought properties, such as aluminum, steel, nickel, various alloys, etc. In one embodiment, the wrought portion 202 is formed from an aluminum super alloy, such as Inconel. The additive portion 204 may be formed from any material that is bondable to the wrought portion 202. For example, in one embodiment, the additive portion 204 is formed from an aluminum alloy. The wrought portion 202 and the additive portion 204 together define a cavity 206. The cavity 206 corresponds to a precise model of at least a portion of the injection molded part 100 of Fig. 1 that is formed using the injection mold component 200. It should be understood that the injection mold component 200 is used in conjunction with other mold components in an injection mold. For example, the injection mold component 200 may be referred to as an “A side,” which engages with a “B side” mold component during operation of the injection mold. For example, the “B side” mold component may include a projection that defines an interior cavity of the injection molded part 100.

[0024] Fig. 2B is a detailed view A of a portion of the injection mold component 200 of Fig. 2A in a partially formed state, according to an embodiment. The wrought portion 202 is defined by a build plate 208. The additive portion 204 is defined by a plurality of layers 210 that are formed sequentially on top of the build plate 208 via additive manufacturing techniques. For example, in one embodiment, the plurality of layers 210 are formed using powder bed technology. However, the plurality of layers 210 may be similarly formed using other additive manufacturing techniques. The plurality of layers 210 are formed (e.g.,

printed) on the build plate 208 so as to form a near net shape of the additive portion 204. The near net shape of the additive portion 204 at least partially defines a first volumetric part cavity 212. It should be understood that a second mold component may also at least partially define the first volumetric part cavity 212. The near net shape of the additive portion 204 includes extra material that is later removed via subtractive manufacturing techniques (e.g., machined) to form a net shape defined by a finished interior surface 214, which is shown by a dashed line in Fig. 2B. In other words, the near net shape of the additive portion 204 is a slightly oversized version of the final net shape of the additive portion 204. As will be appreciated, the subtractive manufacturing technique used to remove the extra material of the near net shape is performed at a higher resolution (e.g., a tighter dimensional tolerance) than that of the additive manufacturing technique. In some embodiments, the extra material included in the near net shape of the additive portion 204 is defined at least in part by the resolution or step size of each layer of the additive portion 204. For example, an implementation that utilizes a larger step size will have a larger near net shape of the additive portion 204 – and therefore more material that will need to be removed via subtractive manufacturing – relative to an implementation that utilizes a smaller step size.

[0025] In some embodiments, the injection molded part 100 and the injection mold component 200 are defined by digital three-dimensional models. The model of the injection molded part 100 corresponds to the net shape of the injection mold component 200. The features of the model and the net shape are defined with relatively precise dimensional tolerances. For example, in some embodiments, the dimensional tolerance of the model and the net shape are ± 0.200 to ± 0.500 mm. In some embodiments, the near net shape of the injection mold component 200 includes at least 0.500 mm of additional material relative to the net shape. The near net shape is used to define the plurality of layers printed onto the build plate 208.

[0026] In some embodiments, the plurality of layers 210 include machining pick-up points identifying the extra material from each layer that needs to be removed from a portion of each layer that in order to form the finished interior surface 214 having the surface finish and size that will be define the features of the injection molded part 100.

[0027] Although not illustrated in Fig. 2A, the plurality of layers 210 may also define cooling passages. The cooling passages may be connected to a cooling circuit to circulate a fluid (e.g., water or coolant) through the injection mold component 200. In operation, the coolant absorbs heat from the mold, which has absorbed heat from the hot material injected therein. The coolant operates to keep the mold at a proper temperature to solidify the material at the most efficient rate. In some embodiments, the cooling passages are spaced from the finished interior surface 214 of the injection mold component 200 and follow the contours of the finished interior surface 214. The cooling passages are defined when the plurality of layers 210 are formed via additive manufacturing. According to various embodiments, the cooling passages are not processed using subtractive manufacturing techniques along their entire length (however, it should be understood that subtractive manufacturing techniques may be used to tap the inlet and outlet of the passages). Instead, the cooling passages retain a relatively rough surface finish imparted by the additive manufacturing process. It has been found that the rough surface finish imparted by the additive manufacturing process enhances heat transfer from the injection mold component 200 to the coolant by promoting turbulence as the fluid is circulated through the coolant passages. Additionally, the rough surface finish increases the surface area in the coolant passages that is exposed to the coolant fluid, thereby further enhancing heat transfer. As used herein, the term “rough surface finish” refers to a surface finish imparted by the printing of the plurality of layers 210 without further processing (e.g., via subtractive manufacturing). Similarly, it should be understood that material feed passages, vent passages, and other features may be similarly formed via additive manufacturing. It has been found that the enhanced cooling capability of the cooling passages formed using additive manufacturing techniques cools and solidifies the injected material more quickly than conventional cooling passages, thereby reducing production time.

[0028] Fig. 2C illustrates the detailed view A of the injection mold component 200 of Fig. 2A in a finished state, according to an embodiment. More specifically, Fig. 2C illustrates the injection mold component 200 as shown in Fig. 2B, after being processed via a subtractive manufacturing process. In particular, the subtractive manufacturing process includes removing material from the wrought portion 202 up to the finished interior surface 214 so as to define an opening 218 in the wrought portion 202. The subtractive manufacturing process also includes removing material from the additive portion 204 up to

the finished interior surface 214. Put another way, material is removed from both of the wrought portion 202 and from the additive portion 204 via the subtractive manufacturing process so as to form a net shape of the injection mold component 200. The net shape of the injection mold component 200 defines a second volumetric part cavity 220 corresponding to a precise model of at least a portion of the injection molded part (e.g., the injection molded part 100 of Fig. 1) to be formed using the injection mold including the injection mold component 200.

[0029] As shown in Fig. 2C, the build plate 208 (the wrought portion 202 of the injection mold component 200) at least partially defines the net shape of the injection mold component 200. Accordingly, the injection mold component 200 includes the benefits of both additive and subtractive manufacturing. For example, the wrought portion 202 is extremely durable and can withstand high impact loads without exhibiting excessive wear or deformation over time. Additionally, the additive portion 204 is fast and inexpensive to manufacture and includes enhanced cooling capabilities.

[0030] In some embodiments, the wrought portion 202 defines a high-stress area of the injection mold component 200, such as a mating surface that engages a corresponding mating surface of an opposite side of the mold. In operation, the mating surfaces experience significant stress as the mold components are repeatedly engaged and disengaged. Utilizing a material having wrought properties in this portion of the mold components enables the mold components to operate over many thousands of cycles before needing to be repaired or replaced. In other embodiments, the wrought portion 202 may define other areas of the injection mold component 200. For example, the wrought portion 202 may define high-wear surfaces that engage slides or other mold components.

[0031] Fig. 3 is a flow diagram illustrating a method 300 of manufacturing an injection mold component, according to an embodiment. For example, the method 300 may be used to form the injection mold component 200 of Figs. 2A-2C. However, the method 300 may be similarly used to form other components.

[0032] At 302, a build plate is provided. The build plate is formed of a material having wrought properties. For example, in one embodiment, the build plate is formed from Inconel.

[0033] At 304, a plurality of layers of a material are printed onto the build plate so as to form a near net shape of an injection mold component. The near net shape of the injection mold component defines a first volumetric part cavity.

[0034] At 306, material is removed from each of the build plate and the plurality of layers so as to form a net shape of the injection mold component. The net shape of the injection mold component defines a second volumetric part cavity corresponding to a model of the at least a portion of the injection molded part to be formed using the injection mold. The build plate at least partially defines the net shape of the injection mold component.

[0035] It should be appreciated that the hybrid manufacturing systems and methods described herein may be similarly utilized to form any type of component and are not limited to manufacturing injection mold tooling components. Instead, the hybrid manufacturing systems and methods including both additive and subtractive manufacturing techniques may be used to produce any type of component. For example, the hybrid manufacturing systems and methods may be utilized to form any component that may be formed using additive manufacturing techniques and that also requires a high-wear surface having wrought properties.

[0036] While this specification contains many specific implementation details, these should not be construed as limitations on the scope of what may be claimed, but rather as descriptions of features specific to particular implementations. Certain features described in this specification in the context of separate implementations can also be implemented in combination in a single implementation. Conversely, various features described in the context of a single implementation can also be implemented in multiple implementations separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a subcombination or variation of a subcombination.

[0037] It should be understood by those of skill in the art who review this disclosure that various features are described and claimed without restricting the scope of these features to the precise numerical ranges provided unless otherwise noted. Accordingly, insubstantial or

inconsequential modifications or alterations of the subject matter described and claimed are considered to be within the scope of the invention as recited in the appended claims.

[0038] It is important to note that the construction and arrangement of the system shown in the various example implementations is illustrative only and not restrictive in character. All changes and modifications that come within the spirit and/or scope of the described implementations are desired to be protected. It should be understood that some features may not be necessary and implementations lacking the various features may be contemplated as within the scope of the application, the scope being defined by the claims that follow. When the language “at least a portion” and/or “a portion” is used the item can include a portion and/or the entire item unless specifically stated to the contrary.

WHAT IS CLAIMED IS:

1. A method of manufacturing an injection mold, the method comprising:
providing a build plate;
printing a plurality of layers of a material onto the build plate so as to form a near net shape of an injection mold component, the near net shape of the injection mold component defining a first volumetric part cavity; and
removing material from each of the build plate and the plurality of layers so as to form a net shape of the injection mold component, the net shape of the injection mold component defining a second volumetric part cavity,
wherein the build plate at least partially defines the net shape of the injection mold component.
2. The method of claim 1, wherein the second volumetric part cavity corresponds to a model of at least a portion of an injection molded part to be formed using the injection mold.
3. The method of claim 1, wherein the build plate is formed from metal with wrought properties.
4. The method of claim 1, wherein the plurality of layers of the material further define cooling passages.
5. The method of claim 4, wherein the cooling passages have a rough surface finish imparted by the printing of the plurality of layers.
6. The method of claim 1, wherein the injection mold component is a first injection mold component, and further comprising coupling a second injection mold component to the first injection mold component such that the second injection mold component at least partially engages the first injection mold component so as to define a third volumetric part cavity corresponding to a model of an injection molded part to be formed using the injection mold.
7. The method of claim 6, wherein the build plate defines a first impact surface of the first injection mold component, the first impact surface structured to engage a second

impact surface of the second injection mold component during production of the injection molded part.

8. A method of manufacturing a part, the method comprising:
providing a build plate;
printing a plurality of layers of a material onto the build plate so as to form a near net shape of a mold component;

removing material from each of the build plate and the plurality of layers so as to form a net shape of the mold component corresponding to a model of a part, wherein the build plate at least partially defines the net shape of the mold component; and

injecting a thermoplastic material into a cavity defined by each of the build plate and the plurality of layers so as to form the part.

9. The method of claim 8, wherein the build plate is formed from metal with wrought properties.

10. The method of claim 8, wherein the mold component is a first mold component, and wherein the build plate defines a first wear surface of the first mold component, the first wear surface structured to engage a second wear surface of a second mold component during production of the part.

11. The method of claim 8, wherein the plurality of layers of the material further define cooling passages.

12. The method of claim 11, wherein the cooling passages have a rough surface finish imparted by the printing of the plurality of layers.

13. The method of claim 8, wherein the mold component is a first mold component, and further comprising coupling a second mold component to the first mold component such that the second mold component at least partially engages the first mold component so as to define a third volumetric part cavity corresponding to the model of the part.

14. An injection mold, comprising:
a first injection mold component, comprising:

a first build plate; and
a first plurality of layers printed onto the first build plate,
wherein, upon printing the first plurality of layers onto the first build plate, each of the first build plate and the first plurality of layers are machined so as to form a first net shape of the first injection mold component, the first net shape of the first injection mold component defining a first volumetric part cavity corresponding to a model of at least a portion of an injection molded part to be formed using the injection mold.

15. The injection mold of claim 14, wherein the first build plate is formed from metal with wrought properties.

16. The injection mold of claim 14, wherein the first build plate at least partially defines the first net shape of the first injection mold component.

17. The injection mold of claim 16, further comprising a second injection mold component, the second injection mold component comprising:

a second build plate; and
a second plurality of layers printed onto the build plate,
wherein, upon printing the second plurality of layers onto the second build plate, each of the second build plate and the second plurality of layers are machined so as to form a second net shape of the second injection mold component, the second net shape of the second injection mold component defining a second volumetric part cavity corresponding to the model of at least a portion of the injection molded part to be formed using the injection mold.

18. The injection mold of claim 17, wherein the first build plate defines a first wear surface and the second build plate defines a second wear surface, the first and second wear surfaces structured to engage each other during production of the injection molded part.

19. The injection mold of claim 14, wherein the first plurality of layers further define cooling passages.

20. The injection mold of claim 19, wherein the cooling passages have a rough surface finish imparted by the printing of the plurality of layers.

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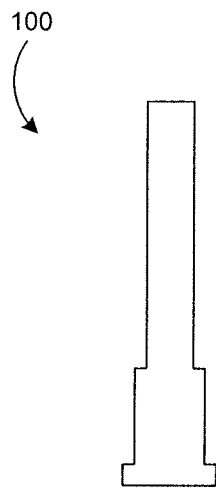


Fig. 1

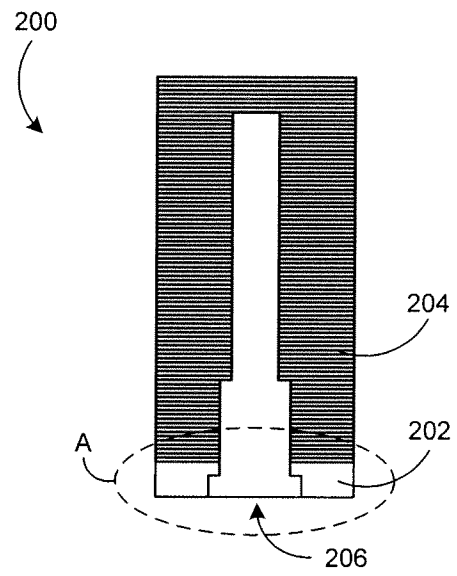


Fig. 2A

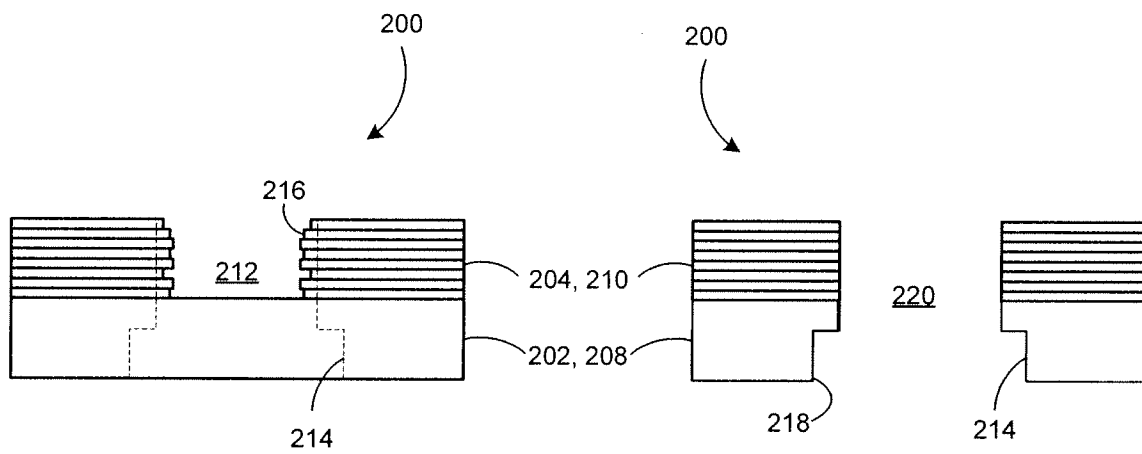


Fig. 2B

Fig. 2C

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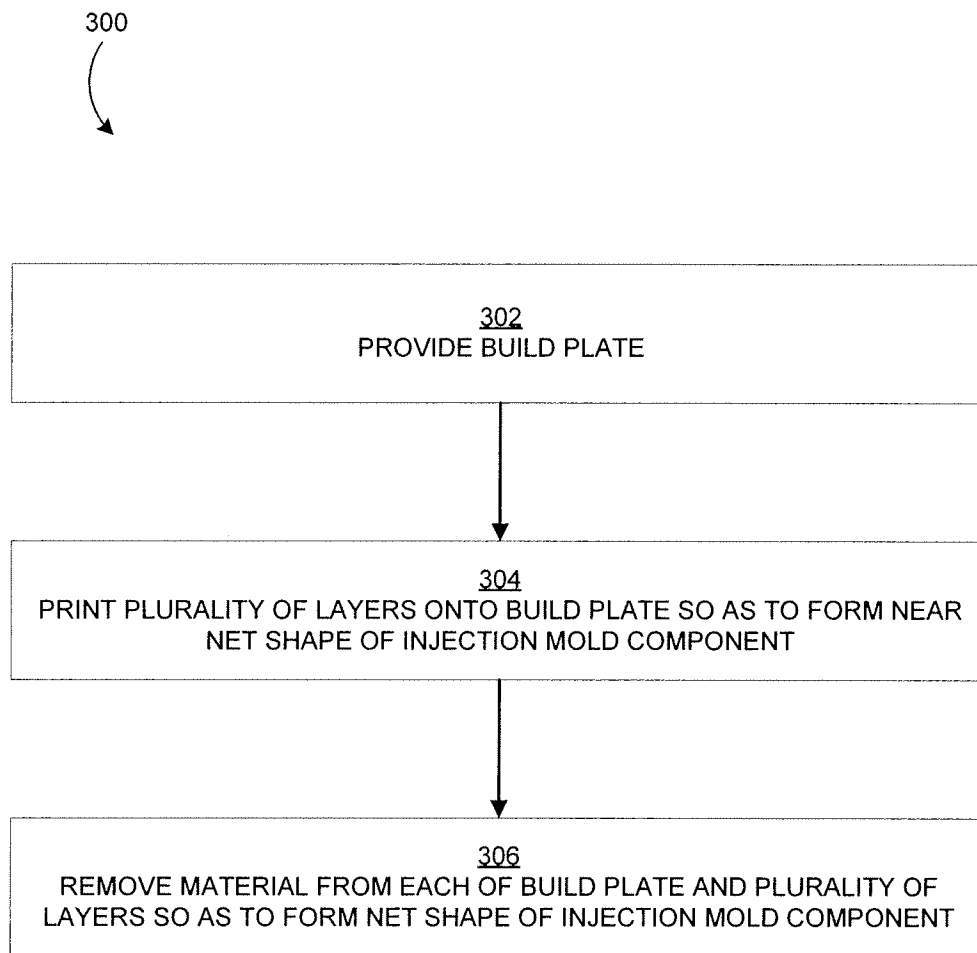


Fig. 3

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 17/26947

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - B29C 45/26; B29C 33/00; B33Y 80/00 (2017.01)

CPC - B29C 33/301; B29C 33/302; B29C 33/3842; B29C 45/26; B33Y 80/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History Document

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

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

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2015/167965 A1 (Cummins Inc.) 05 November 2015 (05.11.2015); entire document, but especially: para [0005]- para [0007], para [0016], para [0017], fig. 2, fig. 3	1-20
X, P	US 2016/0303794 A1 (Atwood et al.) 20 October 2016 (20.10.2016); entire document	1-20
A	US 6,258,311 B1 (Jens et al.) 10 July 2001 (10.07.2001); entire document	1-20
A	US 2014/0277664 A1 (Stump) 18 September 2014 (18.09.2014); entire document	1-20
A	Sachs et al. "Production of Injection Molding Tooling With Conformal Cooling Channels Using the Three Dimensional Printing Process" Polymer Engineering and Science, Vol 40 Issue 5 (May 2000): pages 1232-1247; entire document	1-20
A	US 5,260,014 A (Holton et al.) 09 November 1993 (09.11.1993); entire document	1-20

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

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Date of the actual completion of the international search

07 June 2017

Date of mailing of the international search report

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