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Double vacuum debulk processing

Abstract

Methods and a double vacuum processing system are presented. A double vacuum processing system comprises a first vacuum zone; a second vacuum zone encompassing the first vacuum zone; a first vacuum pump connected to the first vacuum zone and configured to draw a vacuum within the first vacuum zone; a second vacuum pump connected to the second vacuum zone and configured to draw a vacuum within the second vacuum zone; and a diverter valve. The diverter valve is configured to alternate between pneumatically connecting the first vacuum zone to the second vacuum pump or connecting the first vacuum zone to the first vacuum pump.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION (1) This application claims the benefit of U.S. Provisional Patent Application Ser. No. 63/383,154, filed Nov. 10, 2022, and entitled "Improved Double Vacuum Debulk Processing," which is incorporated herein by reference in its entirety.

BACKGROUND INFORMATION
1. Field
(1) The present disclosure relates generally to processing composite materials and more specifically to curing composite materials using a double vacuum debulk process and apparatus.
2. Background
(2) Composite materials are strong, light-weight materials created by combining two or more functional components. For example, a composite material may include reinforcing fibers bound in polymer resin matrix. The fibers can take the form of a unidirectional tape, woven cloth or fabric, or a braid.
(3) After the different layers of a composite laminate have been laid up, the layers of composite material may be consolidated and cured upon exposure to temperature and pressure, thus forming the final composite structure. Conventionally composite laminates are cured in an autoclave. Autoclaves are large, expensive, and have a high processing time. Autoclaves are often a bottleneck for manufacturing processes.
(4) Therefore, it would be desirable to have a method and apparatus that takes into account at least some of the issues discussed above, as well as other possible issues.
SUMMARY
(5) An embodiment of the present disclosure provides a double vacuum processing system. The double vacuum processing system comprises a first vacuum zone; a second vacuum zone

encompassing the first vacuum zone; a first vacuum pump connected to the first vacuum zone and configured to draw a vacuum within the first vacuum zone; a second vacuum pump connected to the second vacuum zone and configured to draw a vacuum within the second vacuum zone; and a diverter valve. The diverter valve is configured to alternate between pneumatically connecting the first vacuum zone to the second vacuum pump or connecting the first vacuum zone to the first vacuum pump.
(6) Another embodiment of the present disclosure provides a double vacuum processing system. The double vacuum process system comprises two vacuum pumps; a cure tool configured to support a composite laminate for curing; and a diverter valve. The cure tool comprises a first channel and a second channel, each of the first channel and the second channel extends through a thickness of the cure tool. The diverter valve is pneumatically connected to the first channel and the second channel. The diverter valve is configured to alternate between connecting a first vacuum zone formed in part by the cure tool to a respective one of the two vacuum pumps.
(7) A further embodiment of the present disclosure provides a method of performing a cure cycle on a composite laminate. Vacuum is pulled in two vacuum zones using two vacuum pumps, the two vacuum zones comprising a first vacuum zone enclosing the composite laminate and a second vacuum zone enclosing the first vacuum zone. The two vacuum zones are pneumatically connected such that a single vacuum pump of the two vacuum pumps pulls vacuum in both the first vacuum zone and the second vacuum zone. Gas extraction is performed on the composite laminate while the two vacuum zones are pneumatically connected. The two vacuum zones are pneumatically isolated following gas extraction and prior to curing the composite laminate.
(8) A yet further embodiment of the present disclosure provides a method of performing gas extraction in a double vacuum debulk of a composite laminate. A vacuum is pulled in a first vacuum zone enclosing the composite laminate. A second vacuum is pulled in a second vacuum zone enclosing the first vacuum zone. The composite laminate is heated while pulling the vacuum and the second vacuum. A diverter valve is activated to pneumatically connect the first vacuum zone to the second vacuum zone during heating in order to perform at least a portion of the gas extraction of the double vacuum debulk.
(9) Another embodiment of the present disclosure provides a method of performing a thermal cycle in a double vacuum debulk of a composite laminate. A vacuum is drawn in a vacuum bag encompassing a composite laminate. A vacuum is drawn in a rigid chamber encompassing the vacuum bag. The vacuum bag is vented to the rigid chamber to equalize vacuum levels within the vacuum bag and the rigid chamber during a double vacuum portion of the thermal cycle. The vacuum bag is switched to a discrete vacuum source for a remainder of the thermal cycle.
(10) The features and functions can be achieved independently in various embodiments of the present disclosure or may be combined in yet other embodiments in which further details can be seen with reference to the following description and drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) The novel features believed characteristic of the illustrative embodiments are set forth in the appended claims. The illustrative embodiments, however, as well as a preferred mode of use, further objectives and features thereof, will best be understood by reference to the following detailed description of an illustrative embodiment of the present disclosure when read in conjunction with the accompanying drawings, wherein:
(2) FIG. **1** is an illustration of an aircraft in accordance with an illustrative embodiment;
(3) FIG. **2** is an illustration of a block diagram of a manufacturing environment in accordance with an illustrative embodiment;

(4) FIG. **3** is an illustration of a partial cross-sectional view of a double vacuum processing system in accordance with an illustrative embodiment;
(5) FIG. **4** is an illustration of a partial cross-sectional view of a double vacuum processing system in accordance with an illustrative embodiment;
(6) FIG. **5** is an illustration of a partial cross-sectional view of a double vacuum processing system in accordance with an illustrative embodiment;
(7) FIG. **6** is an illustration of a partial cross-sectional view of a double vacuum processing system in accordance with an illustrative embodiment;
(8) FIG. **7** is an illustration of a partial cross-sectional view of a double vacuum processing system in accordance with an illustrative embodiment;
(9) FIG. **8** is a flowchart of a method of performing a cure cycle on a composite laminate in accordance with an illustrative embodiment;
(10) FIG. **9** is a flowchart of a method of performing gas extraction in a double vacuum debulk of a composite laminate in accordance with an illustrative embodiment;
(11) FIG. **10** is a flowchart of a performing a thermal cycle in a double vacuum debulk of a composite laminate in accordance with an illustrative embodiment;
(12) FIG. **11** is an illustration of an aircraft manufacturing and service method in a form of a block diagram in accordance with an illustrative embodiment; and
(13) FIG. **12** is an illustration of an aircraft in a form of a block diagram in which an illustrative embodiment may be implemented.

DETAILED DESCRIPTION

(14) The illustrative examples recognize and take into account one or more different considerations. The illustrative examples recognize and take into account that autoclaves are very expensive to acquire, maintain, and operate. Additionally, the use of autoclaves creates a bottle neck in the production system. There can be lengthy queue times for parts waiting to be cured.
(15) The illustrative examples recognize and take into account that alternatives to autoclaves have been developed for curing composite laminates. Conventional double vacuum debulk and curing utilizes a double vacuum degassing step. Regulation of the vacuum within the two vacuum zones can be undesirably difficult. The illustrative examples present double vacuum debulk processes and apparatuses that allow for better control of vacuum levels.
(16) Turning now to FIG. **1**, an illustration of an aircraft is depicted in accordance with an illustrative embodiment. Aircraft **100** has wing **102** and wing **104** attached to body **106**. Aircraft **100** includes engine **108** attached to wing **102** and engine **110** attached to wing **104**.
(17) Body **106** has tail section **112**. Horizontal stabilizer **114**, horizontal stabilizer **116**, and vertical stabilizer **118** are attached to tail section **112** of body **106**.
(18) Aircraft **100** is an example of an aircraft having components formed of composite products cured using double vacuum debulking. For example, a portion of wing **102** or wing **104** can be formed using double vacuum debulking. As another example, a portion of body **106** can be formed using double vacuum debulking.
(19) Turning now to FIG. **2**, an illustration of a block diagram of a manufacturing environment is depicted in accordance with an illustrative embodiment. Portions of aircraft **100** of FIG. **1** can be manufactured in manufacturing environment **200**.
(20) Manufacturing environment **200** contains double vacuum processing system **202** configured to debulk and cure composite laminate **204**. Composite laminate **204** can take any desirable form. In some illustrative examples, composite laminate **204** comprises a plurality of prepreg plies. In some illustrative examples, composite laminate **204** comprises a honeycomb core.
(21) Double vacuum processing system **202** comprises first vacuum zone **206** enclosing composite laminate **204** and second vacuum zone **208** encompassing first vacuum zone **206**. Second vacuum zone **208** is formed by rigid chamber **210**. Rigid chamber **210** is configured to withstand pressure **212** to be applied within rigid chamber **210** during processing of composite laminate **204**.

(22) Rigid chamber **210** includes top **222** and walls **224** connected to top **222** to form cavity **226**. In some illustrative examples, rigid chamber **210** can also be referred to as lid **228** of double vacuum processing system **202**.
(23) First vacuum zone **206** is formed by vacuum bag **216** sealed to cure tool **230**. Cure tool **230** is configured to support composite laminate **204** during curing.
(24) Rigid chamber **210** is sealed to at least one of vacuum bag **216** or cure tool **230**. In some illustrative examples, rigid chamber **210** is sealed to cure tool **230**. In some illustrative examples, rigid chamber **210** is sealed to vacuum bag **216**. In some illustrative examples, rigid chamber **210** is sealed to vacuum bag **216** such that rigid chamber **210** and vacuum bag **216** are raised and lowered together. In these illustrative examples, second vacuum zone **208** is maintained prior to forming first vacuum zone **206** around composite laminate **204** on cure tool **230**. Raising and lowering rigid chamber **210** connected to vacuum bag **216** can reduce manufacturing time. In some illustrative examples, raising and lowering rigid chamber **210** connected to vacuum bag **216** can enable an automated curing process.
(25) In some illustrative examples, when rigid chamber **210** is sealed and connected to vacuum bag **216**, vacuum bag **216** is sealed to cure tool **230**. In some illustrative examples, sealant material (not depicted) is applied between vacuum bag **216** and cure tool **230** to form first vacuum zone **206**.
(26) First vacuum pump **232** is connected to first vacuum zone **206**. First vacuum pump **232** is configured to control pressure **218** within first vacuum zone **206**. First vacuum pump **232** is configured to pull vacuum **220** within first vacuum zone **206** to degas composite laminate **204**.
(27) Second vacuum pump **234** is configured to control pressure **212** within second vacuum zone **208**. Second vacuum pump **234** is connected to second vacuum zone **208**. Second vacuum pump **234** is configured to pull vacuum **214** within second vacuum zone **208** to allow vacuum bag **216** to be slack during degas of composite laminate **204**. To allow vacuum bag **216** to be slack during degassing, vacuum **214** and vacuum **220** are substantially the same. To regulate vacuum **214** and vacuum **220**, diverter valve **236** is present in double vacuum processing system **202**.
(28) Double vacuum processing system **202** comprises first vacuum zone **206**, second vacuum zone **208** encompassing first vacuum zone **206**, first vacuum pump **232** connected to first vacuum zone **206** and configured to draw vacuum **220** within first vacuum zone **206**, second vacuum pump **234** connected to second vacuum zone **208** and configured to draw vacuum **214** within second vacuum zone **208**, and diverter valve **236** configured to alternate between pneumatically connecting first vacuum zone **206** to second vacuum pump **234** or connecting first vacuum zone **206** to first vacuum pump **232**. In some illustrative examples, activating diverter valve **236** pneumatically connects first vacuum zone **206** to second vacuum zone **208**. In some illustrative examples, activating diverter valve **236** to pneumatically connect first vacuum zone **206** to second vacuum zone **208** comprises activating diverter valve **236** to close a pneumatic connection from first vacuum zone **206** to first vacuum pump **232** and open a pneumatic connection from first vacuum zone **206** to second vacuum pump **234**. During degassing, first vacuum pump **232** initially pulls vacuum **220** within vacuum bag **216**. During degassing, diverter valve **236** is activated to pneumatically couple first vacuum zone **206** to second vacuum pump **234**. First vacuum zone **206** and second vacuum zone **208** being both pneumatically connected to the same vacuum pump, second vacuum pump **234**, maintaining vacuum **214** and vacuum **220** at substantially the same level is simpler than using two vacuum pumps and regulators. First vacuum zone **206** is substantially smaller than second vacuum zone **208**. Due to the volumetric differences between first vacuum zone **206** and second vacuum zone **208**, any equal adjustments made to the separate vacuum systems using first vacuum pump **232** and second vacuum pump **234** would result in a temporary imbalance in the vacuum levels between first vacuum zone **206** and second vacuum zone **208**. The smaller volume of first vacuum zone **206** changes much more quickly than the large volume of second vacuum zone **208**. Placing first vacuum zone **206** in communication with second vacuum zone **208** chamber during the gas extraction phase means that any adjustments to vacuum

levels, vacuum **214** and vacuum **220**, will happen in unison between first vacuum zone **206** and second vacuum zone **208**. Diverter valve **236** is actuated to alternate between allowing communication between and isolating first vacuum zone **206** and second vacuum zone **208**.
(29) Cure tool **230** forms a first portion of first vacuum zone **206** and vacuum bag **216** completes first vacuum zone **206**. In some illustrative examples, communication between first vacuum zone **206** and second vacuum zone **208** is through cure tool **230**. In some illustrative examples, double vacuum processing system **202** comprises channel **238** through cure tool **230** connecting first vacuum zone **206** to second vacuum zone **208** through diverter valve **236**. Additional not depicted conduits are present to pneumatically connect diverter valve **236** to first vacuum zone **206** and second vacuum zone **208**.
(30) Cure tool **230** forms a bottom portion of second vacuum zone **208**. Rigid chamber **210** forms a top portion of second vacuum zone **208**. In some illustrative examples, channel **238** is not present. In some illustrative examples, double vacuum processing system **202** comprises channel **240** through rigid chamber **210** connecting first vacuum zone **206** to second vacuum zone **208** through diverter valve **236**.
(31) In other illustrative examples, channel **240** is not present. In some illustrative examples, diverter valve **236** can be connected to conduits connected to second vacuum pump.
(32) In some illustrative examples, vacuum bag **216** comprises pressure relief valve **242** in vacuum bag **216**. In some illustrative examples, pressure relief valve **242** is present to prevent inflation of vacuum bag **216**.
(33) Double vacuum processing system **202** comprises two vacuum pumps, first vacuum pump **232** and second vacuum pump **234**, cure tool **230** configured to support composite laminate **204** for curing, and diverter valve **236** pneumatically connected to first channel, channel **244**, and second channel, channel **238**, of cure tool **230**. Each of first channel, channel **244**, and second channel, channel **238**, extend through a thickness of cure tool **230**. Diverter valve **236** is configured to alternate between connecting first vacuum zone **206** formed in part by cure tool **230** to a respective one of the two vacuum pumps, first vacuum pump **232** and second vacuum pump **234**.
(34) Vacuum bag **216** is sealed to cure tool **230** to form first vacuum zone **206** enclosing composite laminate **204**. First channel, channel **244**, extends into first vacuum zone **206**. In some illustrative examples, second channel, channel **238**, extends into second vacuum zone **208**.
(35) After degassing with first vacuum zone **206** and second vacuum zone **208** in pneumatic communication, first vacuum zone **206** is pneumatically isolated from second vacuum zone **208**. During debulk of composite laminate **204**, first vacuum pump **232** pulls vacuum **220** within first vacuum zone **206** enclosing composite laminate **204**. During debulk of composite laminate **204**, second vacuum pump **234** pulls a second vacuum, vacuum **214**, within second vacuum zone **208** surrounding first vacuum zone **206**. Composite laminate **204** is heated while vacuum **220** is within first vacuum zone **206** and vacuum **214** is within second vacuum zone **208**. Afterwards, vacuum **214** in second vacuum zone **208** is released to compress composite laminate **204**.
(36) In some illustrative examples, during compression portions of the debulk, vacuum **220** with first vacuum zone **206** is a higher vacuum than vacuum **214** in second vacuum zone **208**. During some of the processing, pressure **212** in second vacuum zone **208** is greater than pressure **218** in first vacuum zone **206** to allow for compression of composite laminate **204**. A higher pressure in second vacuum zone **208** applies a compression during recompression and curing. Pressure **212** and **237** are controlled during debulk and curing to prevent vacuum bag **216** from expanding or inflating.
(37) The illustration of manufacturing environment **200** in FIG. **2** is not meant to imply physical or architectural limitations to the manner in which an illustrative embodiment may be implemented. Other components in addition to or in place of the ones illustrated may be used. Some components may be unnecessary. Also, the blocks are presented to illustrate some functional components. One or more of these blocks may be combined, divided, or combined and divided into different blocks

when implemented in an illustrative embodiment.
(38) Although not depicted, in some illustrative examples, a heat source is positioned within or on top of cure tool **230** to provide heat to composite laminate **204**. As another example, illustrations of double vacuum processing system **202** are simplified for descriptive purposes only. As an example, any desirable vacuum components such as cauls, breathers, release films, or other vacuum supporting components although not depicted, can be present in first vacuum zone **206**.
(39) In some illustrative examples, vacuum bag **216** also has a pressure relief valve. In these illustrative examples, the pressure relief valve vents from first vacuum zone **206** into second vacuum zone **208**.
(40) Turning now to FIG. **3**, an illustration of a partial cross-sectional view of a double vacuum processing system is depicted in accordance with an illustrative embodiment. Double vacuum processing system **300** can be used to form a component of aircraft **100** of FIG. **1**. Double vacuum processing system **300** is a physical implementation of double vacuum processing system **202** of FIG. **2**. Double vacuum processing system **300** is used to debulk and cure composite laminate **304**. Double vacuum processing system **300** comprises cure tool **302**. Cure tool **302** is configured to support a composite laminate, such as composite laminate **304**, during curing. Vacuum bag **306** is sealed over composite laminate **304** by seals **308** to form first vacuum zone **310**. Cure tool **302** forms a first portion of first vacuum zone **310**. Vacuum bag **306** completes first vacuum zone **310**.
(41) Cure tool **302** forms a bottom portion of second vacuum zone **314**. Rigid chamber **312** forms a top portion of second vacuum zone **314**. In this illustrative example, rigid chamber **312** is sealed to cure tool **302**. Rigid chamber **312** comprises top **313** and walls **315**. Rigid chamber **312** includes top **313** and walls **315** connected to top **313** to form cavity **317**. In this illustrative example, rigid chamber **312** is positioned over and sealed to cure tool **302** to form second vacuum zone **314**. Second vacuum zone **314** encompasses first vacuum zone **310**.
(42) First vacuum pump **316** is connected to first vacuum zone **310** and configured to draw a vacuum within first vacuum zone **310**. First vacuum pump **316** is pneumatically connected to first vacuum zone **310**. As depicted, first vacuum pump **316** is pulling a vacuum in first vacuum zone **310**.
(43) Second vacuum pump **318** is connected to second vacuum zone **314** and configured to draw a vacuum within second vacuum zone **314**. Diverter valve **320** is configured to alternate between pneumatically connecting first vacuum zone **310** to second vacuum pump **318** or connecting first vacuum zone **310** to first vacuum pump **316**.
(44) In this illustrative example, channel **322** through cure tool **302** connects first vacuum zone **310** to diverter valve **320**. In this illustrative example, channel **324** through cure tool **302** connects first vacuum zone **310** to second vacuum zone **314** through diverter valve **320**.
(45) Double vacuum processing system **300** comprises two vacuum pumps, first vacuum pump **316** and second vacuum pump **318**, cure tool **302** configured to support composite laminate **304** for curing, and diverter valve **320**. Cure tool **302** comprises a first channel, channel **322**, and a second channel, channel **324**. Each of the first channel and the second channel extends through a thickness of cure tool **302**.
(46) Diverter valve **320** is pneumatically connected to the first channel, channel **322**, and the second channel, channel **324**. Diverter valve **320** is configured to alternate between connecting first vacuum zone **310** formed in part by cure tool **302** to a respective one of the two vacuum pumps.
(47) Turning now to FIG. **4**, an illustration of a partial cross-sectional view of a double vacuum processing system is depicted in accordance with an illustrative embodiment. View **400** is a view of double vacuum processing system **300** of FIG. **3** during gas extraction. In view **400**, diverter valve **320** has been activated to place first vacuum zone **310** in communication with second vacuum zone **314**. In this illustrative example, diverter valve **320** was activated to pneumatically connect first vacuum zone **310** to second vacuum zone **314** during heating in order to perform at least a portion of the gas extraction of the double vacuum debulk. In view **400**, second vacuum pump **318** pulls a

vacuum in both first vacuum zone **310** and second vacuum zone **314**. By placing first vacuum zone **310** in pneumatic communication with second vacuum zone **314**, the vacuum is equalized between the two vacuum zones.

(48) Turning now to FIG. **5**, an illustration of a partial cross-sectional view of a double vacuum processing system is depicted in accordance with an illustrative embodiment. View **500** is a view of double vacuum processing system **300** of FIG. **3** during reconsolidation of composite laminate **304**. Between view **400** and view **500**, diverter valve **320** was activated to pneumatically isolate first vacuum zone **310** from second vacuum zone **314**. The two vacuum zones, first vacuum zone **310** and second vacuum zone **314**, are pneumatically isolated following gas extraction and prior to curing composite laminate **304**.

(49) Turning now to FIG. **6**, an illustration of a partial cross-sectional view of a double vacuum processing system is depicted in accordance with an illustrative embodiment. Double vacuum processing system **600** can be used to form a component of aircraft **100** of FIG. **1**. Double vacuum processing system **600** is a physical implementation of double vacuum processing system **202** of FIG. **2**. Double vacuum processing system **600** is an alternate design to double vacuum processing system **300** of FIGS. **3-5**.

(50) Double vacuum processing system **600** is used to debulk and cure composite laminate **604**. Double vacuum processing system **600** comprises cure tool **602**. Cure tool **602** is configured to support a composite laminate, such as composite laminate **604**, during curing. Vacuum bag **606** is sealed over composite laminate **604** by seals **608** to form first vacuum zone **610**. Cure tool **602** forms a first portion of first vacuum zone **610**. Vacuum bag **606** completes first vacuum zone **610**.

(51) Cure tool **602** forms a bottom portion of second vacuum zone **614**. Rigid chamber **612** forms a top portion of second vacuum zone **614**. In this illustrative example, rigid chamber **612** is sealed to cure tool **602**. Rigid chamber **612** comprises top **613** and walls **615**. Rigid chamber **612** includes top **613** and walls **615** connected to top **613** to form cavity **617**. In this illustrative example, rigid chamber **612** is positioned over and sealed to cure tool **602** to form second vacuum zone **614**. Second vacuum zone **614** encompasses first vacuum zone **610**.

(52) First vacuum pump **616** is connected to first vacuum zone **610** and configured to draw a vacuum within first vacuum zone **610**. First vacuum pump **616** is pneumatically connected to first vacuum zone **610**. As depicted, first vacuum pump **616** is pulling a vacuum in first vacuum zone **610**.

(53) Second vacuum pump **618** is connected to second vacuum zone **614** and configured to draw a vacuum within second vacuum zone **614**. Diverter valve **620** is configured to alternate between pneumatically connecting first vacuum zone **610** to second vacuum pump **618** or connecting first vacuum zone **610** to first vacuum pump **616**.

(54) In this illustrative example, channel **622** through cure tool **602** connects first vacuum zone **610** to diverter valve **620**. Channel **624** through rigid chamber **612** connects first vacuum zone **610** to second vacuum zone **614** through diverter valve **620**.

(55) Turning now to FIG. **7**, an illustration of a partial cross-sectional view of a double vacuum processing system is depicted in accordance with an illustrative embodiment. Double vacuum processing system **700** can be used to form a component of aircraft **100** of FIG. **1**. Double vacuum processing system **700** is a physical implementation of double vacuum processing system **202** of FIG. **2**. Double vacuum processing system **700** is an alternate design to double vacuum processing system **300** of FIGS. **3-5**.

(56) Double vacuum processing system **700** is used to debulk and cure composite laminate **704**. Double vacuum processing system **700** comprises cure tool **702**. Cure tool **702** is configured to support a composite laminate, such as composite laminate **704**, during curing. Vacuum bag **706** is sealed over composite laminate **704** by seals **708** to form first vacuum zone **710**. Cure tool **702** forms a first portion of first vacuum zone **710**. Vacuum bag **706** completes first vacuum zone **710**.

(57) Cure tool **702** forms a bottom portion of second vacuum zone **714**. Rigid chamber **712** forms a

top portion of second vacuum zone **714**. In this illustrative example, rigid chamber **712** is sealed to cure tool **702**. Rigid chamber **712** comprises top **713** and walls **715**. Rigid chamber **712** includes top **713** and walls **715** connected to top **713** to form cavity **717**. In this illustrative example, rigid chamber **712** is positioned over and sealed to cure tool **702** to form second vacuum zone **714**. Second vacuum zone **714** encompasses first vacuum zone **710**.
(58) First vacuum pump **716** is connected to first vacuum zone **710** and configured to draw a vacuum within first vacuum zone **710**. First vacuum pump **716** is pneumatically connected to first vacuum zone **710**. As depicted, first vacuum pump **716** is pulling a vacuum in first vacuum zone **710**.
(59) Second vacuum pump **718** is connected to second vacuum zone **714** and configured to draw a vacuum within second vacuum zone **714**. Diverter valve **720** is configured to alternate between pneumatically connecting first vacuum zone **710** to second vacuum pump **718** or connecting first vacuum zone **710** to first vacuum pump **716**.
(60) In this illustrative example, channel **722** through cure tool **702** connects first vacuum zone **710** to diverter valve **720**. In this illustrative example, diverter valve **720** is connected to second vacuum pump **718** by conduit **724**.
(61) The illustration of double vacuum processing system **300** in FIGS. **3-7** is not meant to imply physical or architectural limitations to the manner in which an illustrative embodiment may be implemented. Other components in addition to or in place of the ones illustrated may be used. Some components may be unnecessary. For example, instead of being sealed to cure tool **602**, in some illustrative examples, rigid chamber **612** is sealed to vacuum bag **606**. In these illustrative examples, rigid chamber **612** and vacuum bag **606** can be raised and lowered together relative to cure tool **602**.
(62) Turning now to FIG. **8**, a flowchart of a method of performing a cure cycle on a composite laminate is depicted in accordance with an illustrative embodiment. Method **800** can be performed to form a component of aircraft **100** of FIG. **1**. Method **800** can be performed using double vacuum processing system **202** of FIG. **2**. Method **800** can be performed using double vacuum processing system **300** of FIGS. **3-5**. Method **800** can be performed using double vacuum processing system **600** of FIG. **6**. Method **800** can be performed using double vacuum processing system **700** of FIG. **7**.
(63) Method **800** pulls vacuum in two vacuum zones using two vacuum pumps, the two vacuum zones comprising a first vacuum zone enclosing the composite laminate and a second vacuum zone enclosing the first vacuum zone (operation **802**). Method **800** pneumatically connects the two vacuum zones such that a single vacuum pump of the two vacuum pumps pulls vacuum in both the first vacuum zone and the second vacuum zone (operation **804**). Method **800** performs gas extraction on the composite laminate while the two vacuum zones are pneumatically connected (operation **806**). Method **800** pneumatically isolates the two vacuum zones following gas extraction and prior to curing the composite laminate (operation **808**). Afterwards, method **800** terminates.
(64) In some illustrative examples, pneumatically connecting the two vacuum zones comprises actuating a diverter valve pneumatically connected to the two vacuum pumps and configured to alternate between connecting the first vacuum zone to respective ones of the two vacuum pumps (operation **810**).
(65) In some illustrative examples, method **800** vents the second vacuum zone after pneumatically isolating the two vacuum zones and prior to curing (operation **812**). In some illustrative examples, method **800** heats the composite laminate as the second vacuum zone compresses the composite laminate to cure the composite laminate (operation **814**).
(66) Turning now to FIG. **9**, a flowchart of a method of performing gas extraction in a double vacuum debulk of a composite laminate is depicted in accordance with an illustrative embodiment. Method **900** can be performed to form a component of aircraft **100** of FIG. **1**. Method **900** can be performed using double vacuum processing system **202** of FIG. **2**. Method **900** can be performed

using double vacuum processing system **300** of FIGS. **3-5**. Method **900** can be performed using double vacuum processing system **600** of FIG. **6**. Method **900** can be performed using double vacuum processing system **700** of FIG. **7**.

(67) Method **900** pulls a vacuum in a first vacuum zone enclosing the composite laminate (operation **902**). Method **900** pulls a second vacuum in a second vacuum zone enclosing the first vacuum zone (operation **904**). Method **900** heats the composite laminate while pulling the vacuum and the second vacuum (operation **906**). Method **900** activates a diverter valve to pneumatically connect the first vacuum zone to the second vacuum zone during heating in order to perform at least a portion of the gas extraction of the double vacuum debulk (operation **908**). Afterwards, method **900** terminates.

(68) In some illustrative examples, pulling the vacuum in the first vacuum zone is performed by a first vacuum pump (operation **910**). In some illustrative examples, pulling the second vacuum in the second vacuum zone is performed by a second vacuum pump (operation **912**). In some illustrative examples, activating the diverter valve to pneumatically connect the first vacuum zone to the second vacuum zone comprises activating the diverter valve to close a pneumatic connection from the first vacuum zone to the first vacuum pump and open a pneumatic connection from the first vacuum zone to the second vacuum pump (operation **914**).

(69) In some illustrative examples, method activates the diverter valve to pneumatically disconnect the first vacuum zone from the second vacuum zone (operation **916**). In some illustrative examples, method cures the composite laminate after pneumatically disconnecting the first vacuum zone from the second vacuum zone (operation **918**). In some illustrative examples, curing the composite laminate comprises venting the second vacuum zone to compress the composite laminate (operation **920**); and applying heat to the composite laminate (operation **922**).

(70) Turning now to FIG. **10**, a flowchart of a performing a thermal cycle in a double vacuum debulk of a composite laminate is depicted in accordance with an illustrative embodiment. Method **1000** can be performed to form a component of aircraft **100** of FIG. **1**. Method **1000** can be performed using double vacuum processing system **202** of FIG. **2**. Method **1000** can be performed using double vacuum processing system **300** of FIGS. **3-5**. Method **1000** can be performed using double vacuum processing system **600** of FIG. **6**. Method **1000** can be performed using double vacuum processing system **700** of FIG. **7**.

(71) Method **1000** draws a vacuum in a vacuum bag encompassing a composite laminate (operation **1002**). Method **1000** draws a vacuum in a rigid chamber encompassing the vacuum bag (operation **1004**). Method **1000** vents the vacuum bag to the rigid chamber to equalize vacuum levels within the vacuum bag and the rigid chamber during a double vacuum portion of the thermal cycle (operation **1006**). Method **1000** switches the vacuum bag to a discrete vacuum source for a remainder of the thermal cycle (operation **1008**). Afterwards, method **1000** terminates.

(72) In some illustrative examples, method **1000** vents the rigid chamber to atmosphere after switching the vacuum bag to a discrete vacuum source (operation **1010**). In some illustrative examples, method **1000** cures the composite laminate with the rigid chamber vented to the atmosphere (operation **1012**).

(73) As used herein, the phrase “at least one of,” when used with a list of items, means different combinations of one or more of the listed items may be used and only one of each item in the list may be needed. For example, “at least one of item A, item B, or item C” may include, without limitation, item A, item A and item B, or item B. This example also may include item A, item B, and item C or item B and item C. Of course, any combinations of these items may be present. In other examples, “at least one of” may be, for example, without limitation, two of item A; one of item B; and ten of item C; four of item B and seven of item C; or other suitable combinations. The item may be a particular object, thing, or a category. In other words, at least one of means any combination items and number of items may be used from the list but not all of the items in the list are required.

(74) As used herein, "a number of," when used with reference to items means one or more items.
(75) The flowcharts and block diagrams in the different depicted embodiments illustrate the architecture, functionality, and operation of some possible implementations of apparatuses and methods in an illustrative embodiment. In this regard, each block in the flowcharts or block diagrams may represent at least one of a module, a segment, a function, or a portion of an operation or step.
(76) In some alternative implementations of an illustrative embodiment, the function or functions noted in the blocks may occur out of the order noted in the figures. For example, in some cases, two blocks shown in succession may be executed substantially concurrently, or the blocks may sometimes be performed in the reverse order, depending upon the functionality involved. Also, other blocks may be added in addition to the illustrated blocks in a flowchart or block diagram. Some blocks may be optional. For example, operation **810** through operation **814** may be optional. For example, operation **910** through operation **922** may be optional.
(77) Illustrative embodiments of the present disclosure may be described in the context of aircraft manufacturing and service method **1100** as shown in FIG. **11** and aircraft **1200** as shown in FIG. **12**. Turning first to FIG. **11**, an illustration of an aircraft manufacturing and service method in a form of a block diagram is depicted in accordance with an illustrative embodiment. During pre-production, aircraft manufacturing and service method **1100** may include specification and design **1102** of aircraft **1200** in FIG. **12** and material procurement **1104**.
(78) During production, component and subassembly manufacturing **1106** and system integration **1108** of aircraft **1200** takes place. Thereafter, aircraft **1200** may go through certification and delivery **1110** in order to be placed in service **1112**. While in service **1112** by a customer, aircraft **1200** is scheduled for routine maintenance and service **1114**, which may include modification, reconfiguration, refurbishment, or other maintenance and service.
(79) Each of the processes of aircraft manufacturing and service method **1100** may be performed or carried out by a system integrator, a third party, and/or an operator. In these examples, the operator may be a customer. For the purposes of this description, a system integrator may include, without limitation, any number of aircraft manufacturers and major-system subcontractors; a third party may include, without limitation, any number of vendors, subcontractors, and suppliers; and an operator may be an airline, a leasing company, a military entity, a service organization, and so on.
(80) With reference now to FIG. **12**, an illustration of an aircraft in a form of a block diagram is depicted in which an illustrative embodiment may be implemented. In this example, aircraft **1200** is produced by aircraft manufacturing and service method **1100** of FIG. **11** and may include airframe **1202** with plurality of systems **1204** and interior **1206**. Examples of systems **1204** include one or more of propulsion system **1208**, electrical system **1210**, hydraulic system **1212**, and environmental system **1214**. Any number of other systems may be included.
(81) Apparatuses and methods embodied herein may be employed during at least one of the stages of aircraft manufacturing and service method **1100**. One or more illustrative embodiments may be manufactured or used during at least one of component and subassembly manufacturing **1106**, system integration **1108**, in service **1112**, or maintenance and service **1114** of FIG. **11**.
(82) A portion of airframe **1202** of aircraft **1200** can be formed by one of method **800**, method **900**, method **1000**. At least one of method **800**, method **900**, method **1000** can be performed during component and subassembly manufacturing **1106**. A composite structure formed using one of method **800**, method **900**, method **1000** can be present and utilized during in service **1112**. At least one of method **800**, method **900**, method **1000** can be performed during maintenance and service **1114** to form a replacement part.
(83) The illustrative examples provide improved double vacuum debulk processing. The double vacuum debulk system of the illustrative examples comprises a diverter valve that enables communication between a first vacuum zone and a second vacuum zone during degassing of a composite laminate within the first vacuum zone. Communication between the first vacuum zone

and the second vacuum zone can reduce the complexity of performing gas extraction of a double vacuum debulk. Communication between the first vacuum zone and the second vacuum zone can improve quality of the resulting composite by preventing compression of the composite laminate during gas extraction. Communication between the first vacuum zone and the second vacuum zone can improve quality of the resulting composite by preventing expansion of the vacuum bag during gas extraction.

(84) A double vacuum debulk process can include a single vacuum phase, a double vacuum phase, and a consolidation phase. During the single vacuum phase, a composite laminate is placed in a vacuum bag under one atmosphere of pressure. During the single vacuum phase, air is trapped in the composite laminate by vacuum clamping pressure.

(85) During a double vacuum phase, the composite laminate in the vacuum bag is placed in a rigid vacuum chamber and the vacuum chamber is evacuated to cancel out atmospheric pressure (clamping force) on the vacuum bag. The composite laminate is then heated to the minimum resin viscosity with no clamping but under vacuum evacuation. Entrapped air and volatiles are extracted from the laminate during this phase of the debulk.

(86) To improve upon the conventional processing, the illustrative examples place the first vacuum zone and the second vacuum zone in communication to improve the double vacuum phase. The illustrative examples prevent vacuum bag relaxation and vacuum bag compaction of the composite laminate while in the evacuated double vacuum debulk chamber.

(87) Double vacuum debulk (DVD) processing is most effective when the vacuum levels in the vacuum bag and rigid chamber are equal. If vacuum level of the rigid chamber is higher than the vacuum bag then the vacuum bag can balloon and destroy the vacuum seal. If the vacuum level of the laminate vacuum bag is too high then clamping force remains on the composite laminate and impedes the air extraction.

(88) The current state of the art is to use vacuum regulators to equalize vacuum levels. The problem with using vacuum regulators is that the large difference in the internal volume of the laminate vacuum bag (very small) and the DVD chamber (very large) causes the laminate bag and DVD chamber to respond at vastly different rates when adjustments are made to equalize vacuum levels. This makes an equalization process undesirably difficult.

(89) The novel solution to this problem presented in the illustrative examples is to vent the laminate vacuum bag to the rigid chamber cavity to equalize vacuum levels between the two vacuum zones during the Double Vacuum portion of the thermal cycle. The illustrative examples prevent pressure differences between the first vacuum zone and the second vacuum zone to prevent ballooning or impedances to the air extraction by created communication between the first vacuum zone and the second vacuum zone.

(90) Following gas extraction, the first vacuum zone and the second vacuum zone are isolated. Prior to venting the DVD chamber the laminate vacuum bag would be switched back to a discrete vacuum source for the remainder of the cure. Following gas extraction, consolidation is performed. During consolidation, the vacuum chamber is vented. Venting the rigid chamber reapplies clamping pressure to the composite laminate to consolidate the plies post air extraction. The low viscosity resin flows over the composite laminate, preventing air from reentering the laminate.

(91) The description of the different illustrative embodiments has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the embodiments in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. Further, different illustrative embodiments may provide different features as compared to other illustrative embodiments. The embodiment or embodiments selected are chosen and described in order to best explain the principles of the embodiments, the practical application, and to enable others of ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

Claims

1. A method of performing a cure cycle on a composite laminate comprising: pulling vacuum in two vacuum zones using two vacuum pumps, the two vacuum zones comprising a first vacuum zone in a vacuum bag enclosing the composite laminate and a second vacuum zone enclosing the first vacuum zone; pneumatically connecting the two vacuum zones such that a single vacuum pump of the two vacuum pumps pulls vacuum in both the first vacuum zone and the second vacuum zone; performing gas extraction on the composite laminate while the two vacuum zones are pneumatically connected; pneumatically isolating the two vacuum zones following gas extraction and prior to curing the composite laminate; venting the first vacuum zone to the second vacuum zone by a pressure relief valve in the vacuum bag to prevent inflation of the vacuum bag; and heating and curing the composite laminate.
2. The method of claim 1, wherein pneumatically connecting the two vacuum zones comprises actuating a diverter valve pneumatically connected to the two vacuum pumps and configured to alternate between connecting the first vacuum zone to respective ones of the two vacuum pumps.
3. The method of claim 1 further comprising: venting the second vacuum zone after pneumatically isolating the two vacuum zones and prior to curing.
4. The method of claim 3 wherein the heating and curing the composite laminate further comprises: heating the composite laminate as the second vacuum zone compresses the composite laminate to cure the composite laminate.
5. The method of claim 1 further comprising: sealing the vacuum bag to a cure tool to form the first vacuum zone of the two vacuum zones enclosing the composite laminate.
6. The method of claim 5 further comprising: sealing a rigid chamber to one of the cure tool or the vacuum bag to form the second vacuum zone of the two vacuum zones enclosing the first vacuum.
7. The method of claim 6, further comprising a channel through the rigid chamber connecting the first vacuum zone to the second vacuum zone through a diverter valve.
8. The method of claim 5, further comprising a channel through the cure tool connecting the first vacuum zone to the second vacuum zone through a diverter valve.
9. A method of performing gas extraction in a double vacuum debulk of a composite laminate comprising: pulling a vacuum in a vacuum bag forming a first vacuum zone enclosing the composite laminate; pulling a second vacuum in a second vacuum zone enclosing the first vacuum zone; heating the composite laminate while pulling the vacuum and the second vacuum; activating a diverter valve to pneumatically connect the first vacuum zone to the second vacuum zone during heating in order to perform at least a portion of the gas extraction of the double vacuum debulk; and venting the first vacuum zone to the second vacuum zone by a pressure relief valve in the vacuum bag to prevent inflation of the vacuum bag.
10. The method of claim 9, wherein: pulling the vacuum in the first vacuum zone is performed by a first vacuum pump; pulling the second vacuum in the second vacuum zone is performed by a second vacuum pump; and activating the diverter valve to pneumatically connect the first vacuum zone to the second vacuum zone comprises activating the diverter valve to close a pneumatic connection from the first vacuum zone to the first vacuum pump and open a pneumatic connection from the first vacuum zone to the second vacuum pump.
11. The method of claim 9 further comprising: activating the diverter valve to pneumatically disconnect the first vacuum zone from the second vacuum zone; and curing the composite laminate after pneumatically disconnecting the first vacuum zone from the second vacuum zone.
12. The method of claim 11, wherein curing the composite laminate comprises: venting the second vacuum zone to compress the composite laminate; and applying heat to the composite laminate.
13. The method of claim 9 further comprising: sealing the vacuum bag to a cure tool to form the first vacuum zone enclosing the composite laminate.

14. The method of claim 13 further comprising: sealing a rigid chamber to one of the cure tool or the vacuum bag to form the second vacuum zone enclosing the first vacuum zone.
15. A method of performing a thermal cycle in a double vacuum debulk of a composite laminate comprising: drawing a first vacuum in a vacuum bag encompassing a composite laminate; drawing a second vacuum in a rigid chamber encompassing the vacuum bag; venting the vacuum bag to the rigid chamber to equalize vacuum levels within the vacuum bag and the rigid chamber during a double vacuum portion of the thermal cycle; and switching the vacuum bag to a discrete vacuum source for a remainder of the thermal cycle; venting the first vacuum to the second vacuum by a pressure relief valve in the vacuum bag to prevent inflation of the vacuum bag; and heating and curing the composite laminate.
16. The method of claim 15 further comprising: venting the rigid chamber to atmosphere after switching the vacuum bag to a discrete vacuum source.
17. The method of claim 16 wherein the heating and curing the composite laminate further comprises: curing the composite laminate with the rigid chamber vented to the atmosphere.
18. The method of claim 15 further comprising: sealing the vacuum bag to a cure tool to form the first vacuum encompassing the composite laminate.
19. The method of claim 18 further comprising: sealing the rigid chamber to one of the cure tool or the vacuum bag to form the second vacuum encompassing the first vacuum.
20. The method of claim 15, wherein switching the vacuum bag to a discrete vacuum source for a remainder of the thermal cycle comprises activating a diverter valve pneumatically connecting the vacuum bag to two vacuum pumps including the discrete vacuum source.