United States Patent Application Publication	20250263344
Kind Code	A1
Publication Date	August 21, 2025
Inventor(s)	Waugh; Katherine E. et al.

EXPANDABLE MALE DIE BLADDER FOR MATCH DIE SHAPE-FORMING SYSTEMS AND METHODS

Abstract

A shape forming tool for pre-carbonization compression of a fibrous preform includes a female forming tool comprising a die recess, a support structure moveable with respect to the female forming tool, and at least one bladder coupled to the support structure and configured to be received into the die recess. The support structure is configured to move the bladder(s) with respect to the female forming tool. The bladder(s) is/are configured to be inflated to apply a compressive force to compress and form a fibrous preform between the bladder(s) and the female forming tool.

Inventors: **Waugh; Katherine E. (Coronado, CA), Koroly; Christopher C. (Spring Valley, CA), Pujar; Vijay V. (San Diego, CA), Linck; John S. (Pueblo, CO), Rosenbrock; Kyle (Pueblo, CO)**

Applicant: **GOODRICH CORPORATION** (Charlotte, NC)

Family ID: **1000008589290**

Assignee: **GOODRICH CORPORATION (Charlotte, NC)**

Appl. No.: **19/204252**

Filed: **May 09, 2025**

Related U.S. Application Data

parent US division 17977781 20221031 parent-grant-document US 12325668 child US 19204252

Publication Classification

Int. Cl.: **C04B35/83** (20060101)

U.S. Cl.:

CPC **C04B35/83** (20130101); C04B2235/5248 (20130101); C04B2235/5256 (20130101); C04B2235/604 (20130101)

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS
[0001] This application is a divisional of, claims priority to and the benefit of, Non-provisional patent application Ser. No. 17/977,781, filed Oct. 31, 2022, and titled "EXPANDABLE MALE DIE BLADDER FOR MATCH DIE SHAPE-FORMING SYSTEMS AND METHODS," which is incorporated by reference herein in their entirety for all purposes.
FIELD
[0002] The present disclosure relates to systems and methods for shape forming composites, and more specifically, to systems and methods for shape forming fiber-reinforced composites.
BACKGROUND
[0003] Composite bodies are utilized in various industries, including the aerospace industry. Needled fiber-reinforced composites are often produced as planar (e.g., flat plate) structures, for example utilizing planar oxidized polyacrylonitrile (PAN) fiber-based preforms followed by carbonization and chemical vapor infiltration (CVI) densification. To make the fiber-reinforcement or a composite material part, it is well known to use a preform that has been needled. This can be achieved by needling two-dimensional plies.
SUMMARY
[0004] According to various embodiments, a shape forming tool is disclosed, comprising a female forming tool comprising a die recess, a support structure moveable with respect to the female forming tool, and a first bladder coupled to the support structure and configured to be received into the die recess. The support structure is configured to move the first bladder with respect to the female forming tool. The first bladder is configured to be inflated to apply a compressive force to compress and form a fibrous preform between the first bladder and the female forming tool.
[0005] In various embodiments, in response to being inflated, the first bladder is configured to extend laterally from a first side of a recess surface of the female forming tool to a second side of the recess surface, opposite from the first side.
[0006] In various embodiments, in response to being inflated, the first bladder is configured to extend vertically from the support structure to a bottom surface of the recess surface of the female forming tool.
[0007] In various embodiments, the shape forming tool further comprises a center die extending from the support structure toward the female forming tool.
[0008] In various embodiments, the first bladder is mounted to a first side of the center die.
[0009] In various embodiments, the shape forming tool further comprises a second bladder mounted to a second side of the center die.
[0010] In various embodiments, the center die is configured to compress the fibrous preform against the female forming tool.
[0011] In various embodiments, the shape forming tool further comprises a control unit configured to control a position of the center die with respect to the female forming tool, and control a first state of the first bladder and a second state of the second bladder.
[0012] In various embodiments, the shape forming tool further comprises gripper plates configured to clamp opposing lateral ends of the fibrous preform to the female forming tool.
[0013] In various embodiments, the control unit is further configured to control the gripper plates.
[0014] A method for controlling a shape-forming process is disclosed, comprising moving a support structure with respect to a female forming tool, inflating a first bladder, and compressing a

fibrous preform between the first bladder and the female forming tool in response to the first bladder being inflated.
[0015] In various embodiments, the method further comprises clamping opposing lateral ends of the fibrous preform to the female forming tool.
[0016] In various embodiments, the method further comprises varying a clamping force on at least one lateral end of the opposing lateral ends.
[0017] In various embodiments, the clamping force is varied based on a measured pressure of the first bladder.
[0018] In various embodiments, the method further comprises receiving a bladder pressure of the first bladder at a control unit, and controlling a gripper plate with the control unit based upon the bladder pressure.
[0019] In various embodiments, the method further comprises receiving at least one of a fibrous preform tension measurement, a fibrous preform compression measurement, or a support structure position measurement at the control unit.
[0020] A method for manufacturing a fiber-reinforced composite part is disclosed, the method comprising positioning a fibrous preform with a female forming tool, the female forming tool comprising a die recess, and forming the fibrous preform into a shaped body. The forming comprises moving a first bladder at least partially into the die recess and over the fibrous preform, wherein the first bladder is mounted to a support structure, activating the first bladder, applying a first compressive force to a bottom wall of the fibrous preform with the first bladder in response to activating the first bladder, and applying a second compressive force to a first sidewall of the fibrous preform with the first bladder in response to activating the first bladder.
[0021] In various embodiments, a first caul plate is disposed between the first bladder and the fibrous preform, and at least one of the first compressive force or the second compressive force is applied to the fibrous preform via the first caul plate.
[0022] In various embodiments, the forming further comprises moving a second bladder at least partially into the die recess and over the fibrous preform, wherein the second bladder is mounted to the support structure, activating the second bladder, applying a third compressive force to the bottom wall of the fibrous preform with the second bladder in response to activating the second bladder, and applying a fourth compressive force to a second sidewall of the fibrous preform with the second bladder in response to activating the second bladder.
[0023] In various embodiments, the forming further comprises moving a center die at least partially into the die recess and applying a fifth compressive force to the bottom wall of the fibrous preform with the center die. In various embodiments, the first bladder is coupled to a first side of the center die and the second bladder is coupled to a second side of the center die.
[0024] The foregoing features and elements may be combined in various combinations without exclusivity, unless expressly indicated herein otherwise. These features and elements as well as the operation of the disclosed embodiments will become more apparent in light of the following description and accompanying drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0025] FIG. **1**A is a schematic sectional illustration of a shape forming system for pre-carbonization compression and shaping a fibrous preform into a shaped body prior to its bladder being activated, in accordance with various embodiments;
[0026] FIG. **1**B is a schematic sectional illustration of the system of FIG. **1**A with its bladder activated to apply compressive forces to the fibrous preform, in accordance with various embodiments;

[0027] FIG. **2** is a perspective illustration of a female forming tool (a female die), in accordance with various embodiments;
[0028] FIG. **3**A is a schematic sectional view of the shape forming system with gripper plates in a closed position, in accordance with various embodiments;
[0029] FIG. **3**B is a schematic sectional view of a gripper plate having protrusions in a closed position, in accordance with various embodiments;
[0030] FIG. **4** is a flow chart for a method of manufacturing a fiber-reinforced composite part of the present disclosure, in accordance with various embodiments;
[0031] FIG. **5** is a schematic sectional illustration of a shape forming system for pre-carbonization compression and shaping a fibrous preform into a shaped body having a center die and bladders disposed on opposing side of the center die, in accordance with various embodiments;
[0032] FIG. **6** is a schematic sectional illustration of the shape forming system of FIG. **5** and further comprising a caul plate for each of the bladders, in accordance with various embodiments;
[0033] FIG. **7** is a perspective illustration of the shape forming system of FIG. **1**A and FIG. **1**B with the bladder in an activated state, in accordance with various embodiments; and
[0034] FIG. **8** is a perspective illustration of the shape forming system of FIG. **6** with the first and second bladders in an activated state, in accordance with various embodiments.

DETAILED DESCRIPTION

[0035] All ranges and ratio limits disclosed herein may be combined. It is to be understood that unless specifically stated otherwise, references to “a,” “an,” and/or “the” may include one or more than one and that reference to an item in the singular may also include the item in the plural.
[0036] The detailed description of exemplary embodiments herein makes reference to the accompanying drawings, which show exemplary embodiments by way of illustration and its best mode, and not of limitation. While these exemplary embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, it should be understood that other embodiments may be realized and that logical, chemical and mechanical changes may be made without departing from the spirit and scope of the invention. For example, the steps recited in any of the method or process descriptions may be executed in any order and are not necessarily limited to the order presented. Moreover, many of the functions or steps may be outsourced to or performed by one or more third parties. Furthermore, any reference to singular includes plural embodiments, and any reference to more than one component or step may include a singular embodiment or step. Also, any reference to attached, fixed, connected or the like may include permanent, removable, temporary, partial, full and/or any other possible attachment option. Additionally, any reference to without contact (or similar phrases) may also include reduced contact or minimal contact.
[0037] As used herein, “fiber volume ratio” means the ratio of the volume of the fibers of the fibrous preform to the total volume of the fibrous preform. For example, a fiber volume ratio of 25% means the volume of the fibers in the fibrous preform is 25% of the total volume of fibrous preform.
[0038] As used herein, the term “fiber density” is used with its common technical meaning with units of g/cm.sup.3 or g/cc. The fiber density may refer specifically to that of the individual fibers in the fibrous preform. The density will be measured, unless otherwise noted, by taking the weight divided by the geometric volume of each fiber. The density may refer to an average density of a plurality of fibers included in a fibrous preform.
[0039] As used herein, “CVI/CVD” may refer to chemical vapor infiltration and/or chemical vapor deposition. Accordingly, CVI/CVD may refer to chemical vapor infiltration or deposition or both.
[0040] In general, there are currently two primary methods of manufacturing carbon/carbon (“C/C”) materials. The first method involves the layup and cure of a carbon fiber, phenolic resin matrix composite, followed by pyrolysis and subsequent phenolic resin infiltration and pyrolysis cycles. Multiple resin infiltration, cure, and pyrolysis cycles are typically used until the part

achieves the desired density. The second method involves fabrication of an oxidized polyacrylonitrile fiber (OPF) or carbon fiber preform, followed by carbonization (for OPF preforms) and chemical vapor infiltration (CVI) densification. The chemical vapor infiltration cycles are continued, in conjunction with machining the preform between infiltration cycles if desired, until the desired part density is achieved. Combinations of these two basic process methods are also in use and may include variations in preform architecture, infiltration resin type, and chemical vapor infiltration conditions. A third method may involve a combination of the two aforementioned processes including layup and cure of a carbon fiber, phenolic resin matrix composite, followed by pyrolysis, and CVI densification.

[0041] After a fibrous OPF preform (also referred to herein as a fibrous preform) is made, it is carbonized to convert the OPF into carbon fibers. Typically, fibrous preforms are carbonized by placing the preforms in a furnace with an inert atmosphere. As is well-understood, the heat of the furnace causes a chemical conversion which drives off the non-carbon chemical species from the preform. The resulting preform generally has the same fibrous structure as the fibrous preform before carbonizing; however, the OPF have been converted to 100%, or nearly 100%, carbon. After the preform has been carbonized, the preform is densified. In general, densification involves filling the voids, or pores, of the fibrous preform with additional carbon material. This may be done using the same furnace used for carbonization or a different furnace. Typically, chemical vapor infiltration and deposition ("CVI/CVD") techniques are used to densify the porous fibrous preform with a carbon matrix. This commonly involves heating the furnace and the carbonized preforms, and flowing hydrocarbon gases into the furnace and around and through the fibrous preforms. As a result, carbon from the hydrocarbon gases separates from the gases and is deposited on and within the fibrous preforms. When the densification step is completed, the resulting C/C part has a carbon fiber structure with a carbon matrix infiltrating the fiber structure, thereby deriving the name "carbon/carbon".

[0042] Fiber-reinforced composite parts of the present disclosure may be formed using OPF fabrics that are shape-formed prior to carbonization. Fiber-reinforced composite parts of the present disclosure may be formed using multi-axial, non-crimp, stitch-bonded, OPF fabrics that are shape-formed prior to carbonization. Fiber-reinforced composite parts of the present disclosure may be particularly useful for high temperature aerospace applications, such as for re-entry vehicle applications or other high temperature applications such as where a hot gas impinges on the vehicle after being rapidly compressed and heated as a result of a high pressure bow shock in front of the vehicle. Fiber-reinforced composite parts of the present disclosure may be especially useful in these applications because of the superior high temperature characteristics of C/C material. In particular, the carbon/carbon material used in C/C parts is a good conductor of heat and is able to dissipate heat generated during high temperature conditions. Carbon/carbon material is also highly resistant to heat damage, and thus, may be capable of sustaining forces during severe conditions without mechanical failure.

[0043] Application of OPF-based carbon-carbon composites has been generally limited to simple flat structures including C/C aircraft brake disks. C/C components including leading edges, structural members and other contour-shape carbon composites are often produced as planar structures (i.e., flat, planar components); however, these materials tend to maintain low interlaminar properties. A shape formed 3D C/C part offers opportunity for similar in-plane C/C properties with higher interlaminar properties than planar C/C.

[0044] FIG. **1**A and FIG. **1**B are schematic views of a shape forming tool **120** for pre-carbonization compression and shaping a fibrous preform **110**, in accordance with various embodiments. Shape forming tool **120** may be configured as a matched die forming tool. Shape forming tool **120** may be configured for forming a shaped fibrous preform **110** from a multi-layered preform; e.g., a stack of a plurality of layers of material. Shape forming tool **120** may include a female forming tool **122** and an expandable male die arrangement comprising a bladder **124** and a vertically translating support structure **126**. This expandable male die tooling design allows the shape forming tool **120** to have enough flexibility to maintain pressure application on the fibrous preform **110** (including the sidewalls **118**) as the thickness of the material decreases during the pre-carbonization compression process. Support structure **126** may comprise a caul plate (e.g., a metal plate among others) or other type of support structure moveable with respect to female forming tool **122**. In various embodiments, female forming tool **122** and/or support structure **126** is made from a metal or metal alloy material. In various embodiments, bladder **124** is made from a rubber material or other elastomeric material capable of expanding (i.e., increasing in volume) in response to being inflated with a compressed fluid.

[0045] With reference to FIG. **2**, the female forming tool **122** extends longitudinally along a longitudinal centerline **106** of the female forming tool **122** (e.g., along X-axis) between and to a first end **170** of the female forming tool **122** and a second end **172** of the female forming tool **122**. The female forming tool **122** extends laterally (e.g., along a Y-axis) between and to a first side **174** of the female forming tool **122** and a second side **176** of the female forming tool **122**. The female forming tool **122** extends vertically (e.g., along a Z-axis) between and to a bottom side **178** of the female forming tool **122** and a top side **180** of the female forming tool **122**.

[0046] The female forming tool **122** is configured with at least one die recess **182**; e.g., an aperture such as a pocket, a channel, a groove, etc. The die recess **182** of FIG. **2** extends (e.g., partially) vertically into the female forming tool **122** from one or more top surfaces **184** of the female forming tool **122** to a recess surface **186** of the female forming tool **122**, where the top surfaces **184** of FIG. **2** are arranged on opposing sides of the recess surface **186** at the female forming tool top side **180**. The die recess **182** of FIG. **2** extends longitudinally in (e.g., through) the female forming tool **122**, for example, between and to the female forming tool first end **170** and/or the female forming tool second end **172**. The die recess **182** of FIG. **2** extends laterally in (e.g., within) the female forming tool **122**, for example, between opposing lateral sides of the recess surface **186**.

[0047] The recess surface **186** is a concave or concave-convex surface and may have a curved geometry; e.g., a compound curvature. The recess surface **186** of FIG. **2**, for example, has a curved (e.g., arcuate, splined, etc.) cross-sectional geometry in a lateral-vertical reference plane; e.g., a Y-Z plane. The recess surface **186** may also have a curved (e.g., arcuate, splined, etc.) cross-sectional geometry in a longitudinal-vertical reference plane; e.g., a X-Z plane. This recess curvature may change as the recess surface **186** of the die recess **182** extends laterally and/or longitudinally, which may provide the recess surface **186** with a complex 3D curvature. In various embodiments, the recess curvature may remain uniform as the recess surface **186**/the die recess **182** extends laterally and/or longitudinally. The recess surface **186** may be configured without any sharp corners or sharp transitions.

[0048] In various embodiments, the recess surface **186** comprises a radii surface **181** which forms a rounded, convex surface transition between a sidewall portion **185** of the recess surface **186** and the female forming tool top surface **184**. The fibrous preform may be bent around or over radii surface **181**. Radii surface **181** may minimize wrinkling of the fibrous preform **110** during the forming process. Radii surface **181** may facilitate attachment of lateral ends of fibrous preform **110** to gripper plates (e.g., see gripper plates **204** of FIG. **3**A). Radii surface **181** may extend between and to the female forming tool first end **170** and the female forming tool second end **172**. In various embodiments, an angled surface **183** oriented at an angle (e.g., between 5 and 75 degrees) with respect to the female forming tool top surface **184** is disposed between the radii surface **181** and the female forming tool top surface **184**. Angled surface **183** may extend between and to the female forming tool first end **170** and the female forming tool second end **172**.

[0049] With reference to FIG. **1**A and FIG. **1**B, methods for manufacturing a fiber-reinforced part of the present disclosure include pre-carbonization compression of a fibrous preform **110**. Fibrous preform **110** may comprise polyacrylonitrile (PAN) or OPF fibers extending in three directions and leaving a plurality of pores or open spaces and may be prepared for shape-forming, compression, and carbonization; though fibrous preform **110** may comprise various types of fibers, including carbon fibers, glass fibers, aromatic polyamide fibers, among others. In various embodiments, fibrous preform **110** is formed by stacking layers of PAN or OPF fibers and superimposing the layers (e.g., by stacking sheets of fabric). The layers may be needled perpendicularly to each other (i.e., along the Z-direction) with barbed, textile needles or barbless, structuring needles. In various embodiments, the layers are needled at an angle of between 0° and 80° (e.g., 0°, 30°, 45°, 60°, 80°, etc.) with respect to the Z-direction to each other. The needling process generates a series of z-fibers through fibrous preform **110** that extend perpendicularly to the fibrous layers. The z-fibers are generated through the action of the needles pushing fibers from within the layer (x-y or in-plane) and reorienting them in the z-direction (through-thickness). Needling of the fibrous preform may be done as one or more layers are added to the stack or may be done after the entire stack of layers is formed. The needles may also penetrate through only a portion of fibrous preform **110**, or may penetrate through the entire fibrous preform **110**. In addition, resins are added, in various embodiments, to fibrous preform **110** by either injecting the resin into the preform following construction or coating the fibers or layers prior to forming the fibrous preform **110**. The needling process may take into account needling parameters optimized to maintain fiber orientation, minimize in-plane fiber damage, and maintain target interlaminar properties.

[0050] After needling the fibrous preform **110** (if needling is used), the non-woven fibrous preform **110** may be both compressed to higher fiber volume ratio and formed to shape in a single-step shape-forming process (i.e., using the shape forming tool of the present disclosure). It should be understood, moreover, that fibrous preforms **110** not subject to needling prior to pre-carbonization compression are also within the scope of the present disclosure.

[0051] In various embodiments, prior to being shape-formed, the fibrous preform **110** comprises a generally planar shape and may be placed over the female forming tool **122**. After the fibrous preform **110** is placed over the female forming tool **122**, the bladder **124** and support structure **126** are placed over the fibrous preform **110** and into the female forming tool **122**, thereby beginning the shaping and compressing of the fibrous preform **110** as the fibrous preform is pressed into the female forming tool **122**. In various embodiments, the bladder **124** and support structure **126** may be first placed into the female forming tool **122** to push the fibrous preform **110** down to the bottom of the recess surface **186**. In various embodiments, the fibrous preform **110** may also be first pushed down to the bottom of the recess surface **186** by hand. In various embodiments, the fibrous preform **110** may also be first pushed down to the bottom of the recess surface **186** using an auxiliary tool.

[0052] With reference to FIG. **3**A, once the fibrous preform **110** is generally pushed down (in the negative Z-direction) in place against the bottom of the recess surface **186** (e.g., by hand or using the bladder **124**), the opposing lateral ends **202** of fibrous preform **110** may be clamped to female forming tool **122** using one or more gripper plates **204**. The gripper plates **204** may be arranged in one or more arrays disposed along a respective opposing side **174**, **176** of the female forming tool **122**. In various embodiments, discrete gripper plates **204** are longitudinally spaced from each neighboring (e.g., adjacent) gripper plate **204** in the same gripper plate array. However, in various embodiments, a single gripper plate **204** may extend longitudinally along the side of the female forming tool **122**.

[0053] Each gripper plate **204** may include a first plate portion **206** oriented substantially parallel with a clamping surface **208** of the female forming tool **122**. A grip surface **210** of the gripper plate **204** may be configured to contact the fibrous preform **110**. The grip surface **210** may be configured with a relatively high coefficient of static friction and/or kinetic friction, whereas each female forming tool clamping surface **208** may be configured with a relatively low coefficient of static friction and/or kinetic friction. The grip surface **210**, for example, may be textured whereas each female forming tool clamping surface **208** may be smooth; e.g., polished. The grip surface **210** may also be formed from a material with a higher coefficient of static friction and/or kinetic friction than the material of the female forming tool **122**.

[0054] The grip surface **210** of FIG. **3**A may be aligned with a respective portion of the female forming tool clamping surface **208**. The grip surface **210** of FIG. **3**A, for example, at least partially or completely laterally and/or longitudinally overlaps the respective portion of the female forming tool clamping surface **208**.

[0055] In various embodiments, the gripper plates **204** may be controlled—e.g., by a control unit **201**—in concert with the bladder **124**. In various embodiments, control unit **201** includes one or more controllers (e.g., processors) and one or more tangible, non-transitory memories capable of implementing digital or programmatic logic. In various embodiments, for example, the one or more controllers are one or more of a general purpose processor, digital signal processor (DSP), application specific integrated circuit (ASIC), field programmable gate array (FPGA), or other programmable logic device, discrete gate, transistor logic, or discrete hardware components, or any various combinations thereof or the like. In various embodiments, the control unit **201** controls, at least various parts of, and operation of various components of, the shape forming tool **120**. The control unit **201** may control a position of the support structure **126**, thereby controlling a position of the bladder **124**. Control unit **201** may control an inflation pressure of bladder **124** (e.g., via compressed fluid source **128**). The control unit **201** may control a position of the gripper plates **204** (e.g., a clamping force and/or a tension force applied to the fibrous preform **110**).

[0056] In various embodiments, control unit **201** may be configured to send a control signal to the support structure **126** (i.e., to a control mechanism thereof, such as a linear actuator or other mechanism for controlling a position of the support structure **126**). Control unit **201** may be further configured to send a control signal to gripper plates **204** (i.e., to a control mechanism thereof, such as a linear actuator or other mechanism for controlling a position of the gripper plate **204**) to control a clamping pressure and/or a clamping tension applied to the fibrous preform **110** by the gripper plates **204**. Control unit **201** may be configured to receive feedback signals (e.g., via a force sensor or the like) from gripper plates **204** (e.g., indicating a clamping force and/or a tension force applied to the fibrous preform **110** by the gripper plates) and may control the pressure of bladder **124**, the position of support structure **126**, and/or the position of gripper plates **204** in concert based upon these feedback signals. In this manner, tension exerted by gripper plates **204** and the shape forming pressure applied by bladder **124** (and or center die **326** (see FIG. **5**)) may be actively adjusted simultaneously, or nearly simultaneously, during the manufacturing process.

[0057] In various embodiments, gripper plates **204** comprise one or more actuators **215**, schematically shown in FIG. **3**A, configured to control lateral movement of the gripper plates **204** to apply tension to fibrous preform **110**. In various embodiments, actuators **215** are linear actuators configured to move gripper plates **204** laterally with respect to female forming tool **122**. Actuators **215** may cause the fibrous preform **110** to be further tensioned as the bladder applies pressure to the fibrous preform **110** (e.g., as support structure **126** is moved toward fibrous preform **110** and/or as the inflation pressure in bladder **124** is increased). In this regard actuators **215** may be controlled by control unit **201**.

[0058] In various embodiments, the pressure of bladder **124** is used as a setpoint for when to operate the gripper plates **204**. As one non-limiting example, if commanding a bladder pressure of 10 psi, when the bladder pressure reaches 5 psi (halfway to full pressure) then the control unit **201** may command the gripper plate **204** to operate (i.e., to apply a clamping force). In general, control unit **201** may receive a measured pressure of the bladder **124** and vary a clamping pressure or a tension applied to the fibrous preform **110** based upon the measured pressure of the bladder **124**. Additionally, feedback from position sensors (e.g., to indicate vertical position of support structure **126**) or feedback from pressure sensors (e.g., directly measuring compression on the preform) may also be fed into the control unit **201** to operate the gripper plates **204**. In various embodiments, a strain gauge (or similar) may be used to send preform tension feedback to the control unit **201** in order to increase or decrease gripper plate tension.

[0059] In various embodiments, and with reference to FIG. **3**B, grip surface **210** of one or more gripper plates **204** may also include one or more protrusions **212** for penetrating into the fibrous preform **110**. The protrusions **212** may thereby lock a portion of the fibrous preform **110** in place; e.g., constrain movement of the respective engaged preform portion.

[0060] With reference to FIG. **4**, a flow diagram of a method **400** for forming a fibrous OPF preform **110** into a shaped body is provided, in accordance with various embodiments. For ease of description, the method **400** is described below with reference to FIG. **1**A through FIG. **3**B. The method **400** of the present disclosure, however, is not limited to use of the exemplary shape forming tool **120** of FIG. **1**A through FIG. **3**B.

[0061] In step **402**, the fibrous preform **110** is provided. Fibrous preform **110** may be configured as a multi-layered preform. The preform **110** of FIG. **3**A and FIG. **3**B, for example, includes a stack **114** of a plurality of layers of material **111**A-C (generally referred to as "**111**"). This stack **114** includes the top layer of material **111**A at/forming a top side of the fibrous preform **110** and the bottom layer of material **111**B at/forming a bottom side of the fibrous preform **110**. The stack **114** may also include at least one (or more) intermediate layer of material **111**C vertically between the top layer of material **111**A and the bottom layer of material **111**B.

[0062] Each layer of material **111** may share a common (e.g., the same) construction and/or material makeup. Each layer of material **111** in the stack **114**, for example, may be formed by a sheet/layer of fibrous material; e.g., non-woven oxidized polyacrylonitrile (PAN) fibers. However, one or more layers of dissimilar construction may also be included (e.g., a non-woven with a chopped fiber mat sacrificial material).

[0063] In step **404**, the fibrous preform **110** is arranged with the female forming tool **122**. The fibrous preform **110** is disposed on the female forming tool **122** at its top side **180** (see FIG. **5**). The bottom layer of material **111**B may engage (e.g., vertically contacts, is abutted against, lays flush on, etc.) the female forming tool top surfaces **184**. In various embodiments, heat is added to the fibrous preform **110** during the shape forming process. For example, tool **120** may be heated whereby heat is conducted from the tool **120** into the fibrous preform **110**. In various embodiments, it is further contemplated that heaters, separate from the tool **120**, may be provided for heating the fibrous preform **110** during the shape-forming process. In various embodiments, components of the shape forming tool **120** may be heated in an oven prior to being introduced to the fibrous preform **110**, for example to a shape forming temperature of between 150° F. and 400° F. (65° C.-205° C.) in various embodiments, between 200° F. and 350° F. (93° C.-177° C.) in various embodiments, between 200° F. and 300° F. (93° C.-149° C.) in various embodiments, and between 225° F. and 275° F. (107° C.-135° C.) in various embodiments.

[0064] In various embodiments, moisture is added to the fibrous preform **110** during the shape-forming process. For example, a sizing agent comprising a fluid and/or fluid vapor such as water, steam, and/or polyvinyl alcohol may be applied to the fibrous preform **110** (e.g., before being shape formed). Adding the sizing agent to the fibrous preform **110** may dampen the fibers thereof which tends to relax the fibers of the fibrous preform thereby aiding in the bending, forming, and/or stretching of the fibrous preform. Adding the sizing agent to the fibrous preform **110** may tend to reduce wrinkling of the fibrous preform **110**. Sizing may help to protect the fiber from handling damage and provide lubricity allowing the fibers to slide easily during preforming/compaction and aid in preventing wrinkling and kinking. Sizing agents of the present disclosure include water soluble polymers. The sizing agent may comprise an aqueous solution. The sizing agent and may comprise long chain alcohols such as polyvinyl alcohols, modified starch, cellulose gum such as carboxymethyl cellulose, modified wax, acrylates, and/or mixtures thereof. In various embodiments, up to about 700 mL (23.7 fluid oz) of water or more may be applied to the fibrous preform **110**, though the amount of water is a variable parameter based on a variety of factors, including the size and volume of the fibrous preform **110**. In various embodiments, approximately 1 milliliter (ml) of water may be added for every 2.5 cubic inches of fibrous preform (1 ml/2.5

in.sup.3), wherein the term approximately as used in this context can only mean ±0.5 ml. Stated differently, between 0.5 ml and 1.5 ml of water may be added to the fibrous preform for every 2.5 cubic inches of fibrous preform. However, it should be understood that other amounts of water or sizing agent may be added to the fibrous preform without departing from the scope of the present disclosure. Moreover, the fibrous preform may be preconditioned in a humidity chamber at a humidifying temperature (e.g., between 100° F. (37.8° C.) and 200° F. (93.3° C.)) and a relative humidity (e.g., between 75% and 90% humidity). Adding the sizing agent to the fibrous preform **110** may tend to reduce wrinkling of the fibrous preform **110** and support stabilizing the preform into the desired shape. In this manner, the fibrous preform **110** may be compressed to higher fiber volume ratio and formed to shape using heat, moisture, and pressure into contoured shapes using tool **120** as desired for a particular fiber-reinforced composite part application.

[0065] The fibrous preform **110** may be pushed down (in the negative Z-direction) to the bottom of the recess surface **186** of the female forming tool **122** (see FIG. **3**A). The bottom layer of material **111**B may engage (e.g., vertically contacts, is abutted against, lays flush on, etc.) the female forming tool clamping surfaces **208**. The top layer of material **111**A may be disposed next to and under the gripper plates **204**. The gripper plates **204** of FIG. **3**A, for example, are disposed along a periphery of the fibrous preform **110** and its stack **114**. More particularly, each of the gripper plates **204** of FIG. **3**A (see also FIG. **3**B) longitudinally and laterally overlaps the fibrous preform **110** and its stack **114** along opposing sides of the periphery. However, it should be understood that the shape forming process of the present disclosure may be performed without gripper plates **204** (e.g., the periphery of the fibrous preform **110** may extend freely from between the female forming tool **122** and the bladder **124**).

[0066] The fibrous preform **110** and its stack **114** of the layers of material **111** may have a planar configuration. Prior to forming the shaped body **116**, for example, the fibrous preform **110** and its stack **114** of the layers of material **111** may be configured as a flat plate. Of course, in other embodiments, one or more of the layers of material **111** in the stack **114** may slightly bend (e.g., droop) into the die recess **182**.

[0067] In step **406**, the fibrous preform **110** is formed into the shaped body **116**. During this formation step **406**, support structure **126** and bladder **124** may together move (e.g., downward) vertically from a first position to a (e.g., closed) position (e.g., see FIG. **1**B and FIG. **3**A). In various embodiments, support structure **126** and bladder **124** are moved downward together as an assembly. The bladder **124** may be inflated using a compressed fluid source **128**. The compressed fluid source **128** may comprise a compressed air tank, a hydraulic reservoir, or any other suitable compressed fluid source for filling the bladder **124** with a compressed fluid. As the bladder **124** is filled, the bladder **124** may begin to expand and compress the fibrous preform **110** and its stack **114** that overlaps (e.g., spans laterally and longitudinally across) the die recess **182**. More particularly, the bladder **124** vertically presses against the top layer of material **111**A (e.g., at the bottom wall **117**) and also laterally presses against the top layer of material **111**A (at the sidewalls **118**).

[0068] As the bladder **124** is filled with a compressed fluid, the bladder **124** may expand laterally (e.g., along the Y-axis) to compress (e.g., see compression forces represented by arrows **194** in FIG. **1**B) a sidewall **118** of the fibrous preform **110**. Moreover, the bladder **124** may expand vertically (e.g., along the Z-axis) to compress (e.g., see compression forces represented by arrows **196** in FIG. **1**B) a bottom wall **117** of the fibrous preform **110**. Support structure **126** may react compression forces **196**. Stated differently, support structure **126** may be secured from being biased away from female forming tool **122** by compression forces **196**. In various embodiments, the support structure **126** may be moved (e.g., downward) in the vertical direction (e.g., along the Z-axis) to compress (e.g., see compression forces represented by arrows **196** in FIG. **1**B) the bottom wall **117** of the fibrous preform **110**. In various embodiments, the support structure **126** may be moved (e.g., downward) in the vertical direction (e.g., along the Z-axis) to compress (e.g., see compression forces represented by arrows **196** in FIG. **1**B) the sidewalls **118** of the fibrous preform **110**.

Expansion timing of bladder **124** may depend on physical translation, cycle time, and/or temperature.

[0069] As the bladder **124** expands and/or the support structure **126** is moved downward, the bladder **124** may reshape the stack **114** of the layers of material **111** to conform to (e.g., take the shape of) the recess surface **186**. The fibrous preform **110** and its stack **114** of the layers of material **111**, more particularly, are press formed (e.g., stamped) into the shaped body **116** between the bladder **124** and the recess surface **186** of female forming tool **122**. Stated differently, inflating the bladder **124** and/or moving the support structure **126** downward causes the bladder to expand in the vertical direction and/or the lateral direction to exert lateral forces (see arrows **192**) and/or lateral forces (see arrows **194**) into the fibrous preform **110**.

[0070] In various embodiments, with the bladder **124** in the inflated position, the bladder **124** may extend laterally from a first side of the recess surface **186** to a second side of the recess surface **186**, opposite from the first side. Moreover, with the bladder **124** in the inflated position, the bladder **124** may extend vertically from the support structure **126** to a bottom surface of the recess surface **186**.

[0071] In various embodiments, with the bladder **124** in the inflated position, the shape forming tool **120** and shaped body **116** may be heated to the shape forming temperature (e.g., loaded into an oven) for a predetermined duration (e.g., between an hour and 24 hours in various embodiments). Pressure may be maintained and/or increased within bladder **124** (and/or support structure **126** may be moved downward) while the compressed assembly is in the oven so that the bladder **124** is biased toward the female forming tool **122** as the shaped body **116** compresses and/or shrinks over time. Stated differently, the bladder **124** and/or support structure **126** may be electronically controlled—e.g., by control unit **201**—to maintain a predetermined pressure (e.g., as a function of time, temperature, and/or pressure) on shaped body **116** during the heating process. In this regard, control unit **201** may be configured to control a position of the support structure **126** with respect to the female forming tool **122** and may be further configured to control a first state (e.g., inflated or deflated) of the first bladder **324***a* and a second state (e.g., inflated or deflated) of the second bladder **324***b*

[0072] Shape forming tool **120** may form the fibrous preform **110** into the shaped body **116** comprising a final, or near final, shape of the desired fiber-reinforced composite part. In various embodiments, the shaped body **116** comprises a U-shape cross-sectional geometry (e.g., in the Y-Z plane). In various embodiments, the shaped body **116** comprises a complex curvature, depending on the geometry of the recess surface **186** of the female forming tool **122**. With reference to FIG. **1**B, shaped body **116** including a sidewall **118** bent at an angle α with respect to a bottom wall **117** is illustrated, in accordance with various embodiments. In various embodiments, angle α is between one degree and one hundred and seventy-nine degrees) (1°-179°, between thirty degrees and one hundred and seventy degrees) (30°-170°, between thirty degrees and one hundred and twenty degrees) (30°-120°, between forty-five degrees and one hundred and seventy degrees) (45°-170°, between sixty degrees and one hundred and seventy degrees) (60°-170°, between ninety degrees and one hundred and seventy degrees) (90°-170°, between thirty degrees and one hundred and seventy degrees) (30°-170°, between eighty degrees and one hundred degrees) (80°-100°, or about ninety degrees) (90°. The angle α is generally chosen based on the shape of the desired fiber-reinforced composite part.

[0073] The shape forming tool **120** and its components **122**, **124**, **126** are described above using the terms “bottom” and “top” with reference to exemplary orientations in the drawings. The present disclosure, however, is not limited to any particular formation system orientations. For example, in other embodiments, the female forming tool **122** may alternatively be configured as a top die.

[0074] In step **408**, the shaped body **116** is released from the shape forming tool **120** for further processing. The shaped body **116** may be removed from the die recess **182** and placed into a similarly shaped graphite fixture which is configured to maintain the compressed shape of the shaped body **116** during a subsequent carbonization process. The components of the graphite fixture may be made from a graphite material or other material suitable for withstanding carbonization and/or densification temperatures.

[0075] In step **510**, and with the shaped body **116** secured in compression within a graphite fixture, the shaped body **116** may be carbonized to maintain shape and decrease fiber volume. In various embodiments, shaped body **116** together with graphite fixture may be placed in a furnace for carbonization. The carbonization process may be employed to convert the fibers of the shaped body **116** into pure carbon fibers, as used herein only "pure carbon fibers" means carbon fibers comprised of at least 99% carbon. The carbonization process is distinguished from the densification process described below in that the densification process involves infiltrating the pores of the shaped body **116** and depositing a carbon matrix within and around the carbon fibers of the shaped body **116**, and the carbonization process refers to the process of converting the fibers of the fibrous preform **110** into pure carbon fibers.

[0076] The shape-formed fibrous preform **110** may be carbonized by placing the shape-formed fibrous preform **110** in a furnace with an inert atmosphere. In general, the carbonization process involves heating the shape-formed fibrous preform **110** in a furnace to a temperature greater than about 1,600 degrees Celsius (2912 Fahrenheit). Typically, an inert atmosphere of nitrogen, argon or a vacuum is provided in the furnace during the carbonization process. The heat of the furnace causes a chemical conversion of the OPF that converts the fibers to carbon fibers and drives off other chemicals. Although it is sometimes preferred that the fibers in the carbonized fiber preform be 100% carbon fiber, it is generally acceptable for a less than full conversion to take place. The resulting carbonized fiber preform generally has the same fibrous structure as the fibrous preform before carbonizing. During carbonization, the total mass and the total fiber volume in each fibrous preform is typically reduced due to the loss of non-carbon compounds.

[0077] Fiber density of the fibrous preform **110** may increase during carbonization (e.g., from about 1.37 g/cc in OPF state to about 1.77-1.85 g/cc after carbonization, depending on the final carbonization temperature). In various embodiments, the OPF fibers shrink during carbonization, as OPF may have a char/carbon yield of around 50%. As used herein "char/carbon yield" means the remaining mass of the OPF after degrading the OPF using the carbonization process.

[0078] After carbonization, the carbonized shaped body **116** may be densified using chemical vapor infiltration (CVI), as described in further detail below. After carbonization, shaped body **116** may be densified. In various embodiments, the shaped body **116** is removed from graphite fixture prior to densification. In various embodiments, the shaped body **116** is placed in a perforated graphite fixture during one or more densification runs. The shaped body **116** may be densified with pyrolytic carbon by CVI using optimized process conditions to maintain shape and support efficient carbon densification. In general, densification involves filling the voids, or pores, of the fibrous preform with additional carbon material. This may be done using the same furnace used for carbonization or a different furnace. Typically, chemical vapor infiltration and deposition ("CVI/CVD") techniques are used to densify the porous fibrous preform with a carbon matrix. This commonly involves heating the furnace and the carbonized preforms, and flowing hydrocarbon gases (e.g., at least one of methane, ethane, propane, butane, and/or the like, as described herein) into the furnace and around and through the fibrous preforms. In various embodiments, the CVI/CVD process may include a temperature gradient. In various embodiments, the CVI/CVD process may include a pressure gradient. In various embodiments, the CVI/CVD process may include a temperature and a pressure gradient.

[0079] CVI/CVD densification may be conducted in a vacuum or partial vacuum (e.g., at pressures of 1-15 torr) or in an inert atmosphere at a temperature in the range from about 900° C. to about 1100° C. (1,652° F. to about 2,012° F.), and in various embodiments in the range of up to about 1,000° C. (1,832° F.) (wherein the term about in this context only means +/−100° C.) for a period of time in the range from about 150 hours to about 650 hours, and in various embodiments, in the range from about 300 hours to about 500 hours (wherein the term about in this context only means

+/−24 hours).

[0080] As a result, carbon from the hydrocarbon gases separates from the gases and is deposited on and within the fibrous preforms. Typically, the densification process is continued until the preform reaches a density in the range from 1.6 to 1.9 grams per cubic centimeter (g/cc), and in various embodiments, a density of approximately 1.80 g/cc. When the densification step is completed, the resulting C/C part has a carbon fiber structure with a carbon matrix infiltrating the fiber structure, thereby deriving the name “carbon/carbon.”

[0081] After a first CVI/CVD cycle of 300 to 500 hours, an intermediate heat treat is typically performed, in the same furnace. This heat treat (>1600° C.) serves to dimensionally stabilize the shaped body **116**, increase its thermal properties, and increase its porosity for subsequent densification. The shaped body **116** may then be machined to open the porosity further, to help allow for final density to be achieved using only one more CVI/CVD cycle. Part densities after first machining may be in the range of 1.4 to 1.7 g/cc, depending on the part thickness, overall size, and placement within the furnace. Typical, average density range is 1.55-1.65 g/cc.

[0082] The densification process may be continued until the preform reaches a desired density, for example in the range from 1.7 to 1.9 grams per cubic centimeter (g/cc), and in various embodiments, a density of approximately 1.80 g/cc. The CVI/CVD process may be continued with the shaped body **116** removed from the perforated graphite fixture. In this manner, the outer surfaces of the shaped body **116** may be more directly exposed to the gas flow. Moreover, the shaped body **116** may be machined in between carbon CVI densification processes (e.g., between fixtured carbon CVI densification and non-fixtured carbon CVI densification and/or between successive non-fixtured carbon CVI densification processes). Machining (e.g., grinding, sanding, milling, grit blasting, etc.) the shaped body **116** may be performed to achieve a final desired part shape. Machining the shaped body **116** may be performed to expose voids, or pores, of the shaped body **116** so as to facilitate infiltration with additional carbon material during subsequent carbon CVI densification. When the densification step is completed, and the desired density is achieved, the resulting C/C part has a carbon fiber structure with a carbon matrix infiltrating the fiber structure, thereby deriving the name “carbon/carbon.”

[0083] Following the CVI/CVD densification process, the C/C (or other fiber-reinforced composite) part may undergo a final heat treatment (FHT) process. This may be done using the same furnace used for densification or a different furnace. If done using the same furnace, the flow of hydrocarbon gases would be stopped following the end of the densification process and the temperature increased. FHT may be conducted in a vacuum or partial vacuum (e.g., at pressures of 1-15 torr) or in an inert atmosphere at a temperature in the range from about 1200° C. to about 2600° C. (2,921° F. to about 4,712° F.), and in various embodiments in the range from about 1400° C. to about 2200° C. (2,552° F. to about 3,992° F.) (wherein the term about in this context only means +/−100° C.) for a period of time in the range from about 4 hours to about 14 hours, and in various embodiments, in the range from about 8 hours to about 12 hours (wherein the term about in this context only means +/−2 hours). In various embodiments, the FHT process imparts high temperature dimensional stability to the final fiber-reinforced composite part. In various embodiments, the FHT process imparts desired thermal properties associated with thermal shock such as high thermal conductivity, high heat capacity, and/or high emissivity.

[0084] With respect to FIG. **5**, elements with like element numbering, as depicted in FIG. **1**A and FIG. **1**B, are intended to be the same and will not necessarily be repeated for the sake of clarity.

[0085] FIG. **5** is a schematic view of a shape forming tool **320** for pre-carbonization compression and shaping a fibrous preform **110**, in accordance with various embodiments. Shape forming tool **320** may be similar to shape forming tool **120**, except that shape forming tool **320** further comprises a center die **326** and two bladders (e.g., bladder **324***a* and bladder **324***b*) coupled to opposite sides of the center die **326**. Center die **326** may be made from a metal or metal alloy. In various embodiments, bladder **324***a* is mounted to a first laterally facing side of center die **326** and bladder **324***b* is mounted to an opposing, second laterally facing side of center die **326**.

[0086] In various embodiments, center die **326** may be supported by support structure **126** and may move together therewith. In various embodiments, center die **326** extends from the support structure **126** toward the female forming tool **122**. In response to support structure **126** moving vertically (e.g., downward along the Z-axis), the center die **326** may compress (e.g., see compression forces represented by arrows **197** in FIG. **5**) a bottom wall **117** of the fibrous preform **110**. Moreover, bladder **324***a* and bladder **324***b* may be inflated with a compressed fluid from compressed fluid source **128**. In various embodiments, the inflation of bladders **324***a* and **324***b* and the vertical movement of support structure **126** may be performed in concert by control unit **201**. In various embodiments, center die **326** is moved vertically (e.g., downward) against bottom wall **117** to begin compressing the fibrous preform **110** and to secure the bottom wall **117** of the fibrous preform **110** in place. The bladders **324***a* and **324***b* may then be inflated to compress the remainder of the bottom wall **117** and the sidewalls **118** of the fibrous preform **110**. Gripper plates **204** (see FIG. **3**A) may simultaneously be operated to maintain a desired tension on fibrous preform **110** during the shape-forming process. In this regard, gripper plates **204** may also be operated in concert with the inflation of bladders **324***a* and **324***b* and the vertical movement of support structure **126** using control unit **201** and feedback from various components (e.g., bladder pressure, vertical positioning of support structure **126**, compressive forces on fibrous preform **110**, and/or tension on fibrous preform **110**, among other factors as desired).

[0087] FIG. **6** is a schematic view of shape forming tool **320** further including caul plates (e.g., first caul plate **301** and second caul plate **302**) disposed between the first and second bladders **324***a*, **324***b* and the female forming tool **122**, in accordance with various embodiments. First caul plate **301** may be disposed between first bladder **324***a* and female forming tool **122**. Second caul plate **302** may be disposed between second bladder **324***b* and female forming tool **122**. First and second caul plates **301**, **302** may aid in uniformly applying pressure to fibrous preform **110**. Moreover, by using caul plates **301**, **302**, the shape of the inner surface of the fibrous preform **110** may be more precisely controlled. In various embodiments, features may be formed into the inner surface of fibrous preform **110** using caul plates **301**, **302**. Caul plates **301**, **302** may be made from a metal or metal alloy.

[0088] In response to actuation, the bladders **324***a*, **324***b* will expand to apply uniform pressure to caul plates **301** and **302**, respectively, that will form inner surface (i.e., the surface facing away from the female forming tool **122**) of the fibrous preform **110**. Caul plate **301** may be moveable with respect to caul plate **302**. Caul plates **301**, **302** may provide a more rigid forming than would be provided with only the bladders **324***a*, **324***b*. Caul plates **301**, **302** may be more rigid than bladders **324***a*, **324***b*.

[0089] FIG. **7** is a perspective illustration of the shape forming system of FIG. **1**A and FIG. **1**B with the bladder **124** in an activated state, in accordance with various embodiments. In various embodiments, bladder **124** extends from and between the first end **170** of the female forming tool **122** and the second end **172** of the female forming tool **122**. However, in various embodiments, two or more discrete bladders **124** may be disposed along the longitudinal direction (e.g., along the X-direction).

[0090] FIG. **8** is a perspective illustration of the shape forming system of FIG. **6** with the first and second bladders **324***a*, **324***b* in activated states, in accordance with various embodiments. In various embodiments, bladders **324***a*, **324***b* extend from and between the first end **170** of the female forming tool **122** and the second end **172** of the female forming tool **122**. However, in various embodiments, bladder **324***a* or bladder **324***b* may comprise two or more discrete bladders disposed along the longitudinal direction (e.g., along the X-direction). Likewise, center die **326** may extend from and between the first end **170** of the female forming tool **122** and the second end **172** of the female forming tool **122**. However, in various embodiments, center die **326** may comprise two or more discrete center dies disposed along the longitudinal direction (e.g., along the X-direction).

[0091] Systems and methods are provided. In the detailed description herein, references to “various embodiments”, “one embodiment”, “an embodiment”, “an example embodiment”, etc., indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to affect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described. After reading the description, it will be apparent to one skilled in the relevant art(s) how to implement the disclosure in alternative embodiments.
[0092] Benefits, other advantages, and solutions to problems have been described herein with regard to specific embodiments. However, the benefits, advantages, solutions to problems, and any elements that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as critical, required, or essential features or elements of the invention. The scope of the invention is accordingly to be limited by nothing other than the appended claims, in which reference to an element in the singular is not intended to mean “one and only one” unless explicitly so stated, but rather “one or more.” Moreover, where a phrase similar to “at least one of A, B, or C” is used in the claims, it is intended that the phrase be interpreted to mean that A alone may be present in an embodiment, B alone may be present in an embodiment, C alone may be present in an embodiment, or that any combination of the elements A, B and C may be present in a single embodiment; for example, A and B, A and C, B and C, or A and B and C. Furthermore, no element, component, or method step in the present disclosure is intended to be dedicated to the public regardless of whether the element, component, or method step is explicitly recited in the claims. No claim element herein is intended to invoke 35 U.S.C. 112(f) unless the element is expressly recited using the phrase “means for.” As used herein, the terms “comprises,” “comprising,” or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus.

Claims

1. A method for controlling a shape-forming process, comprising: moving a support structure with respect to a female forming tool; inflating a first bladder; and compressing a fibrous preform between the first bladder and the female forming tool in response to the first bladder being inflated.
2. The method of claim 1, further comprising clamping opposing lateral ends of the fibrous preform to the female forming tool.
3. The method of claim 2, further comprising varying a clamping force on at least one lateral end of the opposing lateral ends.
4. The method of claim 3, wherein the clamping force is varied based on a measured pressure of the first bladder.
5. The method of claim 2, further comprising: receiving a bladder pressure of the first bladder at a control unit; and controlling a gripper plate with the control unit based upon the bladder pressure.
6. The method of claim 1, further comprising receiving at least one of a fibrous preform tension measurement, a fibrous preform compression measurement, or a support structure position measurement at the control unit.
7. A method for manufacturing a fiber-reinforced composite part, the method comprising: positioning a fibrous preform with a female forming tool, the female forming tool comprising a die recess; and forming the fibrous preform into a shaped body, the forming comprising: moving a first bladder at least partially into the die recess and over the fibrous preform, wherein the first bladder

is mounted to a support structure; activating the first bladder; applying a first compressive force to a bottom wall of the fibrous preform with the first bladder in response to activating the first bladder; and applying a second compressive force to a first sidewall of the fibrous preform with the first bladder in response to activating the first bladder.

8. The method of claim 7, wherein a first caul plate is disposed between the first bladder and the fibrous preform, and at least one of the first compressive force or the second compressive force is applied to the fibrous preform via the first caul plate.

9. The method of claim 7, wherein the forming further comprises: moving a second bladder at least partially into the die recess and over the fibrous preform, wherein the second bladder is mounted to the support structure; activating the second bladder; applying a third compressive force to the bottom wall of the fibrous preform with the second bladder in response to activating the second bladder; and applying a fourth compressive force to a second sidewall of the fibrous preform with the second bladder in response to activating the second bladder.

10. The method of claim 9, wherein the forming further comprises: moving a center die at least partially into the die recess; and applying a fifth compressive force to the bottom wall of the fibrous preform with the center die; wherein the first bladder is coupled to a first side of the center die and the second bladder is coupled to a second side of the center die.