

HEAT EXCHANGERS AND COLD PLATES MANUFACTURED VIA LAMINATED OBJECT MANUFACTURING

CROSS-REFERENCE TO RELATED APPLICATIONS

- 5 [0001] The present application claims the benefit of and priority to United States Provisional Application No. 63/527,094, filed on July 17, 2023, the entire disclosure of which is hereby incorporated by reference as if set forth in its entirety herein.

TECHNICAL FIELD

- 10 [0002] Embodiments described herein generally relate to methods and apparatus for fabricating metal laminated object parts, and more specifically to the manufacture of heat exchangers and cold plates via laminated object manufacturing.

BACKGROUND

- 15 [0003] Heat exchangers such as cold plates may be manufactured via multi part construction and joined in a watertight fashion. Some examples of these manufacturing methods include casting, machining and subsequently vacuum brazing, skiving and subsequently friction stir welding, and assembly by additive manufacturing processes. For example, heat exchangers may be assembled via laminated object manufacturing (LOM), which involves assembling complex 3D structures by sequentially depositing layers of material. Each successive layer may be bonded to and/or deposited on the previous layer to gradually assemble the 3D structure.

- 20 [0004] Such methods, however, often limit the capabilities of the manufactured heat exchanger because of design constraints present within each manufacturing approach. Cast parts may not be able to be formed with rapid changes in flow path, edges, or small tubular features enclosed within the cast part without time-intensive additional machining. Additive manufacturing methods such as LOM may require the use of support structures for deposition that cannot be easily removed from the part after bonding, and do not have subtractive elements that allow for the formation of more complex geometries. Parts produced via powder-based additive manufacturing processes must adhere to design constraints that allow powder removal from unsupported flow paths and have support structures removable from channels within the part.

- 25 [0005] Accordingly, a need exists for improved methods and systems of manufacturing heat exchangers.
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SUMMARY

[0006] This summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description section. This summary is not intended to identify or exclude key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

[0007] In one aspect, embodiments relate to a method for producing a heat exchanger via laminated object manufacturing. The method includes patterning a plurality of metal sheets so that at least one metal sheet contains at least one void space of a plurality of void spaces and is otherwise a closed plane; assembling the plurality of metal sheets so that the plurality of void spaces forms at least one channel; and bonding the plurality of assembled metal sheets to form a heat exchanger, wherein the heat exchanger contains at least one flow path formed from the at least one channel and connected to at least two externally accessible ports on the heat exchanger.

[0008] In some embodiments, the at least one void space of each metal sheet is juxtaposed with the at least one void space of an adjacent metal sheet to form the at least one channel.

[0009] In some embodiments, the plurality of void spaces is patterned so as to distribute force throughout the workpiece during bonding.

[0010] In some embodiments, the at least one flow path comprises a fluidly connected plurality of channels.

[0011] In some embodiments, a force applied to the workpiece during bonding is a function of at least one channel geometry.

[0012] In some embodiments, the plurality of channels comprises a plurality of different channel geometries.

[0013] In some embodiments, the plurality of different channel geometries comprises at least one of an arched geometry, a circular geometry, or an elliptical geometry.

[0014] In some embodiments, the plurality of channels comprises a single channel geometry.

[0015] In some embodiments, the plurality of channels is arranged in a parallel fashion.

[0016] In some embodiments, the at least two externally accessible ports are each on different faces of the heat exchanger.

[0017] In some embodiments, a cross-section of the at least one channel culminates in a plurality of cusps along an axial direction of force application to the workpiece.

[0018] In some embodiments, the at least one flow path is configured to promote at least one of internal mixing within the at least one channel, secondary flows within the at least one channel, or adverse pressure gradients within the at least one channel.

5 [0019] In some embodiments, each metal sheet of the plurality of metal sheets is patterned so that the metal sheet maintains its structural integrity when picked up along at least one edge of the metal sheet.

[0020] In some embodiments, at least one of the plurality of metal sheets contains a plurality of void spaces that form the same channel.

10 [0021] In another aspect, embodiments relate to a system for manufacturing a laminated object heat exchanger. The system includes a laminated object manufacturing device configured to pattern a plurality of metal sheets so that at least one metal sheet contains at least one void space of a plurality of void spaces and is otherwise a closed plane; and assemble the plurality of metal sheets so that the plurality of void spaces forms at least one channel; and a pressor configured to bond the plurality of assembled metal sheets to form a heat exchanger, wherein the heat exchanger
15 contains at least one flow path formed from the at least one channel and connected to at least two externally accessible ports on the heat exchanger.

[0022] In some embodiments, the at least one void space of each metal sheet is juxtaposed with the at least one void space of an adjacent metal sheet to form the at least one channel.

20 [0023] In some embodiments, the at least one flow path comprises a fluidly connected plurality of channels.

[0024] In some embodiments, each metal sheet of the plurality of metal sheet is patterned so that the metal sheet maintains its structural integrity when picked up along at least one edge of the metal sheet.

25 [0025] In another aspect, embodiments relate to a heat exchanger formed via a laminated object manufacturing process. The process includes patterning a plurality of metal sheets so that at least one metal sheet contains at least one void space of a plurality of void spaces and is otherwise a closed plane; assembling the plurality of metal sheets so that the plurality of void spaces forms at least one channel; and bonding the plurality of assembled metal sheets to form a heat exchanger, wherein the heat exchanger contains at least one flow path formed from the at
30 least one channel and connected to at least two externally accessible ports on the heat exchanger.

[0026] In some embodiments, the at least one void space of each metal sheet is juxtaposed with the at least one void space of an adjacent metal sheet to form the at least one channel.

[0027] In some embodiments, the at least one flow path comprises a fluidly connected plurality of channels.

[0028] In some embodiments, a force applied to the workpiece during bonding is a function of at least one channel geometry.

5 [0029] In some embodiments, the plurality of channels comprises a plurality of different channel geometries.

[0030] In some embodiments, the at least two externally accessible ports are each on different faces of the heat exchanger.

10 [0031] In some embodiments, each metal sheet of the plurality of metal sheets is patterned so that the metal sheet maintains its structural integrity when picked up along at least one edge of the metal sheet.

[0032] In some embodiments, at least one of the plurality of metal sheets contains a plurality of void spaces that form the same channel.

15 [0033] In some embodiments, at least one metal sheet is a fin in the flow path. In some embodiments, the fin extends into or across the fluid volume such that at least one region of the at least one metal sheet is not subject to mechanical force or bonded with any adjacent sheets.

BRIEF DESCRIPTION OF DRAWINGS

20 [0034] Non-limiting and non-exhaustive embodiments of this disclosure are described with reference to the following figures, wherein like reference numerals refer to like parts throughout the various views unless otherwise specified:

[0035] Figure 1 depicts a cross-section of a portion of a channel in a part region;

[0036] Figure 2 depicts a cross-section of a channel with cusps through a surrounding part region;

25 [0037] Figure 3 depicts a LOM-manufactured cold plate with header cross-channels and external access ports;

[0038] Figure 4 depicts an isometric view of the flow paths of the part in Figure 3 without the surrounding part region visible;

[0039] Figure 5 depicts a single layer comprising a horizontal cross-section of the part in Figure 3; and

30 [0040] Figure 6 depicts a method of making a flat-edged channel geometry within a part.

DETAILED DESCRIPTION

[0041] Various embodiments are described more fully below with reference to the accompanying drawings, which form a part hereof, and which show specific exemplary embodiments. However, the concepts of the present disclosure may be implemented in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided as part of a thorough and complete disclosure, to fully convey the scope of the concepts, techniques and implementations of the present disclosure to those skilled in the art. Embodiments may be practiced as methods, systems or devices. The following detailed description is, therefore, not to be taken in a limiting sense.

10 [0042] Reference in the specification to “one embodiment” or to “an embodiment” means that a particular feature, structure, or characteristic described in connection with the embodiments is included in at least one example implementation or technique in accordance with the present disclosure. The appearances of the phrase “in one embodiment” in various places in the specification are not necessarily all referring to the same embodiment.

15 [0043] In addition, the language used in the specification has been principally selected for readability and instructional purposes and may not have been selected to delineate or circumscribe the disclosed subject matter. Accordingly, the present disclosure is intended to be illustrative, and not limiting, of the scope of the concepts discussed herein.

Definitions

20 [0044] Unless otherwise specified, the following terms as used herein shall have the meanings as provided below:

[0045] The term “laminated object manufacturing” refers to a method of manufacturing a part, containing additive and subtractive steps, beginning with contiguous sheets of material, and processing sheets sequentially to form a part.

25 [0046] The term “bonding” refers to the process through which the contiguous sheets of material are formed into a part. The workpiece is subjected to a combination of heat and applied force which form covalent and/or metallic bonds between the sheets of material, forming an object.

[0047] The term “build volume” refers to the geometric volume enclosed by the external faces of the stack of patterned metal sheets.

30 [0048] The term “part” refers to the cold plate, heat exchanger, or other object manufactured with internal flow paths through LOM.

[0049] The term “workpiece” refers to a stack of metal sheets to be bonded into at least one part and at least one corresponding support structure.

[0050] The term “metal sheet” refers to a metal sheet or foil that is stacked in the workpiece. Each metal sheet may be patterned to contain part regions and support structure regions. In some
5 embodiments, the metal sheet may comprise at least one of aluminum, copper, magnesium, titanium, aluminum alloy, magnesium alloy, and/or titanium alloy.

[0051] The term “sheet” refers generally to a metallic layer between 25 μm to 10 cm in thickness.

[0052] The term “void” refers to a volume cut out of a metal sheet in the support or part region
10 which is fully enclosed and not fluidically connected to any other internal channel or port within the workpiece.

[0053] The term “void space” refers to a pattern of voids intentionally cut in a given volume or region.

[0054] The term “flow path” refers to a traceable path of void space through internal channels
15 in the part from at least one external port to at least a second external port.

[0055] The term “channel” refers to at least a portion of the void space in the flow path.

[0056] The term “channel geometry” refers to the shape and area of the cross-section of a channel. The channel geometry may change throughout the flow path.

[0057] The term “cusp” refers to the extreme edges of the channel geometry, as the discrete
20 layer where the void width is less than the layer height.

[0058] The term “aspect ratio” refers to the width of a channel in a direction perpendicular to the application of force during bonding to the height of a channel in the direction parallel to the application of force during bonding.

[0059] The term “tab” refers to a bridge or other small portion of material on at least one metal
25 sheet, which connects at least one region to a second region. A tab may be an uncut area on a metal sheet.

Embodiments

[0060] Embodiments of this invention include configurations of heat exchangers and cold plates for laminated object manufacturing (LOM). Parts produced via LOM processes may be
30 under two different design constraints, which distinguish the technique from other additive

manufacturing techniques. First, the part region of each layer in a LOM-assembled part must be fully contiguous and/or otherwise connected with tabs so that each layer may be handled during the assembly process. Void spaces in the part region, such as long flow channels, will interrupt or weaken the metal sheets. Second, the LOM workpiece must be configured to transmit force in at least one axial direction during bonding, and any internal voids or channels within the part should therefore be configured to transmit the applied force to adjacent layers.

[0061] In embodiments of this invention, the configurations may include the placement of channels within a part to form fluidically connected flow paths for gasses and fluids. These configurations include descriptions of channel geometry with particular cross-sectional shapes and aspect ratios which enable the formation of channels in a part bonded by a heated press. Embodiments of this invention may also include flow pathing and density of channels within the device, with minimum feature sizes and spacing discussed. Non-limiting examples of these embodiments are further discussed below.

LOM Part

[0062] In laminated object manufacturing, a workpiece consisting of a plurality of metal sheets may be assembled and bonded. The workpiece may be assembled in a laminated fashion with the metal sheets. In this manner, the workpiece may be a layered workpiece assembled by depositing the metal sheets. The metal sheets may be patterned such that the pattern of the metal sheets partitions the workpiece into at least one support region and at least one part region. The metal sheets may be bonded in a heated press, a more complicated bonding machine comprising a heated press and a vacuum chamber, and/or a bonding machine of any configuration appropriate for laminated object manufacturing of metal parts. The metal sheets may be bonded by applying a mechanical force along at least one axial direction of the metal sheets.

[0063] In some embodiments, the part regions may be assembled within a build volume of the workpiece. The build volume may be defined as the geometric volume enclosed by the external faces of the stack of patterned metal sheets.

[0064] In some embodiments, the part regions may be configured to sit at some arbitrary orientation or angle with respect to at least one of the external faces of the build volume. This angle may be selected to reduce or minimize the length of channels or other internal geometric features within a single patterned sheet.

[0065] In some embodiments, each metal sheet may have a unique pattern which comprises a cross-sectional slice of the final part. The pattern on each metal sheet (e.g., a pattern of void spaces) may be configured to transmit force through the metal sheets.

5 [0066] In some embodiments, the metal sheets may be patterned so that material is removed from at least one part region of each metal sheet. This may create a pattern of void spaces within the workpiece. The void spaces may be formed via any appropriate cutting technique, such as drag knife cutting, laser cutting, and/or etching. The void spaces may be formed from regular, geometric patterns and/or random distributions within the workpiece. When layers of metal sheets with these void spaces are stacked together, the void spaces across the layers may form channels
10 and a flow path that allow a gas, fluid, and/or vacuum force to flow therein.

[0067] In some embodiments, each metal sheet may include at least one void space. In other embodiments, a subset of the metal sheets may include at least one void space.

[0068] In some embodiments, the void spaces may be distributed throughout the workpiece. In some embodiments, the void spaces may be patterned so as to distribute force throughout the
15 workpiece during bonding.

[0069] In some embodiments, each metal sheet may be patterned to be a closed plane throughout a part region of the metal sheet. Each metal sheet may be patterned so that the void spaces within the metal sheet do not span an entire dimension of the part region. In some embodiments, each metal sheet may be patterned so that the metal sheet maintains its structural
20 integrity when picked up along at least one edge of the metal sheet.

[0070] In some embodiments, each metal sheet may be patterned so that the part regions of the metal sheet are connected by at least one tab. A single tab may comprise multiple metal sheets.

[0071] In some embodiments, the pattern on the metal sheets may be configured to enhance the removal of swarf, filings, cuttings, shavings, and/or other debris from the patterned metal
25 sheets prior to stacking and bonding. For example, patterning the metal sheets to include void spaces may allow for the introduction of vacuum forces to help remove debris from the patterned metal sheets.

[0072] In some embodiments, the pattern may include alignment features that allow a part region to be aligned in a second machine for forming. Examples of these alignment features may
30 include holes or slots for registration pins, slots or keys for positional and angular alignment, indents, and/or alignment marks or indicators. Examples of these alignment features may also include brackets and/or other raised features (e.g., protrusions) that can be aligned with a jig or

support structure on the machine. In some embodiments, a surface on the part regions may be configured to interface with an electronics enclosure or another source of heat.

[0073] In some embodiments, the pattern may include reinforcement features that will increase the strength of the formed part. These may include thicker regions of the part regions for providing added stiffness or durability, such as trusses (e.g., for roof or bridge assemblies), gussets, embedded fibers, ribs, fillets, and/or fillet welds. Additionally and/or alternatively, these features may include penetrations (e.g., holes, cutouts, threads, passages, ports, notches, channels, etc.) for mounting brackets, holes for bolts, rivets, or other fasteners, and/or screw bosses that receive bolts or other fasteners.

10 [0074] In some embodiments, after bonding, the workpiece may be subjected to a mechanical forming process to form a heat exchanger from the workpiece. The part regions may be separated from at least a portion of the support regions. The part regions may be fully extracted from the support regions prior to being formed into the heat exchanger. The forming process may consist of mechanical translations such as pressing, stamping, bending, hydroforming, and/or other processes that alter the geometry of the part regions. The part regions may then be finished with various post-forming processes.

Channel Configurations

[0075] In embodiments of this invention, metal sheets with void spaces may be stacked together to form channels. Each void space may be juxtaposed with a void space of an adjacent metal sheet to form the channels. In some embodiments, at least one of the metal sheets may contain multiple void spaces that form the same channel.

[0076] In some embodiments, specific channel geometries may be patterned into the stack of metal sheets prior to bonding (e.g., via a pattern of stacked void spaces). There may be more than one channel geometry within the part, with some embodiments containing multiple channel geometries. In some embodiments, a single channel geometry may be used for a flow path. In some embodiments, the channel geometry may vary along a single flow path.

[0077] In some embodiments, channels may have a uniform cross-sectional area along the flow path through the part. In other embodiments, the channels may have a variable cross-sectional area along the flow path through the part.

30 [0078] In some embodiments, the channels may have a uniform thickness along a flow path through the part with respect to a plane of the part. In some embodiments, the thickness of the

channels may be at least the thickness of a single metal sheet. In some embodiments, the thickness of the channels may be a multiple of the thickness of a single metal sheet.

[0079] In some embodiments, the channels may be arranged in a parallel fashion through the part. In other embodiments, the channels may cross each other (e.g., in a zig-zag fashion) along a
5 plane of the part.

[0080] In some embodiments, the channels may have an aspect ratio greater than or equal to 1. The aspect ratio may be defined as the ratio of the width of the channel in the direction perpendicular to the application of force during bonding to the height of the channel in the same direction as the application of force during the bonding,

10 [0081] In embodiments of this invention, the channel shape may be configured to transmit force throughout the part while under the force applied during bonding. In some embodiments, the force which can be applied to the part during bonding may be a function of the channel geometry, with the minimum force being determined by how efficiently the force is directed through the part during bonding. In some embodiments, the force which can be applied to the part
15 may be a function of the stiffness of the metal sheets and the maximum span of a void space within the part.

[0082] In some embodiments, the cross-section of the channel may culminate in two points or cusps along the axial direction of force application to the part, with cusps located at the extreme points of the channel along the axial direction of force application. For any cross-section of a
20 channel, one cusp may be located at the surface of the layer adjacent to the lowest layer in the stack of metal sheets where there is void space comprising a channel. Correspondingly, one cusp may be located at the surface of the layer adjacent to the highest layer in the stack of metal sheets where there is void space comprising a channel.

[0083] In some embodiments, the void space comprising the highest or lowest layer of the
25 channel may have a width less than or equal to the layer height. In other embodiments, the void space may have a width corresponding to a single kerf width cut in the metal sheet regardless of layer height.

[0084] In some embodiments, the nominal cross section may contain curves that have been discretized into steps. The steps may each be a full layer in height, with varying cut widths to
30 determine the width of each step. In other embodiments, the steps may be multiple layers in height.

[0085] In some embodiments, the nominal cross section may contain curves that have been smoothed out during the forming process. A forming process may plastically deform the cross section of the part to smooth out discretized steps of the curve.

[0086] In some embodiments, the channel cross sections may be rhomboid, triangular, hexagonal, and/or another shape configured so that in the axial direction of force application, the applied force culminates in a cusp. Channel cross sections may have arched, circular, and/or elliptical shapes, and/or discrete approximations of these shapes.

[0087] In some embodiments, the angle between a line along the axial direction of force application through the cusp and the outermost point on a channel may be at most 90° . In some embodiments, the angle may be less than 45° . In some embodiments, the angle between two lines forming the boundaries of the cusp may be at most 120° . In some embodiments, the angle between two lines forming the boundaries of the cusp may be less than or equal to 90° .

[0088] In some embodiments, each internal channel may be separated from other features such as internal channels and/or the outer wall of the part by at least one layer thickness of a metal sheet. In other embodiments, the minimum thickness between features may be a function of the overall force applied to the part during bonding and the bonding temperature.

[0089] In some embodiments, at least one cusp on the channel may be replaced with an arbitrarily wide planar layer so long as no force transmission is required across the planar layer to create a bond.

[0090] In some embodiments, there may be unsupported regions in the layers adjacent to the part to direct force such that the shape of the channel and nearby regions are not distorted during the bonding process.

[0091] Figure 1 depicts a line drawing of a cross-section of a portion of a channel 101 in a part region. An arched, semi-elliptical channel 102 is discretized by cutting variable width segments out of each of the metal sheets 103 and 103' comprising the part. A cusp 104 is centered at the top of the void space comprising the channel 101, adjacent to the next solid layer within the part.

[0092] Figure 2 depicts a cross-section of a channel 201 with a cusp 204 through a surrounding part region 202. The axial direction of force application is represented by the dashed line 203 and intersects the cusp 204. The angle 205 formed between the axial direction represented by the dashed line 203 and the outermost extent of the part region 202 may in some embodiments be symmetric about the axis.

Flow Path Configurations

[0093] In embodiments of this invention, at least one flow path may be traced through the part. A complete flow path traced through the part may be defined as a fluidically connected void within the part which is connected to at least two externally accessible ports on the part. The flow path
5 may be formed from at least one channel within the part. The flow path may connect to more than two externally accessible ports. The ports may allow for the introduction of a gas and/or fluid through the flow path. At least one of the ports may be an inlet port and/or an outlet port.

[0094] In some embodiments, the ports may have similar and/or identical dimensions. In some embodiments, the inlet ports and/or outlet ports may have similar and/or identical dimensions. In
10 some embodiments, the ports may have a dimension of at least 500 μm . In some embodiments, the ports may have a dimension less than 5 cm.

[0095] In some embodiments, a flow path may include multiple channels that are fluidly connected. In some embodiments, the flow path may consist of multiple channels in parallel. Multiple channels may merge into one or more flow paths in at least a portion of the part. A single
15 channel may split into multiple channels in at least a portion of the part, creating branching flow paths. Flow paths may be merged or split so that one inlet or outlet port may service multiple complementary ports.

[0096] In some embodiments, a flow path may consist of the void space cut through multiple metal sheets, and the void space comprising a single flow path may comprise multiple layers of
20 metal sheets. Flow paths may be traced through void space cut into multiple metal sheets, in all three dimensions through the part. A flow path may consist of several shorter channels that are connected either with smooth curves or at defined angles, so long as the flow path comprises one continuous void space through the part. In some embodiments, flow paths may be placed in high density configurations within the part, with the tortuosity of the flow paths being greater than 1.

25 [0097] In some embodiments, multiple flow paths may be configured to spiral around an internal axis in the part. The flow paths may approximate a spiral but in a discretized fashion with straight channels. In some embodiments, the flow paths may be configured in a zig-zag pattern. The flow paths may be configured to be asymmetric in the part, with a greater density of void space near one external face of the part that interfaces with a source of heat.

30 [0098] In some embodiments, flow paths may be highly tortuous and span multiple layers of the part so that each layer of the LOM-assembled part is contiguous. For parts assembled in a

build volume at a different orientation than that used in the part, each layer of the part in the direction of force application in the build volume may be contiguous.

[0099] In some embodiments, multiple flow paths may be traced through one part. These flow paths may be arranged in a parallel fashion with ports concentrated on one or more faces of the part. In some embodiments, ports may be placed on different faces of the part. In other
5 embodiments, the ports may be placed on a single face of the part. In yet other embodiments, the multiple flow paths may be configured through the part in a cross-flow pattern, with, for example, horizontal flow paths and vertical flow paths with ports on multiple faces of the part.

[0100] In some embodiments, the flow paths may be incomplete flow paths that are connected
10 to a single port. This may allow for a vacuum force to be introduced into the flow paths but may not allow for a gas or liquid to be pumped through the workpiece.

[0101] Figure 3 depicts a LOM-manufactured cold plate 301 with header cross-channels 302 and external access ports 303. Three different flow path configurations are depicted, including linear zig-zags 304, helical spirals 305, and free-form channel geometries 306 of varying cross-
15 sectional areas. Features internal to the part are shown in dashed lines.

[0102] Figure 4 depicts an isometric view of the flow paths of the part depicted in Figure 3 without the surrounding part region visible. External facing inlet ports 401 and outlet ports 402 are shown feeding fluid headers 403 and 403' that distribute flow into multiple parallel flow paths 404.

[0103] Figure 5 depicts a single layer comprising a horizontal cross-section of the part depicted
20 in Figure 3. The part region 501 is a contiguous layer void space cut in 502 which comprises the channels.

Functions

[0104] In some embodiments, positive pressure chambers such as fluid headers and plenum
25 chambers may be incorporated into the flow path to control and distribute fluid flow through the part. In some embodiments, the residence time of the fluid in a particular chamber of the part may be configured to handle point loads for heat exchange.

[0105] In some embodiments, a pump system may pump gas and/or fluid through the flow
30 path. In some embodiments, inlet ports and/or outlet ports may be fluidically connected to the ambient atmosphere via the pump system.

[0106] In some embodiments, the channel geometries and the flow paths may be configured to promote internal mixing within the channels, promote secondary flows within the channels, promote adverse pressure gradients, and/or otherwise disrupt boundary layers formed in the fluid. In some embodiments, the pressure drop along the flow path may be concentrated near a particular external surface or region of the part. In some embodiments, the channel geometry and flow paths may be configured to have high Dean number flow and high Reynolds number flow to promote mixing and turbulent flow within the channels. In some embodiments, the channel geometry may be configured to change over the flow path to create an adverse pressure gradient which promotes internal mixing.

10 [0107] In some embodiments, the flow paths may receive a vacuum force to help remove debris and/or other unwanted substances that may be present in the workpiece. In some embodiments, the flow paths may receive a reducing or inert gas to remove atmospheric oxygen and/or other oxidizing species that may be present in the workpiece. Examples of such gases may include ammonia, carbon monoxide, chlorine, hydrofluoric acid, hydrogen, hydrogen sulfide, magnesium, and/or saline solution.

[0108] In some embodiments, the physical parameters of the cold plate may be configured to accomplish particular functional outputs. The length of the flow path may be selected in conjunction with a particular flow rate to accomplish a particular residence time in the cold plate. The cross-sectional area of the channel geometry and the length of the flow path may be selected to accomplish a particular pressure drop for a given flow rate. The heat transfer capacity of the cold plate may be tuned by configuring the above properties to tune the residence time and flow rate through the cold plate.

[0109] In some embodiments, the assembled heat exchanger may be used as a heat pipe for evaporative cooling, a heat exchanger, and/or a cold plate. The fluid pumped through the flow path may include at least one of a water, a refrigerant or other coolant, a fluid, and/or a gas.

[0110] Figure 6 depicts a method of making a flat-edged channel geometry within a part. The workpiece is divided into a support structure 601 and a part region 602 via a layer of inhibiting material 603. A void space 604 comprising the channel in the part region 602 is placed below a corresponding void space 605 in the support structure 601. The void spaces 604 and 605 are configured to direct force through the full part region 602 under the force applied during bonding.

Equivalents

[0111] The methods, systems, and devices discussed above are examples. Various configurations may omit, substitute, or add various procedures or components as appropriate. For instance, in alternative configurations, the methods may be performed in an order different from that described, and that various steps may be added, omitted, or combined. Also, features described with respect to certain configurations may be combined in various other configurations. Different aspects and elements of the configurations may be combined in a similar manner. Also, technology evolves and, thus, many of the elements are examples and do not limit the scope of the disclosure or claims.

10 [0112] Embodiments of the present disclosure, for example, are described above with reference to block diagrams and/or operational illustrations of methods, systems, and computer program products according to embodiments of the present disclosure. The functions/acts noted in the blocks may occur out of the order as shown in any flowchart. For example, two blocks shown in succession may in fact be executed substantially concurrent or the blocks may sometimes be executed in the reverse order, depending upon the functionality/acts involved. Additionally, or 15 alternatively, not all of the blocks shown in any flowchart need to be performed and/or executed. For example, if a given flowchart has five blocks containing functions/acts, it may be the case that only three of the five blocks are performed and/or executed. In this example, any of the three of the five blocks may be performed and/or executed.

20 [0113] A statement that a value exceeds (or is more than) a first threshold value is equivalent to a statement that the value meets or exceeds a second threshold value that is slightly greater than the first threshold value, e.g., the second threshold value being one value higher than the first threshold value in the resolution of a relevant system. A statement that a value is less than (or is within) a first threshold value is equivalent to a statement that the value is less than or equal to a 25 second threshold value that is slightly lower than the first threshold value, e.g., the second threshold value being one value lower than the first threshold value in the resolution of the relevant system.

[0114] Specific details are given in the description to provide a thorough understanding of example configurations (including implementations). However, configurations may be practiced 30 without these specific details. This description provides example configurations only, and does not limit the scope, applicability, or configurations of the claims. Rather, the preceding description of the configurations will provide those skilled in the art with an enabling description for

implementing described techniques. Various changes may be made in the function and arrangement of elements without departing from the spirit or scope of the disclosure.

[0115] Having described several example configurations, various modifications, alternative constructions, and equivalents may be used without departing from the spirit of the disclosure. For
5 example, the above elements may be components of a larger system, wherein other rules may take precedence over or otherwise modify the application of various implementations or techniques of the present disclosure. Also, a number of steps may be undertaken before, during, or after the above elements are considered.

CLAIMS

What is claimed is:

1. A method to produce a heat exchanger via laminated object manufacturing, the method
5 comprising:
 patterning a plurality of metal sheets so that at least one metal sheet contains at least one
void space of a plurality of void spaces and is otherwise a closed plane;
 assembling the plurality of metal sheets so that the plurality of void spaces forms at least
one channel; and
10 bonding the plurality of assembled metal sheets to form a heat exchanger, wherein the
heat exchanger contains at least one flow path formed from the at least one channel and
connected to at least two externally accessible ports on the heat exchanger.
2. The method of claim 1 wherein the at least one void space of each metal sheet is
15 juxtaposed with the at least one void space of an adjacent metal sheet to form the at least one
channel.
3. The method of claim 1 wherein the plurality of void spaces is patterned so as to distribute
force throughout the workpiece during bonding.
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4. The method of claim 1 wherein the at least one flow path comprises a fluidly connected
plurality of channels.
5. The method of claim 4 wherein a force applied to the workpiece during bonding is a
25 function of at least one channel geometry.
6. The method of claim 4 wherein the plurality of channels comprises a plurality of different
channel geometries.
- 30 7. The method of claim 6 wherein the plurality of different channel geometries comprises at
least one of an arched geometry, a circular geometry, or an elliptical geometry.
8. The method of claim 4 wherein the plurality of channels comprises a single channel
geometry.

9. The method of claim 4 wherein the plurality of channels is arranged in a parallel fashion.
10. The method of claim 1 wherein the at least two externally accessible ports are each on
5 different faces of the heat exchanger.
11. The method of claim 1 wherein a cross-section of the at least one channel culminates in a plurality of cusps along an axial direction of force application to the workpiece.
- 10 12. The method of claim 1 wherein the at least one flow path is configured to promote at least one of internal mixing within the at least one channel, secondary flows within the at least one channel, or adverse pressure gradients within the at least one channel.
13. The method of claim 1 wherein each metal sheet of the plurality of metal sheets is
15 patterned so that the metal sheet maintains its structural integrity when picked up along at least one edge of the metal sheet.
14. The method of claim 1 wherein at least one of the plurality of metal sheets contains a plurality of void spaces that form the same channel.
- 20 15. A system for manufacturing a laminated object heat exchanger, the system comprising:
a laminated object manufacturing device configured to:
pattern a plurality of metal sheets so that at least one metal sheet contains at least
one void space of a plurality of void spaces and is otherwise a closed
25 plane; and
assemble the plurality of metal sheets so that the plurality of void spaces forms at
least one channel; and
a pressor configured to bond the plurality of assembled metal sheets to form a heat
exchanger, wherein the heat exchanger contains at least one flow path formed from the at least
30 one channel and connected to at least two externally accessible ports on the heat exchanger.
16. The system of claim 15 wherein the at least one void space of each metal sheet is juxtaposed with the at least one void space of an adjacent metal sheet to form the at least one channel.

17. The system of claim 15 wherein the at least one flow path comprises a fluidly connected plurality of channels.
- 5 18. The system of claim 15 wherein each metal sheet of the plurality of metal sheet is patterned so that the metal sheet maintains its structural integrity when picked up along at least one edge of the metal sheet.
19. A heat exchanger formed via a laminated object manufacturing process, the process
10 comprising:
 patterning a plurality of metal sheets so that each metal sheet contains at least one void space of a plurality of void spaces and is otherwise a closed plane;
 assembling the plurality of metal sheets so that the plurality of void spaces forms at least one channel; and
15 bonding the plurality of assembled metal sheets to form a heat exchanger, wherein the heat exchanger contains at least one flow path formed from the at least one channel and connected to at least two externally accessible ports on the heat exchanger.
20. The heat exchanger of claim 19 wherein the at least one void space of each metal sheet is
20 juxtaposed with the at least one void space of an adjacent metal sheet to form the at least one channel.
21. The heat exchanger of claim 19 wherein the at least one flow path comprises a fluidly connected plurality of channels.
- 25 22. The heat exchanger of claim 21 wherein a force applied to the workpiece during bonding is a function of at least one channel geometry.
23. The heat exchanger of claim 21 wherein the plurality of channels comprises a plurality of
30 different channel geometries.
24. The heat exchanger of claim 19 wherein the at least two externally accessible ports are each on different faces of the heat exchanger.

25. The heat exchanger of claim 19 wherein each metal sheet of the plurality of metal sheets is patterned so that the metal sheet maintains its structural integrity when picked up along at least one edge of the metal sheet.
- 5 26. The heat exchanger of claim 19 wherein at least one of the plurality of metal sheets contains a plurality of void spaces that form the same channel.
27. The heat exchanger of claim 19 wherein at least one metal sheet is a fin in the flow path.
- 10 28. The heat exchanger of claim 27 wherein the fin extends into or across the fluid volume such that at least one region of the at least one metal sheet is not subject to mechanical force or bonded with any adjacent sheets.