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Inventor(s)

Sibbach; Arthur William et al.

AUTOMATED FIBER PLACEMENT ASSEMBLY

Abstract

The disclosure herein provides an automated fiber placement assembly for forming a component, such as for a turbine engine or non-turbine engine system, by the placement of separate layers or strips of fiber tows. The automated fiber placement assembly comprises a heated pressure roller to heat the strip of fiber tows as they are placed during formation of the component. The pressure roller can be heated to heat the strip of fiber tows, or an alternate roller, separate from the pressure roller, can be heated to heat the strip of fiber tows.

Inventors: Sibbach; Arthur William (Boxford, MA), Kray; Nicholas Joseph (Mason, OH), Kryj-Kos; Elzbieta (Liberty Township, OH), Armstrong; Douglas Lorrimer (Needham, MA)

Applicant: GENERAL ELECTRIC COMPANY (Schenectady, NY)

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Background/Summary

TECHNICAL FIELD

[0001] The present disclosure relates generally to an automated fiber placement assembly for forming composite parts, and particularly, to a system for applying strips of fiber tows to a substrate during fiber placement.

BACKGROUND

[0002] Many components, such as those for a turbine engine, are made from composite materials that can include a fiber-reinforced matrix and exhibit a high strength-to-weight ratio. Due to the high strength to weight ratio and moldability to adopt relatively complex shapes, composite materials are utilized in various applications. Components made from composite materials can be used in aviation applications, for example, such as forming at least a portion of the fuselage and/or wings, rudder, manifold, turbine engine, airfoil, blades, vanes, or other components of the aircraft.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] A full and enabling disclosure of the present disclosure, including the best mode thereof, directed to one of ordinary skill in the art, is set forth in the specification, which makes reference to the appended figures, in which:

[0004] FIG. 1 is a schematic cross-sectional view of a turbine engine in accordance with an exemplary aspect of the present disclosure.

[0005] FIG. 2 is a schematic isometric view of a composite airfoil assembly and disk assembly suitable for use within the turbine engine of FIG. 1, in accordance with an exemplary aspect of the present disclosure.

[0006] FIG. 3 is schematic isometric view of an automated fiber placement assembly with a pressure roller including a heater and a temperature sensor, in accordance with an exemplary aspect of the present disclosure.

[0007] FIG. 4 is a cross-sectional view of the pressure roller of FIG. 3 including a core, in accordance with an exemplary aspect of the present disclosure.

[0008] FIG. 5 is schematic isometric view of an alternate automated fiber placement assembly with two heated rollers arranged behind a pressure roller, and a heated roller with a backpressure roller positioned forward of the pressure roller, in accordance with an exemplary aspect of the present disclosure.

[0009] FIG. 6 is schematic isometric view of another automated fiber placement assembly with a pressure roller having a heater positioned interior of the pressure roller, in accordance with an exemplary aspect of the present disclosure.

[0010] FIG. 7 is a sectional view of the pressure roller of FIG. 6 taken across section VII-VII, showing a set of pivotable heaters within the interior of the pressure roller, in accordance with an exemplary aspect of the present disclosure.

[0011] FIG. 8 illustrates a flow chart depicting a method of forming a component with an automated fiber placement assembly, in accordance with an exemplary aspect of the present disclosure.

DETAILED DESCRIPTION

[0012] Aspects of the disclosure herein are directed to a system and method for forming a component, such as a component for a turbine engine, or any other components that can be fully or partially formed by automated fiber placement (AFP) assemblies or machines. Automated fiber placement machines can be used to lay successive layers of fiber tows to build upon a substrate or add to a component. Strips of fiber tows used to build the component can be impregnated with adhesive materials, such as resins in one non-limiting example. Heat and pressure application to the resins or adhesive materials can improve bond and adhesion between the strips of fiber tows being

applied and the underlying substrate upon which the fiber tows are applied. Heating of a pressure roller used to apply the strips of fiber tows can provide specific, controlled, or increased heat and pressure in order to form an improved bond or improved adhesion among the applied strips of fiber tows and the underlying substrate or component.

[0013] As described herein, the automated fiber placement assembly can be used to form components or apply fiber tows during the forming of components, such as engine components used in a turbine engine for an aircraft. Such engine components can be an airfoil, for example, such as for a fan blade. It should be understood that the disclosure can apply similarly to other components of the turbine engine, such as a combustor liner or a disk in non-limiting examples, as well as non-aircraft or non-engine components. While described in terms of a component for a turbine engine, it will be appreciated that the present disclosure can apply to any component and need not be specific to a turbine engine or aircraft.

[0014] Reference will now be made in detail to present embodiments of the disclosure, one or more examples of which are illustrated in the accompanying drawings. The detailed description uses numerical and letter designations to refer to features in the drawings. Like or similar designations in the drawings and description have been used to refer to like or similar parts of the disclosure.

[0015] The word “exemplary” is used herein to mean “serving as an example, instance, or illustration.” Any implementation described herein as “exemplary” is not necessarily to be construed as preferred or advantageous over other implementations. Additionally, unless specifically identified otherwise, all embodiments described herein should be considered exemplary.

[0016] As used herein, the terms “first” and “second” may be used interchangeably to distinguish one element or feature from another and are not intended to signify location or importance of the individual elements or features.

[0017] As used herein, the term “upstream” refers to a direction that is opposite the fluid flow direction, and the term “downstream” refers to a direction that is in the same direction as the fluid flow. The terms “fore” or “forward” mean in front of something and “aft” or “rearward” mean behind something.

[0018] The term “fluid” may be a gas or a liquid, or multi-phase.

[0019] Additionally, as used herein, the terms “radial” or “radially” refer to a direction away from a common center. For example, in the overall context of a turbine engine, radial refers to a direction along a ray extending between a center longitudinal axis of the engine and an outer engine circumference.

[0020] All directional references (e.g., radial, axial, higher, lower, front, back, top, bottom, above, upstream, downstream, forward, aft, etc.) as may be used herein are only used for identification purposes to aid the reader's understanding of the present disclosure, and do not create limitations, particularly as to the position, orientation, or use of aspects of the disclosure described herein. Connection references (e.g., attached, coupled, connected, and joined) are to be construed broadly and can include intermediate structural elements between a collection of elements and relative movement between elements unless otherwise indicated. As such, connection references do not necessarily infer that those two elements are directly connected and in fixed relation to one another. The exemplary drawings are for purposes of illustration only and the dimensions, positions, order, and relative sizes reflected in the drawings attached hereto can vary.

[0021] The singular forms “a”, “an”, and “the” include plural references unless the context clearly dictates otherwise. Furthermore, as used herein, the term “set” or a “set” of elements can be any number of elements, including only one.

[0022] The term “composite,” as used herein is, is indicative of a component having two or more materials. A composite can be a combination of at least two or more metallic, non-metallic, or a combination of metallic and non-metallic elements or materials. Examples of a composite material can be, but are not limited to, a polymer matrix composite (PMC), a ceramic matrix composite

(CMC), a metal matrix composite (MMC), carbon fibers, a polymeric resin, a thermoplastic resin, bismaleimide (BMI) materials, polyimide materials, an epoxy resin, glass fibers, and silicon matrix materials.

[0023] As used herein, a “composite” component refers to a structure or a component including any suitable composite material. Composite components, such as a composite airfoil, can include several layers or plies of composite material. The layers or plies can vary in stiffness, material, and dimension to achieve the desired composite component or composite portion of a component having a predetermined weight, size, stiffness, and strength.

[0024] Additionally, as used herein, a “controller” or “controller module” can include a component configured or adapted to provide instruction, control, operation, or any form of communication for operable components to affect the operation thereof. A controller module can include any known processor, microcontroller, or logic device, including, but not limited to: field programmable gate arrays (FPGA), an application specific integrated circuit (ASIC), a full authority digital engine control (FADEC), a proportional controller (P), a proportional integral controller (PI), a proportional derivative controller (PD), a proportional integral derivative controller (PID controller), a hardware-accelerated logic controller (e.g. for encoding, decoding, transcoding, etc.), the like, or a combination thereof. Non-limiting examples of a controller module can be configured or adapted to run, operate, or otherwise execute program code to effect operational or functional outcomes, including carrying out various methods, functionality, processing tasks, calculations, comparisons, sensing or measuring of values, or the like, to enable or achieve the technical operations or operations described herein. The operation or functional outcomes can be based on one or more inputs, stored data values, sensed or measured values, true or false indications, or the like. While “program code” is described, non-limiting examples of operable or executable instruction sets can include routines, programs, objects, components, data structures, algorithms, etc., that have the technical effect of performing particular tasks or implement particular abstract data types. In another non-limiting example, a controller module can also include a data storage component accessible by the processor, including memory, whether transient, volatile or non-transient, or non-volatile memory. Additional non-limiting examples of the memory can include Random Access Memory (RAM), Read-Only Memory (ROM), flash memory, or one or more different types of portable electronic memory, such as discs, DVDs, CD-ROMs, flash drives, universal serial bus (USB) drives, the like, or any suitable combination of these types of memory. In one example, the program code can be stored within the memory in a machine-readable format accessible by the processor. Additionally, the memory can store various data, data types, sensed or measured data values, inputs, generated or processed data, or the like, accessible by the processor in providing instruction, control, or operation to affect a functional or operable outcome, as described herein.

[0025] Additionally, as used herein, elements being “electrically connected,” “electrically coupled,” “communicatively coupled” or “in electrical communication,” as well as terminology similar thereto, can include an electric, wired or wireless, transmission or signal being sent, received, or communicated to or from such connected or coupled elements. Furthermore, such electrical connections or couplings can include a wired or wireless connection, or a combination thereof.

[0026] One or more layers of adhesive can be used in forming or coupling composite components. Adhesives can include resin and phenolics, wherein the adhesive can require curing at elevated temperatures, elevated pressures, or by other hardening techniques.

[0027] As used herein, PMC refers to a class of materials. By way of example, the PMC material is defined in part by a prepreg, which is a reinforcement material pre-impregnated with a polymer matrix material, such as thermoplastic resin. Non-limiting examples of processes for producing thermoplastic prepregs include hot melt pre-pregging in which the fiber reinforcement material is drawn through a molten bath of resin and powder pre-pregging in which a resin is deposited onto the fiber reinforcement material, by way of non-limiting example electrostatically, and then

adhered to the fiber, by way of non-limiting example, in an oven or with the assistance of heated rollers. The prepregs can be in the form of unidirectional tapes or woven fabrics, which are then stacked on top of one another to create the number of stacked plies desired for the part.

[0028] Multiple layers of prepreg are stacked to the proper thickness and orientation for the composite component and then the resin is cured and solidified to render a fiber reinforced composite part. Resins for matrix materials of PMCs can be generally classified as thermosets or thermoplastics. Thermoplastic resins are generally categorized as polymers that can be repeatedly softened and flowed when heated and hardened when sufficiently cooled due to physical rather than chemical changes. Notable example classes of thermoplastic resins include nylons, thermoplastic polyesters, polyaryletherketones, and polycarbonate resins. Specific example of high-performance thermoplastic resins that have been contemplated for use in aerospace applications include, polyetheretherketone (PEEK), polyetherketoneketone (PEKK), polyetherimide (PEI), polyaryletherketone (PAEK), and polyphenylene sulfide (PPS). In contrast, once fully cured into a hard rigid solid, thermoset resins do not undergo significant softening when heated, but instead thermally decompose when sufficiently heated. Notable examples of thermoset resins include epoxy, bismaleimide (BMI), and polyimide resins.

[0029] Instead of using a prepreg, in another non-limiting example, with the use of thermoplastic polymers, it is possible to utilize a woven fabric. Woven fabric can include, but is not limited to, dry carbon fibers woven together with thermoplastic polymer fibers or filaments. Non-prepreg braided architectures can be made in a similar fashion. With this approach, it is possible to tailor the fiber volume of the part by dictating the relative concentrations of the thermoplastic fibers and reinforcement fibers that have been woven or braided together. Additionally, different types of reinforcement fibers can be braided or woven together in various concentrations to tailor the properties of the part. For example, glass fibers, carbon fibers, and thermoplastic fibers could be woven together in various concentrations to tailor the properties of the part. The carbon fibers provide the strength of the system, the glass fibers can be incorporated to enhance the impact properties, which is a design characteristic for parts located near the inlet of the engine, and the thermoplastic fibers provide the binding for the reinforcement fibers.

[0030] In yet another non-limiting example, resin transfer molding (RTM) can be used to form at least a portion of a composite component. Generally, RTM includes the application of dry fibers or matrix material to a mold or cavity. The dry fibers or matrix material can include prepreg, braided material, woven material, or any combination thereof.

[0031] Resin can be pumped into or otherwise provided to the mold or cavity to impregnate the dry fibers or matrix material. The combination of the impregnated fibers or matrix material and the resin are then cured and removed from the mold. When removed from the mold, the composite component can require post-curing processing.

[0032] It is contemplated that RTM can be a vacuum assisted process. That is, the air from the cavity or mold can be removed and replaced by the resin prior to heating or curing. It is further contemplated that the placement of the dry fibers or matrix material can be manual or automated.

[0033] The dry fibers or matrix material can be contoured to shape the composite component or direct the resin. Optionally, additional layers or reinforcing layers of a material differing from the dry fiber or matrix material can also be included or added prior to heating or curing.

[0034] As used herein, CMC refers to a class of materials with reinforcing fibers in a ceramic matrix. Generally, the reinforcing fibers provide structural integrity to the ceramic matrix. Some examples of reinforcing fibers can include, but are not limited to, non-oxide silicon-based materials (e.g., silicon carbide, silicon nitride, or mixtures thereof), non-oxide carbon-based materials (e.g., carbon), oxide ceramics (e.g., silicon oxycarbides, silicon oxynitrides, aluminum oxide (Al.sub.2O.sub.3), silicon dioxide (SiO.sub.2), aluminosilicates such as mullite, or mixtures thereof), or mixtures thereof.

[0035] Some examples of ceramic matrix materials can include, but are not limited to, non-oxide

silicon-based materials (e.g., silicon carbide, silicon nitride, or mixtures thereof), oxide ceramics (e.g., silicon oxycarbides, silicon oxynitrides, aluminum oxide (Al.sub.2O.sub.3), silicon dioxide (SiO.sub.2), aluminosilicates, or mixtures thereof), or mixtures thereof. Optionally, ceramic particles (e.g., oxides of Si, Al, Zr, Y, and combinations thereof) and inorganic fillers (e.g., pyrophyllite, wollastonite, mica, talc, kyanite, and montmorillonite) can also be included within the ceramic matrix.

[0036] Generally, particular CMCs can be referred to as their combination of type of fiber/type of matrix. For example, C/SiC for carbon-fiber-reinforced silicon carbide; SiC/SiC for silicon carbide-fiber-reinforced silicon carbide, SiC/SiN for silicon carbide fiber-reinforced silicon nitride; SiC/SiC—SiN for silicon carbide fiber-reinforced silicon carbide/silicon nitride matrix mixture, etc. In other examples, the CMCs can be comprised of a matrix and reinforcing fibers comprising oxide-based materials such as aluminum oxide (Al.sub.2O.sub.3), silicon dioxide (SiO.sub.2), aluminosilicates, and mixtures thereof. Aluminosilicates can include crystalline materials such as mullite (3Al.sub.2O.sub.3.Math.2SiO.sub.2), as well as glassy aluminosilicates.

[0037] In certain non-limiting examples, the reinforcing fibers may be bundled and/or coated prior to inclusion within the ceramic matrix. For example, bundles of the fibers may be formed as a reinforced tape, such as a unidirectional reinforced tape. A plurality of the tapes may be laid up together to form a preform component. The bundles of fibers may be impregnated with a slurry composition prior to forming the preform or after formation of the preform. The preform may then undergo thermal processing, and subsequent chemical processing to arrive at a component formed of a CMC material having a desired chemical composition. For example, the preform may undergo a cure or burn-out to yield a high char residue in the preform, and subsequent melt-infiltration with silicon, or a cure or pyrolysis to yield a silicon carbide matrix in the preform, and subsequent chemical vapor infiltration with silicon carbide. Additional steps may be taken to improve densification of the preform, either before or after chemical vapor infiltration, by injecting it with a liquid resin or polymer followed by a thermal processing step to fill the voids with silicon carbide. CMC material as used herein may be formed using any known or hereinafter developed methods including but not limited to melt infiltration, chemical vapor infiltration, polymer impregnation pyrolysis (PIP), or any combination thereof.

[0038] Such materials, along with certain monolithic ceramics (i.e., ceramic materials without a reinforcing material), are particularly suitable for higher temperature applications. Additionally, these ceramic materials are lightweight compared to superalloys, yet can still provide strength and durability to the component made therefrom. Therefore, such materials are currently being considered for many gas turbine components used in higher temperature sections of gas turbine engines, such as airfoils (e.g., turbines, and vanes), combustors, shrouds, and other like components that would benefit from the lighter-weight and higher temperature capability these materials can offer.

[0039] The inventors' practice has proceeded in the foregoing manner of designing a system used in the manufacture of a component, such as an airfoil, designing the system to have improved tow fiber application, adhesion, and bond. This system is utilized during the design and creation of several different types of components, such as those utilized in the turbine engine shown in FIG. 1, as well as non-aircraft or non-turbine engine applications.

[0040] FIG. 1 is a schematic cross-sectional diagram of a turbine engine **10** for an aircraft. The turbine engine **10** has a generally longitudinally extending axis or engine centerline **12** extending from a forward **14** to an aft **16**. The turbine engine **10** includes, in a downstream serial flow relationship, a fan section **18** including a fan **20**, a compressor section **22** including a booster or low pressure (LP) compressor **24** and a high pressure (HP) compressor **26**, a combustion section **28** including a combustor **30**, a turbine section **32** including an HP turbine **34**, and an LP turbine **36**, and an exhaust section **38**.

[0041] The fan section **18** includes a fan casing **40** surrounding the fan **20**. The fan **20** includes a

plurality of fan blades **42** disposed radially about the engine centerline **12**. The HP compressor **26**, the combustor **30**, and the HP turbine **34** form an engine core **44** of the turbine engine **10**, which generates combustion gases. The engine core **44** is surrounded by a core casing **46**, which can be coupled with the fan casing **40**.

[0042] An HP shaft or spool **48** disposed coaxially about the engine centerline **12** of the turbine engine **10** drivingly connects the HP turbine **34** to the HP compressor **26**. An LP shaft or spool **50**, which is disposed coaxially about the engine centerline **12** of the turbine engine **10** within the greater diameter annular HP spool **48**, drivingly connects the LP turbine **36** to the LP compressor **24** and fan **20**. The spools **48**, **50** are rotatable about the engine centerline **12** and couple to a plurality of rotatable elements, which can collectively define a rotor **51**.

[0043] The LP compressor **24** and the HP compressor **26** respectively include a plurality of compressor stages **52**, **54**, in which a set of compressor blades **56**, **58** rotate relative to a corresponding set of static compressor vanes **60**, **62** to compress or pressurize the stream of fluid passing through the stage. In a single compressor stage **52**, **54**, multiple compressor blades **56**, **58** can be provided in a ring and can extend radially outwardly relative to the engine centerline **12**, from a blade platform to a blade tip, while the corresponding static compressor vanes **60**, **62** are positioned upstream of and adjacent to the rotating compressor blades **56**, **58**. It is noted that the number of blades, vanes, and compressor stages shown in FIG. **1** were selected for illustrative purposes only, and that other numbers are possible.

[0044] The compressor blades **56**, **58** for a stage of the compressor **24**, **26** can be mounted to (or integral to) a disk **61**, which is mounted to the corresponding one of the HP and LP spools **48**, **50**. The static compressor vanes **60**, **62** for a stage of the compressor **24**, **26** can be mounted to the core casing **46** in a circumferential arrangement.

[0045] The HP turbine **34** and the LP turbine **36** respectively include a plurality of turbine stages **64**, **66**, in which a set of turbine blades **68**, **70** are rotated relative to a corresponding set of static turbine vanes **72**, **74**, also referred to as a nozzle, to extract energy from the stream of fluid passing through the stage. In a single turbine stage **64**, **66**, multiple turbine blades **68**, **70** can be provided in a ring and can extend radially outwardly relative to the engine centerline **12** while the corresponding static turbine vanes **72**, **74** are positioned upstream of and adjacent to the rotating turbine blades **68**, **70**. It is noted that the number of blades, vanes, and turbine stages shown in FIG. **1** were selected for illustrative purposes only, and that other numbers are possible.

[0046] The turbine blades **68**, **70** for a stage of the turbine **34**, **36** can be mounted to a disk **71**, which is mounted to the corresponding one of the HP and LP spools **48**, **50**. The static turbine vanes **72**, **74** for a stage of the compressor **24**, **26** can be mounted to the core casing **46** in a circumferential arrangement.

[0047] Complementary to the rotor portion, the stationary portions of the turbine engine **10**, such as the static vanes **60**, **62**, **72**, **74** among the compressor and turbine sections **22**, **32** are also referred to individually or collectively as a stator **63**. As such, the stator **63** can refer to the combination of non-rotating elements throughout the turbine engine **10**.

[0048] In operation, the airflow exiting the fan section **18** is split such that a portion of the airflow is channeled into the LP compressor **24**, which then supplies a pressurized airflow **76** to the HP compressor **26**, which further pressurizes the air. The pressurized airflow **76** from the HP compressor **26** is mixed with fuel in the combustor **30** and ignited, thereby generating combustion gases. Some work is extracted from these gases by the HP turbine **34**, which drives the HP compressor **26**. The combustion gases are discharged into the LP turbine **36**, which extracts additional work to drive the LP compressor **24**, and an exhaust gas is ultimately discharged from the turbine engine **10** via the exhaust section **38**. The driving of the LP turbine **36** drives the LP spool **50** to rotate the fan **20** and the LP compressor **24**.

[0049] A portion of the pressurized airflow **76** can be drawn from the compressor section **22** as bleed air **77**. The bleed air **77** can be drawn from the pressurized airflow **76** and provided to engine

components for cooling. The temperature of pressurized airflow **76** entering the combustor **30** is significantly increased above the bleed air temperature. The bleed air **77** may be used to reduce the temperature of the core components downstream of the combustor **30**.

[0050] A remaining portion of the pressurized airflow **76** bypasses the LP compressor **24** and engine core **44** as a bypass airflow **78** and exits the turbine engine **10** through a stationary vane row, and more particularly an outlet guide vane assembly **80**, comprising a plurality of airfoil guide vanes **82**, at a fan exhaust side **84**. More specifically, a circumferential row of radially extending airfoil guide vanes **82** are utilized adjacent the fan section **18** to exert some directional control of the airflow **78**.

[0051] Some of the air supplied by the fan **20** can bypass the engine core **44** and be used for cooling of portions, especially hot portions, of the turbine engine **10**, and/or used to cool or power other aspects of the aircraft. In the context of a turbine engine, the hot portions of the engine are normally downstream of the combustor **30**, especially the turbine section **32**, with the HP turbine **34** being the hottest portion as it is directly downstream of the combustion section **28**. Other sources of cooling fluid can be, but are not limited to, fluid discharged from the LP compressor **24** or the HP compressor **26**.

[0052] FIG. **2** is a schematic isometric view of a composite airfoil **100** and a disk **102** suitable for use within the turbine engine **10** of FIG. **1**. The composite airfoil **100** can define a body **104**. The disk **102** is suitable for use as the disk **61**, **71** (FIG. **1**) or any other disk such as, but not limited to, a disk within the fan section **18** (FIG. **1**), the compressor section **22** (FIG. **1**), or the turbine section **32** (FIG. **1**) of the turbine engine **10** (FIG. **1**). The composite airfoil **100** can be rotating or non-rotating such that the composite airfoil **100** can include at least one of the static compressor vanes **60**, **62** (FIG. **1**), the set of compressor blades **56**, **58** (FIG. **1**), the static turbine vanes **72**, **74** (FIG. **1**), the set of turbine blades **68**, **70** (FIG. **1**), or the plurality of fan blades **42** (FIG. **1**). As a non-limiting example, the composite airfoil **100** can be a composite fan blade.

[0053] The composite airfoil **100**, and the body **104** thereof, extends between a leading edge **114** and a trailing edge **116** to define a chord-wise direction, and extends between a root **118** and a tip **120** to define a span-wise direction. The composite airfoil **100** includes a pressure side **122** and a suction side **124**.

[0054] The disk **102** can be rotatable or stationary about a rotational axis **106**. The rotational axis **106** can coincide with, be parallel to, or be offset from the engine centerline **12** (FIG. **1**). The disk **102** includes a plurality of slots **108** extending axially through a radially exterior surface **112** of the disk **102**. The plurality of slots **108** are circumferentially spaced about the disk **102**, with respect to the rotational axis **106**, and permit the composite airfoil **100** to slidably secure to the disk **102**.

[0055] The composite airfoil **100** couples to the disk **102** by inserting at least a portion of the composite airfoil **100** into a respective slot of the plurality of slots **108**. The composite airfoil **100** is held in place by frictional contact with the slot **108** or can be coupled to the slot **108** via any suitable coupling method such as, but not limited to, welding, adhesion, fastening, or the like. While only a single composite airfoil **100** is illustrated, it will be appreciated that there can be any number of composite airfoils **100** coupled to the disk **102**. As a non-limiting example, there can be a plurality of composite airfoil **100** corresponding to a total number of slots of the plurality of slots **108**.

[0056] For the sake of reference, a set of relative reference directions, along with a coordinate system can be applied to the composite airfoil **100** and the disk **102**. An axial direction (Ad) can extend from forward to aft and is shown extending at least partially into the page. The axial direction (Ad) and can be arranged parallel to the rotational axis **106**, which can also be arranged parallel to the engine centerline **12** (FIG. **1**). A radial direction (Rd) extends perpendicular to the axial direction (Ad), which can extend perpendicular to the engine centerline **12**. A circumferential direction (Cd) can be defined perpendicular to the radial direction (Rd), which can be defined as a ray extending from a curvature or along a curvature of a circumference about the axial direction

(Ad), can be defined as a ray extending locally from the radial direction (Rd), and/or can be defined along the circumference of the turbine engine **10** (FIG. **1**) relative to the engine centerline **12** (FIG. **1**) or rotational axis **106**.

[0057] FIG. **3** illustrates a schematic isometric view of an automated fiber placement assembly **150** that applies a strip of fiber tows **152** to a substrate **154**. A fiber tow feeder **148** is provided for feeding the strip of fiber tows **152** for application to the substrate **154**. The substrate **154** can be a mandrel or workpiece, in non-limiting examples, upon which a component is being formed. In another non-limiting examples, the substrate **154** can at least partially form the component, such as including previously placed layers of fiber tows, and can be at least partially completed or finished through the application of the strip of fiber tows **152** to the substrate **154**. In one non-limiting example, the substrate **154** can be a component, such as the composite airfoil **100** of FIG. **2**, while non-turbine or non-engine components are contemplated.

[0058] The strip of fiber tows **152** extends between a first end **156** and a second end **158** and is fed in a feed direction (Fd). A heated pressure roller **160**, suspended by a mount **162** (shown in broken line), applies the strip of fiber tows **152** to the substrate **154** in a placement direction (Pd) while rotating in a rotating direction (Rotd) about a rotational axis (Ra) represented as an "X" as shown. During application, the heated pressure roller **160** applies a compaction pressure to the strip of fiber tows **152** against the substrate **154**, as well as applying heat. In one non-limiting example, the heated pressure roller **160** can be covered by a non-stick coating, such as a polytetrafluoroethylene, while alternate adhesion resistant or low friction materials are contemplated. Multiple layers or stacks of strips of fiber tows **152** can be applied in this manner in order to form the substrate **154**.

[0059] A pressure roller heater **164** can be positioned adjacent the heated pressure roller **160** and can apply heat to the heated pressure roller **160**. In one example, the mount **162** can be used to position the pressure roller heater **164** adjacent the heated pressure roller **160**, while any mounting system is contemplated. A temperature sensor **166** can be positioned adjacent to and behind the pressure roller heater **164** relative to the rotating direction (Rotd). Such a position of the temperature sensor **166** permits temperature measurement of the heated pressure roller **160** after being heated by the pressure roller heater **164**. Such a measurement can be made prior to contact against the strip of fiber tows **152**, to ensure that the heated pressure roller **160** is heated to an intended temperature prior to beginning application of the strip of fiber tows **152**. In alternative non-limiting examples, any suitable placement of the temperature sensor **166**, relative to the heated pressure roller **160**, is contemplated. A cutter assembly **168** includes a cutter head **170** coupled to an actuator **172** that actuates the cutter head **170** to cut the strip of fiber tows **152** against a backplate **174**. Exemplary actuators **172** can include a driver, such as a motor or cylinder which reciprocates to cut the strip of fiber tows **152** with the cutter head **170**.

[0060] A controller **176** is operatively and communicatively coupled to the heated pressure roller **160**, the pressure roller heater **164**, the temperature sensor **166**, the cutter assembly **168**, or any other portion of the automated fiber placement assembly **150**, or a combination thereof. The controller **176** can control cutting of the strip of fiber tows **152** via the cutter assembly **168** by actuation of the cutter head **170** with the actuator **172**. The controller **176** can control the speed or the rate of passage of the strip of fiber tows **152** with the heated pressure roller **160**, such as control of a motor rotating the heated pressure roller **160**, as well as the temperature or amount of heat applied to the heated pressure roller **160** by the pressure roller heater **164**, and therefore, can control a temperature of the heated pressure roller **160**. The temperature sensor **166** can provide a signal to the controller **176** indicative of the temperature of the heated pressure roller **160** after application of heat by the pressure roller heater **164**. If temperatures are outside of expected ranges or thresholds, the temperature of the heated pressure roller **160** can be varied by the controller **176** by changing the temperature or amount of heat emitted the pressure roller heater **164**, which can be verified by feedback from the temperature sensor **166**.

[0061] A heat source **178** can be provided to heat the substrate **154** or the surface of the strip of

fiber tows **152** that does not contact the heated pressure roller **160**. The heat source **178** provides additional heat in order to pre-cure, activate, or otherwise facilitate adhesion or application of the strip of fiber tows **152** to the substrate **154**, in addition to the heat applied by the heated pressure roller **160**. For example, resins provided within the strip of fiber tows **152** can be activated by the addition of heat. The heat source **178** can be operably or communicatively coupled to the controller **176** in order for the controller **176** to control application of heat or the temperature of the applied heat.

[0062] In operation, heat is applied by the pressure roller heater **164** to the heated pressure roller **160**, heating the heated pressure roller **160** to a desired temperature, with a minimum or a maximum temperature, or within a desired temperature range. The temperature sensor **166** can measure the temperature of the heated pressure roller **160** to ensure an intended temperature is reached or within an acceptable range. The heated pressure roller **160** can be rotated about the rotational axis (Ra) during application of heat by the pressure roller heater **164** to provide even heat distribution across the heated pressure roller **160** prior to the introduction of the strip of fiber tows **152**. Such an application of heat prior to introduction of the strip of fiber tows **152** can provide for even application of heat from the heated pressure roller **160** to the strip of fiber tows **152** beginning at the first end **156**. After any initial heating of the heated pressure roller **160**, additional or continuous heat can be applied to the heated pressure roller **160** by the pressure roller heater **164** to ensure consistent application of heat along the full length of the strip of fiber tows **152**.

Measurements by the temperature sensor **166** during application can be used to ensure consistent temperatures, and measurements outside of expected or desired temperatures can be amended through control of the pressure roller heater **164** and with feedback provided by the temperature sensor **166**.

[0063] In an alternative, non-limiting example, application of the heat provided from either or both of the pressure roller heater **164** and the heat source **178** may be switched on or off as desired via the controller **176**. Direct control of application of the heat can provide for heating particular or discrete portions of the strip of fiber tows **152** by controlled application of heat to the heated pressure roller **160**, such as by providing heat by only one of the pressure roller heater **164** or the heat source **178**, or by discretely applying heat to different portions of the heated pressure roller **160** or the strips of fiber tows **152**. Additionally, such control can provide for varying the bond achieved along different areas or portions of the substrate **154** by varying the amount of heat applied at the different areas or portions of the substrate **154**, which can be applied by one or both of the pressure roller heater **164** or the heat source **178**.

[0064] Utilizing the pressure roller heater **164** to heat the heated pressure roller **160** permits direct control of the applied heat at the heated pressure roller **160**, as well as provision of simultaneous pressure applied by the heated pressure roller **160** against the strip of fiber tows **152**. In this way, the heated pressure roller **160** permits an improved bond among the substrate **154** and the strip of fiber tows **152**, which may not be otherwise achieved by application of separate heat and pressure. Additionally, utilizing the dedicated pressure roller heater **164** with the temperature sensor **166** permits the consistent application of heat along the full surface of the heated pressure roller **160** as the strip of fiber tows **152** is applied. Such consistent heat application reduces or eliminates the opportunity for poor adhesion or bond during application of the strip of fiber tows **152**, which may otherwise occur because of inconsistent or varying temperatures or pressures.

[0065] FIG. 4 shows a section view of the heated pressure roller **160**, including an outer wall **180** defining an interior **182**. An adhesion resistant coating **184**, such as a polytetrafluoroethylene coating, is provided on or at least partially forms the outer wall **180** and reduces adhesion of the heated pressure roller **160** to the strip of fiber tows **152** (FIG. 3). A core **186** is provided within the interior **182**. The core **186** can be formed of materials such as ceramics can provide thermal stability or reduce local temperature variations within the interior **182**. In non-limiting examples, the core **186** can include metallic, ceramic, or metal composites, or combinations thereof. A pliable

material **188** can be provided within the interior **182** between the core **186** and the outer wall **180**. In a non-limiting example, the outer wall **180** can partially or fully form the outer wall **180**. The pliable material **188** can increase thermal stability across the heated pressure roller **160**, or across a strip of fiber tows along the heated pressure roller **160**, without creating local hot areas due to increases in local pressure. The pliable material **188** is pliable to conform to a non-uniform shape defined by a strip of fiber tows or defined by an underlying substrate, where local temperature variations may otherwise result along non-flat shapes or geometries. In a non-limiting example, the pliable material **188** can be a urethane foam, or other rubber, compliant, or polymer materials. In a non-limiting example, the interior **182** can be filled with the pliable material **188** to a particular pressure in order to define a particular compaction pressure within the heated pressure roller **160**. Such a compaction pressure can affect the bond among the strip of fiber tows **152** (FIG. 3) and the substrate **154** (FIG. 3), particularly with the complement of added heat by the pressure roller heater **164**, such as by increasing the bond among the substrate **154** and the strip of fiber tows **152**.

[0066] The interior **182** within the core **186** can be filled with the pliable material **188**. In alternative, non-limiting examples, the core **186** can be hollow or filled with a material different than that of the pliable material **188**. The interior **182** within the core **186** can also defined a compaction pressure within the core **186** that can be the same as that of the interior **182** between the core **186** and the outer wall **180**, while alternative pressures are contemplated.

[0067] In an alternative, non-limiting example, the heated pressure roller **160** can incorporate internal heating elements **190** that internally heat the core **186**, and therefore, the heated pressure roller **160**. The internal heating elements **190** can define the pressure roller heater **164** or can be utilized with an external pressure roller heater **164** as shown in FIG. 3, and it is contemplated that the internal heating elements **190** can be utilized in place of or in addition to the external pressure roller heater **164** (FIG. 3), for example. Such heating elements can include slip ring contacts coupling the internal heating elements **190** to the core **186** in order to provide electrical power to the internal heating elements **190**. Another non-limiting example of an alternative core can include an induction heated roller, with a magnetic core (e.g., core **186** can include magnetic materials). Such a core **186** with magnetic materials can be continuous or segmented, having a set of multiple discrete segments, such as in annular arrangement, forming the core **186**, and the internal heating elements **190** can induce an electrical current in the core **186**. In yet another non-limiting example, the core **186** can be heated via infrared heating (e.g., the pressure roller heater **164** can include an infrared heater).

[0068] FIG. 5 is a schematic sectional view of another exemplary automated fiber placement assembly **200** including a pressure roller **202** applying a strip of fiber tows **204** from a fiber tow feeder **234** to a substrate **206**. The pressure roller **202** applies a compaction pressure to the strip of fiber tows **204** against the substrate **206**. A cutter assembly **208** cuts the strip of fiber tows **204** against a backplate **210**. A heat source **212** can apply heat to a bottom surface **214** of the strip of fiber tows **204**, or to the substrate **206** where the strip of fiber tows **204** is to be laid, or a combination thereof. A controller **216** can be operably and communicatively coupled to one or more of the pressure roller **202**, the cutter assembly **208**, or the heat source **212** to permit controlled operation of the automated fiber placement assembly **200**. While the pressure roller **202** is shown without a heater, it is contemplated that the pressure roller **202** can be a heated pressure roller, similar to that of the heated pressure roller **160** of FIG. 3, being heated by a dedicated heater, such as the pressure roller heater **164** (FIG. 3).

[0069] A set of heated pressure rollers **220** includes a first heated pressure roller **222** and a second heated pressure roller **224** in serial arrangement along the strip of fiber tows **2004**. Each of the first and second heated pressure roller **222**, **224** has a dedicated heater as a first pressure roller heater **226** and a second pressure roller heater **228**, and each with a dedicated temperature sensor as a first temperature sensor **230** and a second temperature sensor **232**. The set of heated pressure rollers **220** are positioned behind the pressure roller **202**, relative to the placement direction (Pd). While the set

of heated pressure rollers **220** is shown as two heated pressure rollers, any number of heated pressure rollers is contemplated, including one or more, or a set of multiple heated pressure rollers including at least two heated pressure rollers. Each heated roller of the set of heated pressure rollers **220** can include a dedicated heater and temperature sensor, while an arrangement where a single heater heats more than one heated roller, or an arrangement with less temperature sensors than a one-to-one ratio with the heated rollers is contemplated. The first and second heated pressure rollers **222**, **224** apply both heat and a compaction pressure to the strip of fiber tows **204** against the substrate **206**.

[0070] A first preheat roller **240** is arranged against a top surface **242** of the strip of fiber tows **204** and positioned on the same side of the strip of fiber tows **204** compared to that of the pressure roller **202** and the set of heated pressure rollers **220**. In a non-limiting example, the first preheat roller **240** can be heated, such as by including a first preheat roller heater **246**, which can be internal, while an external heater is contemplated. A second preheat roller **244** is positioned against the bottom surface **214** of the strip of fiber tows **204** and can be similarly heated by a second preheat roller heater **250**. The second preheat roller **244** can be arranged adjacent the first preheat roller **240**. It is contemplated that the first and second preheat rollers **240**, **244** can provide pressure to the strip of fiber tows **204** by sandwiching the strip of fiber tows **204** between the first preheat roller **240** and the second preheat roller **244**. That is, the first and second preheat rollers **240**, **244** can apply both heat and pressure to the strip of fiber tows **204**. A third temperature sensor **248** can measure the temperature of the first preheat roller **240** to ensure proper temperature, and a fourth temperature sensor **252** can measure the temperature of the second preheat roller **244**. The first and second preheat rollers **240**, **244** can be communicatively and operatively coupled to the controller **216**, permitting control of the temperature of the first and second preheat rollers **240**, **244**, the first and second preheat roller heaters **246**, **250**, the third and fourth temperature sensors **248**, **252**, or any additional heaters or temperatures sensors arranged with the first and second preheat rollers **240**, **244**. In a non-limiting example, only one of the first and second preheat rollers **240**, **244** can be heated. In another non-limiting example, the pressure applied by the first and second preheat rollers **240**, **244** can be controlled by the initial positioning of the first and second preheat rollers **240**, **244**, as a function of thickness of the strip of fiber tows **204**, while variable control of a pressure applied between the first and second preheat rollers **240**, **244** by way of the controller **216** is contemplated.

[0071] In operation, the pressure roller **202** applies the strip of fiber tows **204** to the substrate **206** under a predetermined pressure while the cutter assembly **208** can cut the strip of fiber tows **204**. The first and second preheat rollers **240**, **244** can apply heat to the strip of fiber tows **204** prior to application to the substrate **206** by the pressure roller **202**, and can apply pressure to the strip of fiber tows **204** between the first and second preheat rollers **240**, **244**. The first and second preheat rollers **240**, **244** can provide a combination of heat and pressure to the strip of fiber tows **204** prior to application at the pressure roller **202**, in order to at least partially activate or otherwise prepare the strip of fiber tows **204** for application to the substrate **206**. Such heat and pressure applied to the strip of fiber tows **204** prior to the pressure roller **202** provide improved adhesion and bond among the strip of fiber tows **204** and the substrate **206**. Additionally, preheating the strip of fiber tows **204** with the first and second preheat rollers **240**, **244** prior to application at the pressure roller **202** can reduce overall contact time between the strip of fiber tows **204** and the pressure roller **202**, such as by speeding up rotation of the pressure roller **202**, which can reduce sticking at the pressure roller **202** as well as reduce overall application time via the reduction of contact time at the pressure roller **202**. Such reduction in application time or contact time can further improve bond or adhesion by creating lesser opportunity for adhesion at the pressure roller **202**.

[0072] After application of the strip of fiber tows **204** at the pressure roller **202**, with or without applying heat or pressure at the first and second preheat rollers **240**, **244**, the first heated pressure roller **222** can heat the applied strip of fiber tows **204**, as well as apply additional pressure by

squeezing the strip of fiber tows **204** against the substrate **206**. The first heated pressure roller **222** is heated, such as by the first pressure roller heater **226**, to a desired temperature, which can be measured and confirmed by the first temperature sensor **230**, and applies further heat and pressure to the strip of fiber tows **204** after application to the substrate **206** by the pressure roller **202**. Similarly, the second heated pressure roller **224**, heated by the second pressure roller heater **228**, applies additional heat and pressure to the strip of fiber tows **204** after the first heated pressure roller **222**. In a non-limiting example, the successive first and second heated pressure rollers **222**, **224** can be heated to different temperatures to define a temperature gradient across the first and second heated pressure rollers **222**, **224**. The temperature gradient is applied to the strip of fiber tows **204** through the first and second heated pressure rollers **222**, **224**. For example, the first heated pressure roller **222** can be at a relatively higher temperature, and the second heated pressure roller **224** can be at a relatively lower temperature, defining a decreasing temperature gradient extending farther from the pressure roller **202**. The associated first and second temperature sensors **230**, **232** can provide thermal feedback indicating temperatures along the first and second heated pressure rollers **222**, **224** to control the particular temperature gradient along the set of heated pressure rollers **220**.

[0073] Utilizing the temperature gradient can define a temperature profile along the strip of fiber tows **204** heated by the first and second heated pressure rollers **222**, **224**. The temperature profile can be tailored to increase adhesion and bond between the strip of fiber tows **204** and the substrate **206**, thereby improving overall adhesion and bond for the formed component. Additionally, finishing of the component, such as heat or pressure finishing, can be reduced, reducing overall production time and cost.

[0074] FIG. **6** is a schematic, sectional view of another exemplary automated fiber placement assembly **300** including a heated pressure roller **302** applying a strip of fiber tows **304** to a substrate **306** from a fiber tow feeder **326**. The heated pressure roller **302** applies a compaction pressure to the strip of fiber tows **304** against the substrate **306**. The heated pressure roller **302** can be heated by a pressure roller heater **314**, provided interior of the heated pressure roller **302**. A cutter assembly **308** cuts the strip of fiber tows **304** against a backplate **310**. A heat source **312** can apply heat to the strip of fiber tows **304**, to the substrate **306** prior to the strip of fiber tows **304** being laid, or a combination thereof. A controller **318** can be communicatively and operatively coupled to the heated pressure roller **302**, as well as any other portion of the automated fiber placement assembly **300** to permit control and operation thereof by a user.

[0075] FIG. **7** shows a section view of the heated pressure roller **302** of FIG. **6** taken along section VII-VII, showing the pressure roller heater **314** positioned with an interior **316** of the heated pressure roller **302** and arranged as three independent interior heaters **320**, while any suitable number of heaters is contemplated. Each interior heater **320** can be mounted or otherwise positioned in the heated pressure roller **302** adjacent to a contact surface **322**. The contact surface **322** can be defined as a portion of the heated pressure roller **302** that is in contact with the strip of fiber tows **304** (FIG. **6**) as they are being laid. More specifically, the contact surface **322** can change along the heated pressure roller **302** as the heated pressure roller **302** rotates during application of the strip of fiber tows **304** (FIG. **6**). In one non-limiting example, the interior **316** can be filled with a fluid material, such as a liquid or gas, to permit rotation of the heated pressure roller **302** while maintaining the position of the interior heaters **320** at the contact surface **322**.

[0076] Each interior heater **320** can be pivotably mounted within the interior **316**, permitting pivoting of each interior heater **320** relative to the contact surface **322** in a pivoting direction **324**. While the interior heaters **320** are shown in a spaced arrangement, it is contemplated that the interior heaters **320** are positioned adjacent to one another so that no spacing exists, or that such spacing is reduced as possible while permitting pivoting movement of the interior heaters **320**. A staggered arrangement can provide for covering the full width of the strip of fiber tows **304** (FIG. **6**), while permitting room for pivoting movement.

[0077] In operation, heat can be applied to the heated pressure roller **302** by the interior heaters **320**. When the contact surface **322** contacts the strip of fiber tows **304** along a non-flat or non-planar surface, the heated pressure roller **302** or material within the interior **316** can deform complementary to the contact surface **322**, such that the interior heaters **320** are permitted to pivot in the pivoting direction **324** in order to better conform to the shape of the substrate **306** (FIG. 6), while applying heat consistently across the interior heaters **320**, or even discretely among some interior heaters **320** in order to apply heat to only a portion of the strip of fiber tows **304**.

[0078] The ability of the interior heaters **320** to pivot in the pivoting direction **324** provides for greater consistency of heat application among substrates **306** that have complex shapes, such as non-flat shapes. Additionally, individual interior heaters **320** permit heating only a portion of the strip of fiber tows **304** or heating different portions of the strip of fiber tows **304** differently, or both, such that local bond or adhesion can be tailored to local applications of heat, as well as local materials or intended features of the finished component, such as elasticity, hardness, or other inherent features.

[0079] FIG. 8 depicts a flow chart showing a method **400** of forming a component on a substrate, such as the substrate **154**, **206**, **306** of FIGS. 3, 5, and 6 described herein, by the application of successive layers of strips of fiber tows, such as the strips of fiber tows **152**, **204**, **304** (FIGS. 3, 5, and 6). An automated fiber placement assembly, such as the automated fiber placement assembly **150**, **200**, **300** (FIGS. 3, 5, and 6), successively layers the strip of fiber tows **152**, **204**, **304** to build the component upon the substrate **154**, **206**, **306**.

[0080] At **402**, the method **400** can include heating a roller with a heater to define a heated roller. The roller can be the heated pressure roller **160**, **302** (FIGS. 3 and 6), the first and second heated pressure rollers **222**, **224** (FIG. 5), and the first and second preheat rollers **240**, **244** (FIG. 5) as described herein. The heater can be the pressure roller heater **164**, **226**, **228** (FIGS. 3 and 5), the internal heating element **190** (FIG. 4), the first and second preheat roller heaters **246**, **250** (FIG. 5), or the pressure roller heater **314** or the interior heaters **320** (FIGS. 6-7) as described herein. Heating of the rollers can be done prior to application of the strip of fiber tows **152**, **204**, **304** such as heating the rollers to a predetermined temperature before applying the strip of fiber tows **152**, **204**, **304**, in a non-limiting example. In additional non-limiting examples, heating the roller can include heating a roller externally, interior, or both exterior and interior.

[0081] At **404**, the method **400** can include wherein the heated roller is a heated pressure roller, such as the heated pressure roller **160**, **222**, **224**, **302** (FIGS. 3, 5, and 6). The heated pressure roller **160**, **222**, **224**, **302** can be heated by the pressure roller heater **164**, **226**, **228**, **314** and provides an application pressure against the strip of fiber tows **152**, **204**, **304** between the heated pressure roller **160**, **222**, **224**, **302** and the substrate **154**, **206**, **306**. For example, in FIG. 3, the pressure roller heater **164** applies heat to the heated pressure roller **160** to define the heated pressure roller, which then applies both heat and pressure to the strip of fiber tows **152** against the substrate **154**. In FIG. 4, the heated pressure roller **160** can be heated by an internal heating element **190**. In FIG. 5, the heated pressure roller **160** can be the first or second heated pressure roller **222**, **224**, or both, being heated by the first and second pressure roller heaters **226**, **228**, respectively. In FIGS. 6-7, internal pressure roller heaters **314** heat the heated pressure roller **302** from the interior **316**.

[0082] At **406**, the method **400** can include measuring a temperature of the heated pressure roller **160**, **222**, **224** with a temperature sensor, such as the temperature sensor **166**, **230**, **232** of FIGS. 3 and 5. The temperature sensor **166**, **230**, **232** can measure the temperature of the heated pressure roller **160**, **222**, **224** to determine if the temperature meets an intended temperature, a minimum or maximum temperature, or is within a temperature range. Such a measurement can be initiated or directed by a user or by a controller, such as the controller **176**, **216** (FIGS. 3 and 5). The temperature sensor **166**, **230**, **232** can perform a temperature measurement of the heated pressure roller **160**, **222**, **224** and provide a signal to the controller **176**, **216**, **318** representative of the temperature of the heated pressure roller **160**, **222**, **224**. The controller **176**, **216** can utilize the

signal to determine the temperature of the heated pressure roller **160, 222, 224** to determine if the temperature meets the intended temperature, the minimum or maximum temperature, or is within the temperature range.

[0083] At **408**, if the measured temperature is not the intended temperature, or is outside of the minimum, maximum, or temperature range, the method **400** can include adjusting the temperature of the heated pressure roller **160, 222, 224**. For example, the controller **176, 216**, or a user operating the controller **176, 216**, can operate the pressure roller heater **164, 226, 228** to increase or decrease heat output to vary the temperature of the heated pressure roller **160, 222, 224** in order to meet the intended temperature, a minimum or maximum temperature, or temperature range.

[0084] At **410**, the method **400** can include repeating measuring of the heated pressure roller **160, 222, 224** with the temperature sensor **166, 230, 232**, at **406**, and adjusting the temperature of the heated pressure roller **160, 222, 224**, at **408**. During operation of the automated fiber placement assembly **150, 200, 300**, environmental conditions or varying temperatures among the substrate **154, 206**, the strips of fiber tows **152, 204**, or other aspects of the system can result in changes in the temperature of the heated pressure rollers **160, 222, 224** over time. Therefore, it is beneficial to monitor the temperature of the heated pressure rollers **160, 222, 224** with the temperature sensor **166, 230, 232** and increase or decrease the heat output of the heater to ensure that the temperature of the heated pressure roller **160, 222, 224** remains at the intended temperature, above a minimum temperature, below a maximum temperature, or within a temperature range, or combinations thereof.

[0085] At **412**, the method **400** can include wherein the heated roller is one of a set of multiple heated rollers. For example, the set of heated rollers can be the first and second heated pressure rollers **222, 224**, or can be the first and second preheat rollers **240, 244**, or both. Where the set of heated rollers are the first and second heated pressure rollers **222, 224**, the set of heated rollers can have a serial arrangement, contacting the strip of fiber tows at different positions along the length of the strip of fiber tows. Where the set of heated rollers are the first and second preheat rollers **240, 244**, the set of heated rollers can contact the strip of fiber tows at the same position, on opposite sides of the strip of fiber tows, while different positions are contemplated. In additional non-limiting examples, the set of multiple heated rollers can be arranged at different positions along the length of the strip of fiber tows, as well as on opposite sides of the strip of fiber tows **204**.

[0086] At **414**, the method **400** can include wherein the set of multiple heated rollers are a set of multiple heated pressure rollers, like the set of heated pressure rollers **220** of FIG. 5, which can be the first and second heated pressure rollers **222, 224**. The first and second heated pressure rollers **222, 224** are heated by the first and second pressure roller heaters **226, 228**, and apply both heat and pressure to the strip of fiber tows **204** against the substrate **206**. It is contemplated that the temperatures among the set heated pressure rollers **220** can be the same, different, or both where the number of heated pressure rollers permits such an arrangement. At **416**, the method can include applying a temperature gradient to the strip of fiber tows **204** with the set of heated pressure rollers **220**. More specifically, the first and second heated pressure rollers **222, 224** among the set of heated pressure rollers **220** can have defined temperatures that change or vary in a predetermined manner, such as having a constant or non-constant rate of change in temperature, in non-limiting examples.

[0087] At **418**, the method can include wherein the set of multiple heated rollers are a set of preheat rollers, such as the first and second preheat rollers **240, 244** of FIG. 5. A set of preheat rollers can include only one preheat roller, while two or more preheat rollers are contemplated. The first and second preheat rollers **240, 244** can be heated rollers that contact and heat the strip of fiber tows **204** before the strip of fiber tows **204** contacts the substrate **206**. In a non-limiting example, the first and second preheat rollers **240, 244** can be arranged on opposite sides of the strip of fiber tows **204**, as arranged in FIG. 5. In additional non-limiting examples, any number of preheat rollers **240, 244** arranged at any position along the length of the strip of fiber tows **204**, on any side of the strip

of fiber towels **204**, is contemplated.

[0088] It should be appreciated that the method **400**, or portions thereof, can be repeated for multiple layers of strips of fiber towels **152, 204, 304**, such that the component is built through successive layering of the strips of fiber towels **152, 204, 304** which can be accomplished by repeating the method **400** or portions thereof. In a non-limiting example, the method **400** at **404-410** can be repeated to build a component with a heated pressure roller **160, 222, 224, 302**, while maintaining appropriate temperatures for the heated pressure roller. In another non-limiting example, the method **400** at **412-416** can be repeated to build a component with a set of heated pressure rollers **220**, which can be positioned behind a pressure roller **202**. In another non-limiting example, the method **400** at **412** and **418** can be repeated to build a component utilizing the preheat rollers **240, 244**. In further non-limiting examples, it should be appreciated that portions or aspects of the method **400** can be added, removed, mixed, interchanged, or otherwise rearranged in order to define a new method, which include applying heat at an automated fiber placement assembly.

[0089] The aspects described herein provide a process or method **400** of forming a component upon a substrate **154, 206, 306**, such as the composite airfoil **100**, or a portion thereof. Heating of the automated fiber placement assembly, or aspects thereof, can increase or improve adhesion and bond between laid strips of fiber towels and the underlying substrate. Improved adhesion and bond can increase integrity of the formed component, as well as accuracy of the formed component, increasing total component lifetime while reducing maintenance and cost.

[0090] The benefits associated with utilizing a heated roller for an automated fiber placement assembly, or a method, as described herein, provide for improved adhesion and bond among the laid strip of fiber towels and the underlying component. Improved adhesion and bond can increase component lifetime and reduce related maintenance.

[0091] This written description uses examples to disclose the present disclosure, including the best mode, and to enable any person skilled in the art to practice the disclosure, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the disclosure is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they include structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

[0092] Further aspects are provided by the subject matter of the following clauses:

[0093] An automated fiber placement assembly for forming a component on a substrate, the automated fiber placement assembly comprising: a strip of fiber towels; a pressure roller for applying the strip of fiber towels to the substrate in a placement direction; and a roller heater positioned to heat the pressure roller.

[0094] The automated fiber placement assembly of any preceding clause further comprising a temperature sensor positioned adjacent the pressure roller.

[0095] The automated fiber placement assembly of any preceding clause wherein the pressure roller rotates in a rotating direction, and wherein the temperature sensor is positioned downstream of the roller heater relative to the rotating direction.

[0096] The automated fiber placement assembly of any preceding clause wherein the temperature sensor is positioned behind where the strip of fiber towels contacts the substrate, relative to the rotating direction.

[0097] The automated fiber placement assembly of any preceding clause wherein the pressure roller is filled with a fluid material.

[0098] The automated fiber placement assembly of any preceding clause wherein the pressure roller includes an outer wall with an adhesion resistant coating.

[0099] The automated fiber placement assembly of claim **1** wherein the pressure roller defines an interior and comprises a core within the interior.

[0100] The automated fiber placement assembly of any preceding clause wherein the roller heater is positioned within the interior.

[0101] The automated fiber placement assembly of any preceding clause wherein the roller heater is arranged as a set of multiple roller heaters positioned within the interior.

[0102] The automated fiber placement assembly of any preceding clause wherein each roller heater of the set of multiple roller heaters is pivotable to conform to a shape of the substrate.

[0103] The automated fiber placement assembly of any preceding clause further comprising a controller operably coupled to the roller heater for controlling a temperature of the pressure roller.

[0104] An automated fiber placement assembly for forming a component on a substrate, the automated fiber placement assembly comprising: a strip of fiber tows; a pressure roller applying the strip of fiber tows to the substrate in a placement direction; and at least one heated roller contacting the strip of fiber tows to apply heat to the strip of fibers.

[0105] The automated fiber placement assembly of any preceding clause wherein the at least one heated roller is positioned behind the pressure roller relative to the placement direction.

[0106] The automated fiber placement assembly of any preceding clause wherein each heated roller of the at least one heated roller includes a roller heater.

[0107] The automated fiber placement assembly of any preceding clause wherein each heated roller of the at least one heated roller includes a temperature sensor.

[0108] The automated fiber placement assembly of any preceding clause wherein the at least one heated roller comprises at least two heated rollers, and wherein the at least two heated rollers are heated to different temperatures to define a temperature gradient along the at least two heated rollers.

[0109] The automated fiber placement assembly of any preceding clause wherein the at least one heated roller is a preheat roller positioned forward of the pressure roller relative to the placement direction.

[0110] The automated fiber placement assembly of any preceding clause further comprising a backpressure roller sandwiching the strip of fiber tows with the preheat roller.

[0111] The automated fiber placement assembly of any preceding clause wherein the backpressure roller is a heated backpressure roller.

[0112] The automated fiber placement assembly of any preceding clause further comprising a controller operably coupled to the at least one heated roller.

[0113] An automated fiber placement assembly for forming a component on a substrate, the automated fiber placement assembly comprising: a fiber tow feeder for feeding a strip of fiber tows toward the substrate in a feed direction; one or more rollers for applying the strip of fiber tows to the substrate in a placement direction, wherein the one or more rollers includes at least a pressure roller for applying a compaction pressure to the strip of fiber tows against the substrate; and one or more roller heaters positioned to heat at least one roller of the one or more rollers such that the at least one roller is at least one heated roller.

[0114] The automated fiber placement assembly of any preceding clause, wherein the pressure roller is the at least one heated roller, defining a heated pressure roller.

[0115] The automated fiber placement assembly of any preceding clause, further comprising a temperature sensor positioned adjacent to the at least one heated roller.

[0116] The automated fiber placement assembly of any preceding clause, wherein the at least one heated roller is rotatable in a rotating direction for applying the strip of fiber tows to the substrate in the feed direction, and wherein the temperature sensor is positioned behind the one or more roller heaters relative to the rotating direction.

[0117] The automated fiber placement assembly of any preceding clause, wherein the at least one heated roller is at least two heated rollers.

[0118] The automated fiber placement assembly of any preceding clause, wherein each heated roller of the at least two heated rollers has at least one roller heater of the one or more roller heaters

positioned for heating each heated roller of the at least two heated rollers.

[0119] The automated fiber placement assembly of any preceding clause, wherein the at least one heated roller is positioned against the strip of fiber tows for applying a compaction pressure to the strip of fiber tows against the substrate.

[0120] The automated fiber placement assembly of any preceding clause, wherein the at least one heated roller is positioned behind the pressure roller relative to the feed direction.

[0121] The automated fiber placement assembly of any preceding clause, wherein the at least one heated roller comprises at least two heated rollers in serial arrangement behind the pressure roller relative to the feed direction.

[0122] The automated fiber placement assembly of any preceding clause, wherein the at least one heated roller is at least one preheat roller positioned forward of the pressure roller relative to the feed direction.

[0123] The automated fiber placement assembly of any preceding clause, wherein the at least one preheat roller is at least two preheat rollers.

[0124] The automated fiber placement assembly of any preceding clause, wherein the at least two preheat rollers are arranged to contact the strip of fiber tows on opposite sides of the strip of fiber tows.

[0125] The automated fiber placement assembly of any preceding clause, further comprising a core positioned within an interior of the at least one heated roller.

[0126] The automated fiber placement assembly of any preceding clause, wherein the one or more roller heaters are positioned interior of the at least one heated roller.

[0127] The automated fiber placement assembly of any preceding clause, wherein the one or more roller heaters are pivotable.

[0128] The automated fiber placement assembly of any preceding clause, further comprising a controller operably coupled to the one or more roller heaters for controlling a temperature of the at least one heated roller.

[0129] An automated fiber placement assembly for forming a component on a substrate from a strip of fiber tows fed from a fiber tows feeder, the automated fiber placement assembly comprising: one or more rollers including at least a pressure roller; and a roller heater positioned to heat at least one roller of the one or more rollers to define at least one heated roller.

[0130] The automated fiber placement assembly of any preceding clause, wherein the pressure roller is the at least one heated roller, defining a heated pressure roller.

[0131] The automated fiber placement assembly of any preceding clause, wherein the at least one heated roller is a preheat roller for applying heat prior to the pressure roller.

[0132] The automated fiber placement assembly of any preceding clause, further comprising a second pressure roller, wherein the second pressure roller is the at least one heated roller.

[0133] A method of forming a component on a substrate with an automated fiber placement assembly by feeding a strip of fiber tows toward the substrate, the method comprising: heating at least one roller for applying the strip of fiber tows to the substrate to define a heated roller.

[0134] The method of any preceding clause, wherein the heated roller is a heated pressure roller.

[0135] The method of any preceding clause, further comprising applying a compaction pressure to the strip of fiber tows with the heated pressure roller.

[0136] The method of any preceding clause, further comprising applying a compaction pressure to the strip of fiber tows with a pressure roller.

[0137] The method of any preceding clause, further comprising applying a compaction pressure to the strip of fiber tows with the heated roller after applying the compaction pressure with the pressure roller.

[0138] The method of any preceding clause, wherein a roller heater heats the roller.

[0139] The method of any preceding clause, further comprising measuring a temperature of the heated roller with a temperature sensor.

[0140] The method of any preceding clause, further comprising determining if the temperature matches an intended temperature, is below a maximum temperature, above a minimum temperature, or within a temperature range.

[0141] The method of any preceding clause, further comprising adjusting a heat output from the roller heater when the temperature does not match the intended temperature, is not below the maximum temperature, is not above the minimum temperature, or is not within the temperature range.

[0142] The method of any preceding clause, further comprising a controller operably coupled to the roller heater to adjust the heat output.

[0143] The method of any preceding clause, wherein the heated roller is one of a set of heated rollers.

[0144] The method of any preceding clause, wherein the set of heated rollers are a set of heated pressure rollers for applying a compaction pressure to the strip of fiber tows.

[0145] The method of any preceding clause, wherein the set of heated pressure rollers have differing temperature to define a temperature gradient among the set of heated pressure rollers.

[0146] The method of any preceding clause, wherein the set of multiple heated rollers is a set of preheat rollers.

[0147] The method of any preceding clause, wherein the heated roller is a preheat roller.

Claims

1. An automated fiber placement assembly for forming a component on a substrate, the automated fiber placement assembly comprising: a fiber tow feeder for feeding a strip of fiber tows toward the substrate in a feed direction; a first pressure roller for applying the strip of fiber tows to the substrate in a placement direction, wherein the first pressure roller positions along the strip of fiber tows at the substrate and is configured to apply a compaction pressure to the strip of fiber tows against the substrate; a second pressure roller positioned behind the first pressure roller relative to the placement direction; a first roller heater positioned to heat the first pressure roller to a first temperature; and a second roller heater positioned to heat the second pressure roller to a second temperature; wherein the first temperature is different from the second temperature.

2. (canceled)

3. The automated fiber placement assembly of claim 1, further comprising a temperature sensor positioned adjacent to the first pressure roller.

4. The automated fiber placement assembly of claim 3, wherein the first pressure roller is rotatable in a rotating direction for applying the strip of fiber tows to the substrate in the feed direction, and wherein the temperature sensor is positioned behind the first roller heater relative to the rotating direction.

5-8. (canceled)

9. The automated fiber placement assembly of claim 1, further comprising a third pressure roller positioned along the strip of fiber tows at the substrate, and wherein the second pressure roller and the third pressure roller are in serial arrangement behind the first pressure roller relative to the feed direction.

10. The automated fiber placement assembly of claim 1, further comprising at least one preheat roller positioned forward of the first pressure roller relative to the feed direction.

11. The automated fiber placement assembly of claim 10, wherein the at least one preheat roller is at least two preheat rollers.

12. The automated fiber placement assembly of claim 11, wherein the at least two preheat rollers are arranged to contact the strip of fiber tows on opposite surfaces of the strip of fiber tows.

13. The automated fiber placement assembly of claim 1, further comprising a core positioned within an interior of the first pressure roller.

- 14.** The automated fiber placement assembly of claim 13, wherein the roller heater positions interior of the first pressure roller to heat the core.
- 15.** The automated fiber placement assembly of claim 14, wherein the first roller heater is pivotable, relative to the first pressure roller.
- 16.** The automated fiber placement assembly of claim 1, further comprising a controller operably coupled to the first roller heater for controlling a temperature of the first pressure roller.
- 17.** An automated fiber placement assembly for forming a component on a substrate from a strip of fiber tows fed from a fiber tows feeder, the automated fiber placement assembly comprising: one or more pressure rollers configured to provide a compaction pressure to the strip of fiber tows at the substrate; and a roller heater positioned to heat at least one pressure roller of the one or more pressure rollers to define at least one heated pressure roller; wherein the roller heater is pivotable relative to the one or more pressure rollers of the one or more pressure rollers.
- 18.** (canceled)
- 19.** The automated fiber placement assembly of claim 17, further comprising a preheat roller positioned to heat the strip of fiber tows prior to the at least one heated pressure roller.
- 20.** The automated fiber placement assembly of claim 17, further comprising a second roller heater heating a second pressure roller of the one or more pressure rollers to define at least two heated pressure rollers, and wherein the second roller heater is configured to heat the second pressure roller to a different temperature than that of another pressure roller of the at least two heated pressure rollers.
- 21.** An automated fiber placement assembly for forming a component on a substrate, the automated fiber placement assembly comprising: a fiber tow feeder for feeding a strip of fiber tows toward the substrate in a feed direction; a pressure roller for applying the strip of fiber tows to the substrate in a placement direction, wherein the pressure roller positions along the strip of fiber tows at the substrate and is configured to apply a compaction pressure to the strip of fiber tows against the substrate; and a core positioned interior of the pressure roller; and a roller heater positioned to heat the core.
- 22.** The automated fiber placement assembly of claim 21, wherein the roller heater is positioned interior of the core.
- 23.** The automated fiber placement assembly of claim 22, further comprising a pliable material spacing the core from the roller heater.
- 24.** The automated fiber placement assembly of claim 23, wherein the pressure roller further comprises an outer wall, and wherein the pliable material spaces the core from the outer wall.
- 25.** The automated fiber placement assembly of claim 21, wherein the roller heater is separate from the core.
- 26.** The automated fiber placement assembly of claim 17, wherein the roller heater is positioned interior of the one or more pressure rollers.
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