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Systems and methods for joining thermoplastic components

Abstract

A system for joining a first thermoplastic component of a workpiece with a second thermoplastic component of the workpiece includes a first joining plate assembly comprising a housing, a heat plate, and a thermal insulator disposed between the housing and the heat plate, wherein the heat plate defines a heating surface; a second joining plate assembly opposed from the first joining plate assembly; and a clamping assembly engaged with both the first joining plate assembly and the second joining plate assembly.

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Background/Summary

FIELD
(1) This application relates to joining of thermoplastic components and, more particularly, to systems and methods for joining thermoplastic components using thermal conduction.
BACKGROUND
(2) Composite materials are used in various applications. For example, fiber-reinforced plastic composites have relatively high strength-to-weight ratios and, therefore, are commonly used in the aerospace, as well as other industries, such as the automotive industry.
(3) Traditionally, thermoset fiber-reinforced plastic composites, such as carbon fiber-reinforced epoxy-based composites, were used in the aerospace industry. However, in recent years, there has been a growing interest in using thermoplastic resins in fiber-reinforced plastic composites.
(4) The inert nature of thermoplastic materials, meaning the nonreactive nature of the thermoplastic polymer within composite material, makes joining thermoplastic materials very difficult. Therefore, thermoplastic materials are typically joined together with mechanical fasteners, which requires the additional steps of drilling the thermoplastic materials and inserting mechanical fasteners, thereby potentially generating foreign object debris (FOD) during drilling and increasing overall weight due to the presence of the mechanical fasteners.
(5) Accordingly, those skilled in the art continue with research and development efforts in the field of joining thermoplastic materials.
SUMMARY
(6) Disclosed are systems for joining a first thermoplastic component of a workpiece with a second thermoplastic component of the workpiece.
(7) In one example, the disclosed system for joining a first thermoplastic component of a workpiece with a second thermoplastic component of the workpiece includes a first joining plate assembly comprising a housing, a heat plate, and a thermal insulator disposed between the housing and the heat plate, wherein the heat plate defines a heating surface; a second joining plate assembly opposed from the first joining plate assembly; and a clamping assembly engaged with both the first joining plate assembly and the second joining plate assembly.
(8) In another example, the disclosed system for joining a first thermoplastic component of a workpiece with a second thermoplastic component of the workpiece includes a first joining plate assembly comprising a housing, a heat plate, a thermal insulator disposed between the housing and the heat plate, wherein the heat plate defines a heating surface, and a release film received over at least a portion of the heating surface of the heat plate; a second joining plate assembly opposed

from the first joining plate assembly, the second joining plate assembly comprising a second housing, a second heat plate, a second thermal insulator disposed between the second housing and the second heat plate, wherein the second heat plate defines a second heating surface, and a second release film received over at least a portion of the second heating surface of the second heat plate; and a clamping assembly engaged with both the first joining plate assembly and the second joining plate assembly, the clamping assembly applies a clamping force that urges the first joining plate assembly toward the second joining plate assembly.
(9) Also disclosed are methods for joining a first thermoplastic component of a workpiece with a second thermoplastic component of the workpiece.
(10) In one example, the disclosed method for joining a first thermoplastic component of a workpiece with a second thermoplastic component of the workpiece includes (1) clamping the workpiece between a first joining plate assembly and a second joining plate assembly; and (2) transferring heat from at least one of the first joining plate assembly and the second joining plate assembly to the workpiece to establish a joint between the first thermoplastic component and the second thermoplastic component.
(11) Other examples of the disclosed systems and methods for joining a first thermoplastic component of a workpiece with a second thermoplastic component of the workpiece will become apparent from the following detailed description, the accompanying drawings, and the appended claims.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) FIG. **1** is a schematic side view, partially in section, of one example of the disclosed system for joining a first thermoplastic component of a workpiece with a second thermoplastic component of the workpiece;
(2) FIG. **2** is a front elevational view of the first joining plate assembly of the system shown in FIG. **1**;
(3) FIG. **3** is a side cross-sectional view of a workpiece that can be joined using the system of FIG. **1**;
(4) FIG. **4** is a schematic side view, partially in section, of the workpiece shown in FIG. **3** being clamped by the system shown in FIG. **1**;
(5) FIG. **5** is a schematic side view, partially in section, of the workpiece of FIG. **3** received in the system of FIG. **1**, shown after a joint has been formed in the workpiece;
(6) FIG. **6** is a graphical depiction of an example predefined heat cycle undergone by one heat plate of the system of FIG. **1**;
(7) FIG. **7** is a graphical depiction of an example predefined heat cycle undergone by another, opposed heat plate of the system of FIG. **1**;
(8) FIG. **8** is a block diagram depicting one example of the disclosed method for joining a first thermoplastic component of a workpiece with a second thermoplastic component of the workpiece;
(9) FIG. **9** is a block diagram of aircraft production and service methodology; and
(10) FIG. **10** is a schematic illustration of an aircraft.
DETAILED DESCRIPTION
(11) Disclosed are systems and methods for joining a first thermoplastic component of a workpiece with a second thermoplastic component of the workpiece. The disclosed systems and methods may facilitate joining thermoplastic components in a cleaner manner and without adding weight, as compared to the drilling and fastening techniques traditionally used for joining thermoplastic components. Therefore, the disclosed systems and methods may yield joined thermoplastic components at reduced cost and improved cycle time.

(12) Referring to FIG. **1**, in one example, the disclosed system **100** for joining thermoplastic components includes first joining plate assembly **110**, a second joining plate assembly **150** opposed from the first joining plate assembly **110**, and a clamping assembly **190** engaged with both the first joining plate assembly **110** and the second joining plate assembly **150**.
(13) As shown in FIGS. **1** and **2**, the first joining plate assembly **110** of the disclosed system **100** may include a housing **112**, a heat plate **114**, and a thermal insulator **116** disposed between the housing **112** and the heat plate **114**. The housing **112** may provide backing and structural support to the first joining plate assembly **110**. The thermal insulator **116** may be at least partially connected to the housing **112**, and may thermally insulate the housing **112** from the heat generated by the heat plate **114**. For example, but without limitation, the thermal insulator **116** may be formed from, or may include, a ceramic material, which may thermally insulate the housing **112** from the heat generated by the heat plate **114**.
(14) The heat plate **114** may be at least partially connected to the thermal insulator **116**, and may generate heat. In one particular example construction, the heat plate **114** may include one or more resistive heating elements **115**, which generate heat in response to the flow of electrical current. The amount of heat generated by the heat plate **114** may vary and may be controlled, such as by a controller **200** (FIG. **1**), which may be in communication (e.g., wired or wireless) with the first joining plate assembly **110**, and which may regulate the flow of electric current to the resistive heating elements **115**.
(15) The heat plate **114** defines a heating surface **118** that is heated by the heat generated by the heat plate **114**. In one expression, the heat plate **114** is capable of heating the heating surface **118** to a temperature of at least 200° C. In another expression, the heat plate **114** is capable of heating the heating surface **118** to a temperature of at least 250° C. In another expression, the heat plate **114** is capable of heating the heating surface **118** to a temperature of at least 300° C. In another expression, the heat plate **114** is capable of heating the heating surface **118** to a temperature of at least 350° C. In another expression, the heat plate **114** is capable of heating the heating surface **118** to a temperature of at least 400° C. In yet another expression, the heat plate **114** is capable of heating the heating surface **118** to a temperature between about 250° C. and about 350° C.
(16) The first joining plate assembly **110** may also include a temperature sensor T.sub.1. The temperature sensor T.sub.1 may be positioned to sense the temperature of the heating surface **118** of the heat plate **114**. For example, the temperature sensor T.sub.1 may be a thermocouple or the like, and may be incorporated into the first joining plate assembly **110**, such as into the heat plate **114**. The temperature sensor T.sub.1 may be in communication (e.g., wired or wireless) with the controller **200** to facilitate control of the temperature of the heating surface **118** of the heat plate **114**.
(17) In one particular implementation, the system **100** is configured as a relatively small, hand-held device. As a hand-held device, the system **100** may be easily portable (such as by an individual technician). Therefore, the heating surface **118** of the heat plate **114** may have a surface area **120** that is relatively small. In one example, the surface area **120** of the heating surface **118** of the heat plate **114** is at most 1 ft.sup.2. In another example, the surface area **120** of the heating surface **118** of the heat plate **114** is at most 0.5 ft.sup.2. In yet another example, the surface area **120** of the heating surface **118** of the heat plate **114** is at most 0.25 ft.sup.2.
(18) In one particular construction, the heat plate **114** may be relatively flexible and conformable for engaging a contoured surface of a workpiece **10**. Therefore, when the heating surface **118** of the heat plate **114** is engaged with a surface **13** (FIG. **3**) of a workpiece **10** (FIG. **3**) that is contoured, the heat plate **114** conforms to the surface **13**.
(19) The first joining plate assembly **110** may also include a release film **130**. The release film **130** may be received over at least a portion of (if not all of) the heating surface **118** of the heat plate **114**. Compositionally, the release film **130** may be selected for use with thermoplastic composites, such as carbon fiber-reinforced thermoplastic composites. As one specific, non-limiting example,

the release film **130** may be a polyimide film and/or may include a polyimide.

(20) Referring to FIG. **1**, the second joining plate assembly **150** may have a configuration that is substantially the same as the first joining plate assembly **110**. Specifically, the second joining plate assembly **150** of the disclosed system **100** may include a housing **152**, a heat plate **154**, and a thermal insulator **156** disposed between the housing **152** and the heat plate **154**. The housing **152** may provide backing and structural support to the second joining plate assembly **150**. The thermal insulator **156** may be at least partially connected to the housing **152**, and may thermally insulate the housing **152** from the heat generated by the heat plate **154**. For example, but without limitation, the thermal insulator **156** may be formed from, or may include, a ceramic material, which may thermally insulate the housing **152** from the heat generated by the heat plate **154**.

(21) The heat plate **154** may be at least partially connected to the thermal insulator **156**, and may generate heat. In one particular example construction, the heat plate **154** may include one or more resistive heating elements **155**, which generate heat in response to the flow of electrical current. The amount of heat generated by the heat plate **154** may vary and may be controlled, such as by a controller **200**, which may be in communication (e.g., wired or wireless) with the second joining plate assembly **150**, and which may regulate the flow of electric current to the resistive heating elements **155**. The heat plate **154** of the second joining plate assembly **150** may be controllable by the controller **200** independently of the heat plate **114** of the first joining plate assembly **110**.

(22) The heat plate **154** defines a heating surface **158** that is heated by the heat generated by the heat plate **154**. In one expression, the heat plate **154** is capable of heating the heating surface **158** to a temperature of at least 200° C. In another expression, the heat plate **154** is capable of heating the heating surface **158** to a temperature of at least 250° C. In another expression, the heat plate **154** is capable of heating the heating surface **158** to a temperature of at least 300° C. In another expression, the heat plate **154** is capable of heating the heating surface **158** to a temperature of at least 350° C. In another expression, the heat plate **154** is capable of heating the heating surface **158** to a temperature of at least 400° C. In yet another expression, the heat plate **154** is capable of heating the heating surface **158** to a temperature between about 250° C. and about 350° C.

(23) The second joining plate assembly **150** may also include a temperature sensor T.sub.2. The temperature sensor T.sub.2 may be positioned to sense the temperature of the heating surface **158** of the heat plate **154**. For example, the temperature sensor T.sub.2 may be a thermocouple or the like, and may be incorporated into the second joining plate assembly **150**, such as into the heat plate **154**. The temperature sensor T.sub.2 may be in communication (e.g., wired or wireless) with the controller **200**, which controls of the temperature of the heating surface **158** of the heat plate **154**.

(24) As previously mentioned, the system **100** may be configured as a relatively small, hand-held device. Therefore, the heating surface **158** of the heat plate **154** may have a surface area **159** that is relatively small. In one example, the surface area **159** of the heating surface **158** of the heat plate **154** is at most 1 ft.sup.2. In another example, the surface area **159** of the heating surface **158** of the heat plate **154** is at most 0.5 ft.sup.2. In yet another example, the surface area **159** of the heating surface **158** of the heat plate **154** is at most 0.25 ft.sup.2. In one particular configuration, the heating surface **158** of the heat plate **154** of the second joining plate assembly **150** has a surface area **159** that is substantially equal to the surface area **120** of the heating surface **118** of the heat plate **114** of the first joining plate assembly **110**.

(25) In one particular construction, the heat plate **154** of the second joining plate assembly **150** may be relatively flexible and conformable. Therefore, when the heating surface **158** of the heat plate **154** is engaged with a surface **15** (FIG. **3**) of a workpiece **10** (FIG. **3**) that is contoured, the heat plate **154** conforms to the surface **15**.

(26) The second joining plate assembly **150** may also include a release film **160**. The release film **160** may be received over at least a portion of (if not all of) the heating surface **158** of the heat plate **154**. Compositionally, the release film **160** may be selected for use with thermoplastic composites,

such as carbon fiber-reinforced thermoplastic composites. As one specific, non-limiting example, the release film **160** may be a polyimide film and/or may include a polyimide.

(27) While the second joining plate assembly **150** is shown and described having a configuration that is substantially the same as the configuration of the first joining plate assembly **110**, various alternative configurations are contemplated and the use of alternative configurations for the second joining plate assembly **150** (as compared to the first joining plate assembly **110**) will not result in a departure from the scope of the present disclosure. For example, in one example alternative configuration, the second joining plate assembly **150** may be without heat plate and thermal insulator.

(28) Referring to FIGS. **1** and **4**, the clamping assembly **190** of the disclosed system **100** is engaged with both the first joining plate assembly **110** and the second joining plate assembly **150**. For example, the clamping assembly **190** includes a first clamp member **192** and a second clamp member **194**. The first clamp member of the clamping assembly **190** may be engaged with the first joining plate assembly **110** and the second clamp member **194** of the clamping assembly **190** may be engaged with the second joining plate assembly **150**.

(29) The clamping assembly **190** may apply a clamping force F that urges the first joining plate assembly **110** toward the second joining plate assembly **150**. Therefore, as shown in FIG. **4**, when a workpiece **10** is positioned between the first joining plate assembly **110** and the second joining plate assembly **150**, the clamping force F is transferred to the workpiece **10** by the first joining plate assembly **110** and the second joining plate assembly **150**.

(30) The clamping assembly **190** may be any apparatus or system capable of clamping a workpiece **10** (FIG. **3**) between the first joining plate assembly **110** and the second joining plate assembly **150** such that a clamping force F is applied to the workpiece **10**. As one specific, non-limiting example, the clamping assembly **190** may be (or may include) a C-clamp. As another specific, non-limiting example, the clamping assembly **190** may be (or may include) a vise.

(31) Optionally, as shown in FIG. **1**, the first joining plate assembly **110** may include a force sensor F.sub.1 and/or the second joining plate assembly **150** may include a force sensor F.sub.2. The force sensors F.sub.1, F.sub.2 may be positioned to sense the clamping force F (FIG. **4**) being applied by the first joining plate assembly **110** and the second joining plate assembly **150** to the workpiece **10** (FIGS. **3** and **4**). For example, the force sensors F.sub.1, F.sub.2 may be strain gauges or the like, and may be incorporated into the first joining plate assembly **110** and the second joining plate assembly **150**. The force sensors F.sub.1, F.sub.2 may optionally be in communication (e.g., wired or wireless) with the controller **200** or other feature (e.g., a warning on the first joining plate assembly **110** or on the clamping assembly **190**) to provide a visual, audible and/or haptic indication when the applied clamping force F has exceeded a predefined threshold value and/or if the applied clamping force F is not evenly (or otherwise properly) applied.

(32) Referring to FIGS. **3-5**, the disclosed system **100** may be used to form a joint **30** (FIG. **5**) between a first thermoplastic component **12** and a second thermoplastic component **14** of a workpiece **10**. Both the first thermoplastic component **12** of the workpiece **10** and the second thermoplastic component **14** of the workpiece **10** may be components of an aircraft **1102** (FIG. **10**). However, non-aerospace applications are also contemplated.

(33) The first thermoplastic component **12** may include a first reinforcement material **20** (e.g., carbon fiber) embedded in a first thermoplastic matrix material **22** (e.g., a member of the polyaryletherketone (PAEK) family of thermoplastic materials). The second thermoplastic component **14** may include a second reinforcement material **24** (e.g., carbon fiber) embedded in a second thermoplastic matrix material **26** (e.g., a member of the polyaryletherketone (PAEK) family of thermoplastic materials). In one example, the first thermoplastic matrix material **22** may be substantially compositionally identical to the second thermoplastic matrix material **26**. In another example, the first thermoplastic matrix material **22** may be substantially compositionally different from the second thermoplastic matrix material **26**.

(34) As shown in FIGS. **3** and **4**, in one particular implementation, a thermoplastic film **16** may be positioned between the first thermoplastic component **12** and the second thermoplastic component **14** of the workpiece **10**. Compositionally, the thermoplastic film **16** may be, for example, a member of the polyaryletherketone (PAEK) family of thermoplastic materials. Structurally, the thermoplastic film **16** may have, for example, a cross-sectional thickness T of about 0.0005 inch to about 0.01 inch. Significantly, the thermoplastic film **16** may have a lower melting temperature than the first thermoplastic component **12** of the workpiece **10** and a lower melting temperature than the second thermoplastic component **14** of the workpiece **10** (i.e., both the first melting temperature and the second melting temperature are greater than the third melting temperature).
(35) Referring to FIGS. **1** and **3-7**, the controller **200** of the disclosed system **100** may control the heat plate **114** of the first joining plate assembly **110** and the heat plate **154** of the second joining plate assembly **150** based on sensed temperature signals received from the temperature sensors T.sub.1, T.sub.2 to heat the heating surface **118** of the heat plate **114** according to a first predefined heat cycle **600** (FIG. **6**) and the heating surface **158** of the heat plate **154** according to a second predefined heat cycle **700** (FIG. **7**). The applied heat may transfer into the workpiece **10** by thermal conduction and may melt at least a portion of the workpiece **10** (e.g., the thermoplastic film **16**) to form a joint **30** (FIG. **5**) between the first thermoplastic component **12** and the second thermoplastic component **14** of the workpiece **10**.
(36) The first predefined heat cycle **600** and the second predefined heat cycle **700** may be customized for a particular workpiece **10** (FIG. **3**). The first predefined heat cycle **600** may include a temperature ramp-up period **602**, a steady/hold period **604**, and a cool-down period **606**. Likewise, the second predefined heat cycle **700** may include a temperature ramp-up period **702**, a steady/hold period **704**, and a cool-down period **706**. In one implementation, the first predefined heat cycle **600** and/or the second predefined heat cycle **700** may be generated by modeling. In another implementation, the first predefined heat cycle **600** and/or the second predefined heat cycle **700** may be generated by testing (e.g., trial and error).
(37) Thus, upon execution of the first predefined heat cycle **600** and the second predefined heat cycle **700**, a joint **30** may be formed between the first thermoplastic component **12** and the second thermoplastic component **14** of the workpiece **10**.
(38) Referring now to FIG. **8**, also disclosed is a method **500** for joining thermoplastic components. In one example, the disclosed method **500** may begin with the step of assembling **501** a workpiece **10**, as shown in FIG. **3**. The step of assembling **501** the workpiece **10** may be performed prior to other steps, such as prior to the clamping **502** the workpiece **10**.
(39) As shown in FIG. **3**, the step of assembling **501** a workpiece **10** may include positioning a first thermoplastic component **12** against a second thermoplastic component **14**. Both the first thermoplastic component **12** of the workpiece **10** and the second thermoplastic component **14** of the workpiece **10** may be components of an aircraft **1102** (FIG. **10**). However, non-aerospace applications are also contemplated.
(40) The first thermoplastic component **12** may include a first reinforcement material **20** (e.g., carbon fiber) embedded in a first thermoplastic matrix material **22** (e.g., a member of the polyaryletherketone (PAEK) family of thermoplastic materials). The second thermoplastic component **14** may include a second reinforcement material **24** (e.g., carbon fiber) embedded in a second thermoplastic matrix material **26** (e.g., a member of the polyaryletherketone (PAEK) family of thermoplastic materials). In one example, the first thermoplastic matrix material **22** may be substantially compositionally identical to the second thermoplastic matrix material **26**. In another example, the first thermoplastic matrix material **22** may be substantially compositionally different from the second thermoplastic matrix material **26**.
(41) In one particular implementation, the step of assembling **501** a workpiece **10** may further include positioning a thermoplastic film **16** between the first thermoplastic component **12** and the second thermoplastic component **14**. Compositionally, the thermoplastic film **16** may be, for

example, a member of the polyaryletherketone (PAEK) family of thermoplastic materials. Structurally, the thermoplastic film **16** may have, for example, a cross-sectional thickness T of about 0.0005 inch to about 0.01 inch. Significantly, the thermoplastic film **16** may have a lower melting temperature than the first thermoplastic component **12** of the workpiece **10** and a lower melting temperature than the second thermoplastic component **14** of the workpiece **10**.
(42) Referring back to FIG. **8**, the disclosed method **500** further includes the step of clamping **502** the workpiece **10** between a first joining plate assembly **110** (FIG. **1**) and a second joining plate assembly **150** (FIG. **1**). The step of clamping **502** may be performed after the step of assembling **501**.
(43) The first joining plate assembly **110** (FIG. **1**) may be configured as shown and described herein. Likewise, the second joining plate assembly **150** (FIG. **1**) may be configured as shown and described herein.
(44) As shown in FIG. **4**, the clamping **502** may be performed by a clamping assembly **190**. For example, the clamping assembly **190** may include a first clamp member **192** and a second clamp member **194**. The first clamp member of the clamping assembly **190** may be engaged with the first joining plate assembly **110** and the second clamp member **194** of the clamping assembly **190** may be engaged with the second joining plate assembly **150**.
(45) The clamping assembly **190** may apply a clamping force F that urges the first joining plate assembly **110** toward the second joining plate assembly **150**. Therefore, when a workpiece **10** is positioned between the first joining plate assembly **110** and the second joining plate assembly **150**, the clamping force F is transferred to the workpiece **10** by the first joining plate assembly **110** and the second joining plate assembly **150**.
(46) The clamping assembly **190** may be any apparatus or system capable of clamping a workpiece **10** (FIG. **3**) between the first joining plate assembly **110** and the second joining plate assembly **150** such that a clamping force F is applied to the workpiece **10**. As one specific, non-limiting example, the clamping assembly **190** may be (or may include) a C-clamp. As another specific, non-limiting example, the clamping assembly **190** may be (or may include) a vise.
(47) Referring to FIGS. **5** and **8**, the disclosed method **500** further includes the step of transferring **503** heat from at least one of the first joining plate assembly **110** and the second joining plate assembly **150** to the workpiece **10** to establish a joint **30** between the first thermoplastic component **12** and the second thermoplastic component **14** of workpiece **10**. The step of transferring **503** heat may be performed after the step of clamping **502** or simultaneously with the step of clamping **502**.
(48) At this point, those skilled in the art will appreciate that the step of transferring **503** heat from at least one of the first joining plate assembly **110** and the second joining plate assembly **150** to the workpiece **10** may include heating (e.g., resistively heating) the heat plate **114** of the first joining plate assembly **110** and the heat plate **154** of the second joining plate assembly **150** and executing the first predefined heat cycle **600** and the second predefined heat cycle **700** shown in FIGS. **6** and **7**. At this point, those skilled in the art will also appreciate that the transferring **503** of heat from at least one of the first joining plate assembly **110** and the second joining plate assembly **150** to the workpiece **10** (e.g., to the thermoplastic film **16** within the workpiece **10**) is primarily effected by thermal conduction.
(49) Referring to FIG. **8**, the disclosed method **500** may further include the step of unclamping **504** the workpiece **10** from the first joining plate assembly **110** (FIG. **1**) and the second joining plate assembly **150** (FIG. **1**). The step of unclamping **504** may be performed after completion of the step of transferring **503** heat. For example, the step of unclamping **504** may be performed after the first joining plate assembly **110** completes the first predefined heat cycle **600** (FIG. **6**) and the second joining plate assembly **150** completes the second predefined heat cycle **700** (FIG. **7**).
(50) Examples of the subject matter disclosed herein may be described in the context of aircraft manufacturing and service method **1100** as shown in FIG. **9** and aircraft **1102** as shown in FIG. **10**. In one or more examples, the disclosed systems and methods for joining a first thermoplastic

component of a workpiece with a second thermoplastic component of the workpiece may be used in aircraft manufacturing. During pre-production, illustrative method **1100** may include specification and design (block **1104**) of aircraft **1102** and material procurement (block **1106**). During production, component and subassembly manufacturing (block **1108**) and system integration (block **1110**) of aircraft **1102** may take place. Thereafter, aircraft **1102** may go through certification and delivery (block **1112**) to be placed in service (block **1114**). While in service, aircraft **1102** may be scheduled for routine maintenance and service (block **1116**). Routine maintenance and service may include modification, reconfiguration, refurbishment, etc. of one or more systems of aircraft **1102**.

(51) Each of the processes of illustrative method **1100** may be performed or carried out by a system integrator, a third party, and/or an operator (e.g., 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, leasing company, military entity, service organization, and so on.

(52) As shown in FIG. **10**, aircraft **1102** produced by illustrative method **1100** may include airframe **1118** with a plurality of high-level systems **1120** and interior **1122**. Examples of high-level systems **1120** include one or more of propulsion system **1124**, electrical system **1126**, hydraulic system **1128**, and environmental system **1130**. Any number of other systems may be included. Although an aerospace example is shown, the principles disclosed herein may be applied to other industries, such as the automotive industry. Accordingly, in addition to aircraft **1102**, the principles disclosed herein may apply to other vehicles, e.g., land vehicles, marine vehicles, space vehicles, etc.

(53) The disclosed systems and methods for joining a first thermoplastic component of a workpiece with a second thermoplastic component of the workpiece may be employed during any one or more of the stages of the manufacturing and service method **1100**. For example, components or subassemblies corresponding to component and subassembly manufacturing (block **1108**) may be fabricated or manufactured in a manner similar to components or subassemblies produced while aircraft **1102** is in service (block **1114**). Also, one or more examples of the apparatus(es), method(s), or combination thereof may be utilized during production stages (block **1108** and block **1110**), for example, by substantially expediting assembly of or reducing the cost of aircraft **1102**. Similarly, one or more examples of the apparatus or method realizations, or a combination thereof, may be utilized, for example and without limitation, while aircraft **1102** is in service (block **1114**) and/or during maintenance and service (block **1116**).

(54) Although various examples of the disclosed systems and methods for joining a first thermoplastic component of a workpiece with a second thermoplastic component of the workpiece have been shown and described, modifications may occur to those skilled in the art upon reading the specification. The present application includes such modifications and is limited only by the scope of the claims.

Claims

1. A system for joining a first thermoplastic component of a workpiece with a second thermoplastic component of the workpiece, the system comprising: a first joining plate assembly comprising a housing, a heat plate, a thermal insulator disposed between the housing and the heat plate and a release film directly on the heat plate, wherein the heat plate defines a heating surface; a second joining plate assembly opposed from the heating surface of the first joining plate assembly; and a clamping assembly engaged with both the housing of the first joining plate assembly and the second joining plate assembly; wherein the clamping assembly is configured to apply a clamping force that urges the second joining plate assembly toward the first joining plate assembly such that, when the workpiece is between the first joining plate assembly and the second joining plate

assembly, the clamping force is transferred by the first joining plate assembly to the first thermoplastic component of the workpiece and by the second joining plate assembly to the second thermoplastic component of the workpiece.
2. The system of claim 1 wherein the heat plate is capable of heating the heating surface to a temperature of at least 300° C.
3. The system of claim 1 wherein the heating surface of the heat plate has a surface area of at most 1 ft.sup.2.
4. The system of claim 1 wherein the heat plate is at least partially connected to the thermal insulator.
5. The system of claim 1 wherein the thermal insulator comprises a ceramic material.
6. The system of claim 1 wherein the clamping assembly comprises at least one sensor positioned to sense the clamping force.
7. The system of claim 1 further comprising a controller in communication with at least one of the first joining plate assembly and the second joining plate assembly.
8. The system of claim 7 wherein the first joining plate assembly comprises a temperature sensor positioned to sense a temperature of the heating surface of the heat plate, the temperature sensor being in communication with the controller.
9. The system of claim 7 wherein the controller controls the heat plate to heat the heating surface according to a predefined heat cycle wherein the heating surface is configured to transfer the heat into the workpiece by thermal conjunction to join the first thermoplastic component and the second thermoplastic component, when the workpiece is between the first joining plate assembly and the second joining plate assembly, in conjunction with the clamping force being transferred to the workpiece by the first joining plate assembly and the second joining plate assembly.
10. The system of claim 1 configured as a hand-held device.
11. A system for joining a first thermoplastic component of a workpiece with a second thermoplastic component of the workpiece, the system comprising: a first joining plate assembly comprising a housing, a heat plate, a thermal insulator disposed between the housing and the heat plate, wherein the heat plate defines a heating surface, and a release film directly on at least a portion of the heating surface of the heat plate; a second joining plate assembly opposed from the heating surface of the first joining plate assembly, the second joining plate assembly comprising a second housing, a second heat plate, a second thermal insulator disposed between the second housing and the second heat plate, wherein the second heat plate defines a second heating surface, and a second release film received over at least a portion of the second heating surface of the second heat plate; and a clamping assembly engaged with both the housing of the first joining plate assembly and the second housing of the second joining plate assembly, the clamping assembly configured to apply a clamping force that urges the first joining plate assembly toward the second joining plate assembly such that, when the workpiece is between the first joining plate assembly and the second joining plate assembly, the clamping force is transferred by the first joining plate assembly to the first thermoplastic component of the workpiece and by the second joining plate assembly to the second thermoplastic component of the workpiece.
12. A system for joining a first thermoplastic component of a workpiece with a second thermoplastic component of the workpiece, the system comprising: a first joining plate assembly having a workpiece engagement surface and an opposing clamp engagement surface, the first joining plate assembly including: a housing; a heat plate having a heating surface; a thermal insulator disposed between the housing and the heat plate; and a release film disposed directly on the heating surface of the heat plate, the release film defining the workpiece engagement surface; a second joining plate assembly having a workpiece engagement surface and an opposing clamp engagement surface; and a clamping assembly engaged with the clamp engagement surfaces of the first and second joining plate assemblies.
13. The system of claim 12, wherein the heating surface is substantially flat.

14. The system of claim 12, wherein the heat plate comprises a resistive heating element.
15. The system of claim 12, wherein the housing comprises a clamp engagement surface, and wherein the clamping assembly engages with a portion of the clamp engagement surface.
16. The system of claim 15, wherein the clamp engagement surface is substantially flat.
17. The system of claim 15 wherein the first joining plate assembly comprises a temperature sensor positioned to sense a temperature of the heating surface of the heat plate.
18. The system of claim 12 further comprising a force sensor positioned to sense a clamping force applied by the clamping assembly.
19. The system of claim 12 further comprising a controller in communication with the first joining plate assembly.
20. The system of claim 1 wherein the heating surface of the heat plate is flexible and conformable.