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Ceramic matrix composite component and method of forming

Abstract

A ceramic matrix composite (CMC) component and method of forming the CMC component with multiple layers of impregnated matrix fibers, at least one of the multiple layers including at least one CMC prepreg formed from a plurality of twisted tows, twisted through at least one turn/meter.

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Background/Summary

TECHNICAL FIELD
(1) The present disclosure generally relates to a component, more specifically, to a method of forming a ceramic matrix composite component.
BACKGROUND
(2) Composite materials typically 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, such as a turbine engine or an aircraft. Composite materials can be, for example, installed on or define a portion of the fuselage and/or wings, rudder, manifold, airfoil, or other components of the aircraft or turbine engine. Extreme loading and high temperatures can be applied to the composite components of the aircraft or turbine engine. For example, extreme loading can occur to one or more airfoils during ingestion of various materials by the turbine engine.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) 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:
(2) FIG. **1** is a schematic cross-sectional view of a component including multiple plies with reinforcing fibers.
(3) FIG. **2** is a schematic illustration of a process for coating the reinforcing fiber from FIG. **1**.

(4) FIG. **3** is a schematic illustration of an optional second step for the process from FIG. **2**.
(5) FIG. **4** is a schematic illustration of an optional third step for the process from FIG. **2**.
(6) FIG. **5** is a schematic illustration of another optional third step for the process from FIG. **2**.
(7) FIG. **6** is a schematic cross-sectional view of a component according to an aspect of the disclosure herein.
(8) FIG. **7** is a schematic cross-sectional view of a variation of the component from FIG. **6** according to another aspect of the disclosure herein.
(9) FIG. **8** is a schematic cross-sectional view of a variation of the component from FIG. **6** according to yet another aspect of the disclosure herein.
(10) FIG. **9** is a flow chart illustrating a method of processing ceramic fiber for the manufacture of a ceramic matrix composite component.

DETAILED DESCRIPTION

(11) Aspects of the disclosure herein are directed to a ceramic matrix composite (CMC) component and a method for forming the CMC component. It was found that intentionally twisting tows produces more bridging fibers in plies forming the CMC component. Additional bridging fibers increase the intralaminar toughness in each of the multiple plies forming the CMC component. Intentionally twisting the tows also improves the handling characteristics and manufacturability of the CMC component.
(12) Current prepreg ceramic matrix composite structures do not have any bridging fibers intentionally reinforcing the through thickness, denoted herein as “T.” A measured resistance to shear forces is much higher with a certain number of misaligned fibers than that of an unreinforced matrix material. This improvement in intralaminar toughness is due to fibers that are slightly misaligned relative to an in-plane direction (FIG. **6**). These misaligned fibers can bridge intralaminar layers at shallow angles and provide a degree of toughness. This disclosure herein provides a way to intentionally misalign fibers to achieve more robust shallow angle bridging and enable higher intralaminar toughness. The methods and components described herein include fibers that are misaligned by twisting a tow bundle prior to filament winding the tow into prepregs. The tow bundle must be twisted enough to ensure shallow angle bridging, but not so much as to prevent the tow from being impregnated during the winding process.
(13) The term “composite,” as used herein, 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 not limited to, a polymer matrix composite (PMC), a ceramic matrix composite (CMC), a metal matrix composite (MMC), carbon fiber, polymeric resin, thermoplastic, bismaleimide (BMI), polyimide materials, epoxy resin, glass fiber, and silicon matrix materials.
(14) 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.
(15) 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 or other hardening techniques.
(16) In the present disclosure, when a layer is being described as “on” or “over” another layer or substrate, it is to be understood that the layers can either be directly contacting each other or have another layer or feature between the layers, unless expressly stated to the contrary. Thus, these terms are simply describing the relative position of the layers to each other and do not necessarily mean “on top of” since the relative position above or below depends upon the orientation of the device to the viewer.
(17) 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 all 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.

(18) 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.

(19) 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.

(20) 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.

(21) 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 material differing from the dry fiber or matrix material can also be included or added prior to heating or curing.

(22) 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.

(23) 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 components (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.

(24) 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.

(25) 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 can 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, such as melt-infiltration with silicon, 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.
(26) The reinforcing fibers can be at least portions of individual filaments or strands. As used herein, a “ceramic fiber tow,” a “fiber tow,” or simply a “tow” refers to a bundle of a plurality of individual fibers, filaments, or loose strands. The filaments of a tow may be randomly intermingled or arranged in a pattern, and/or may be continuous or non-continuous. For example, a tow may include broken filaments or filament segments. As another example, the filaments of a tow may be substantially parallel, twisted, or otherwise arranged. A tow may act substantially in the same manner as a single or individual filament. It will also be appreciated that an “individual ceramic filament,” or simply an “individual filament,” as used herein, refers to a singular or non-bundled elongate ceramic member.
(27) 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., turbine blades, and vanes), combustors, shrouds and other like components, that would benefit from the lighter-weight and higher temperature capability these materials can offer.
(28) 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.
(29) As may be used herein, the terms “first”, “second”, or “third” may be used interchangeably to distinguish one component from another and are not intended to signify location or importance of the individual components.
(30) The term “at least one of” in the context of, e.g., “at least one of A, B, and C” refers to only A, only B, only C, or any combination of A, B, and C.
(31) The term “turbomachine” or “turbomachinery” refers to a machine including one or more compressors, a heat generating section (e.g., a combustion section), and one or more turbines that together generate a torque output.
(32) The term “gas turbine engine” refers to an engine having a turbomachine as all or a portion of its power source. Example gas turbine engines include turbofan engines, turboprop engines, turbojet engines, turboshaft engines, etc., as well as hybrid-electric versions of one or more of these engines.
(33) As used herein, the terms “axial” and “axially” refer to directions and orientations that extend substantially parallel to a centerline of the gas turbine engine. Moreover, the terms “radial” and “radially” refer to directions and orientations that extend substantially perpendicular to the centerline of the gas turbine engine. 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. In addition, as used herein, the terms “circumferential” and “circumferentially” refer to directions and orientations that extend arcuately about the centerline of the gas turbine engine.

(34) The terms “coupled,” “fixed,” “attached to,” and the like refer to both direct coupling, fixing, or attaching, as well as indirect coupling, fixing, or attaching through one or more intermediate components or features, unless otherwise specified herein.

(35) All directional references (e.g., radial, axial, proximal, distal, upper, lower, upward, downward, left, right, lateral, front, back, top, bottom, above, below, vertical, horizontal, clockwise, counterclockwise, upstream, downstream, forward, aft, etc.) 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 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.

(36) 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.

(37) As used herein “bridging fiber” refers to fibers that extend through the thickness “T” of any ply described herein. A greater bridging the fiber angle the better the chance of a particular fiber participating in bridging between layers. A bridging fiber having a fiber angle of 90 degrees would be extending directly along the thickness direction.

(38) Here and throughout the specification and claims, range limitations are combined and interchanged, such ranges are identified and include all the sub-ranges contained therein unless context or language indicates otherwise. For example, all ranges disclosed herein are inclusive of the endpoints, and the endpoints are independently combinable with each other.

(39) 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.

(40) Referring now to the drawings, FIG. **1** is a schematic cross-sectional view of a prior art component **100** including multiple plies **102**. The component **100** can be formed of a CMC material where manufacturing the component **100** entails stacking and debulking multiple plies **102** to form a laminate, referred to herein as a laminate preform **114**, by a process referred to as “lay-up.” Each ply **102** contains a ceramic reinforcement made up of multiple fibers **106** bundled into individual tows **108** and encased in a ceramic matrix **110**. The ceramic matrix **110** is formed by conversion, by way of non-limiting example with firing, of a matrix precursor as a binder used to impregnate the tows **108**. In one non-limiting process, a the matrix precursor is a matrix slurry utilized to impregnate tows **108** where a set of tows **112** can form a prepreg **104** usually in the form of a ply or sheet. When laid out, each prepreg **104** forms each ply **102**. The multiple fibers **106** can be unidirectionally aligned such that a single layer of ply **102** can include the set of tows **112** aligned and impregnated with the matrix precursor and arranged unidirectionally. For example, a middle ply **102***m* includes fibers **106** extending along a first direction **124**, across the page, and fibers **106** in the plies **102** bordering the middle ply **102***m* extend in a second direction **125**. The first and second directions **124**, **125** can be perpendicular to each other.

(41) The prepregs **104** are typically, but not necessarily, arranged so that tows **108** of adjacent prepregs **104** are oriented transverse to each other, providing greater strength in a laminar plane

(denoted “P”), extending into and out of the page, of the laminate preform **114** (corresponding to the principal (load-bearing) directions of the final CMC component). However, the prepregs may be arranged in other ways as well, e.g., tows of one or more adjacent prepregs may not be oriented transverse or perpendicular to each other but, in various embodiments, may be parallel to each other, offset from each other less than 90 degrees, etc. A stack of prepregs may include adjacent prepregs having a variety of tow orientations with respect to each other.

(42) Referring to FIG. **2**, a process **120** for coating a reinforcing fiber is illustrated. It will be appreciated that the reinforcing fiber can be the fiber **106** or an uncoated tow **108***u* (a tow **108** prior to coating), and hereinafter references to “reinforcing fiber” apply to either fiber **106**, uncoated tows **108***u*, or both. Prior to or as part of forming the prepregs **104**, uncoated tows **108***u* are wound onto a bobbin **116**, or fiber source. The uncoated tows **108***u* can be unwound from the bobbin **116** for coating. The multiple fibers **106**, bundled together in the form of uncoated tows **108***u*, are coated for several purposes, such as to protect them during composite processing, to modify fiber-matrix interface strength, and/or to promote or prevent mechanical and/or chemical bonding of the fiber and matrix. A number of different techniques have been developed for applying fiber coatings, such as slurry-dipping, sol-gel, sputtering, and chemical vapor deposition (CVD). Of these, CVD has been most successful in producing impervious coatings of uniform thickness and controlled composition.

(43) In a typical CVD process, fibers and reactants are heated to some elevated temperature where coating precursors decompose and deposit as a coating. CVD coatings can be applied either in a continuous process or a batch process. In a continuous process, fibers and coating precursors are continuously passed through a reactor.

(44) In a batch process, a length of uncoated tow **108***u* is unwound from the bobbin **116** onto a frame **118**. The uncoated tow **108***u* can be under tension as it is wound onto the frame **118**. For instance, a winding tension may be maintained on the uncoated tow **108***u* as it is unwound from the bobbin **116** onto the frame **118**. In some embodiments, the winding tension may be within a range of about 0.01% of a breaking strength of an uncoated tow **108***u* to about 90% of the breaking strength of the uncoated tow **108***u*.

(45) Once disposed on the frame **118** and unwinding from the bobbin **116** has ceased, the tension on the uncoated tow **108***u* may be relaxed to a steady state tension. For instance, the frame **118** or a component thereof may be relaxed, withdrawn, etc. to change the perimeter of the frame **118**, which relaxes the tension on the fibers **106** defining the uncoated tow **108***u*. The steady state tension on the uncoated tow **108***u* is lower than the winding tension and may be very low, e.g., essentially zero.

(46) After the uncoated tow **108***u* is transferred to the frame **118**, the frame **118** is then introduced into a reactor **122** and remains within the reactor **122** while reactants (denoted “R”) are passed through the reactor **122**. As previously described, a temperature within the reactor **122** may be elevated such that, as reactants R are passed through the reactor **122**, coating precursors decompose and deposit as a coating (denoted “C”) on the uncoated tow **108***u* to form tow **108**. Depositing the coating can include depositing the coating via CVD as previously described herein. The tow **108**, now coated with the coating C, can be impregnated as part of the set of tows **112** (FIG. **1**) to form the component **100** as described herein.

(47) It will be appreciated that FIG. **2** provides only a general, schematic depiction of an apparatus for transferring uncoated fiber from a fiber source to a frame for depositing a coating onto the fiber in a reactor. Other components, such as a drive mechanism, one or more pulleys, one or more sensors, a controller, etc., may be used with the bobbin **116**, frame **118**, and reactor **122** to coat the uncoated tows **108***u* using a batch process as described herein. It will be appreciated that the reinforcing fiber wrapped around the frame **118** may be fiber **106** or uncoated tows **108***u* and hereinafter references to “reinforcing fiber” apply to either fiber **106**, uncoated tows **108***u*, or both. Further, the following description uses the singular term “tow,” but it will be appreciated that the

following description could apply to a single tow (e.g., a single uncoated tow **108***u* wound on the frame **118** that is coated and unwound from the frame **118** as a single coated tow **108**) or to multiple tows (e.g., multiple lengths of uncoated tows **108***u* are wound onto the frame **118**, coated, and unwound from the frame **118** as multiple lengths of coated tows **108**).

(48) FIG. **3** illustrates a first optional step (denoted "A" in FIG. **2**) for forming a twisted tow **242** from the process **120** described herein. The uncoated tows **108***u* are twisted to form an uncoated twisted tow **242***u* prior to being wound on the frame **118**. The process **120** can continue as described herein from corresponding arrow **126** illustrated in FIG. **2** and FIG. **3** to form a coated twisted tow, or simply referred to herein as the twisted tow **242**. Prior to impregnation, the twisted tow **242** can undergo a left-hand twist, or reverse twist, also known as an "S" twist (denoted "S").

(49) FIG. **4** illustrates a second optional step (denoted "B" in FIG. **2**) for forming the twisted tow **242** from the process **120** described herein. The process **120** can continue from corresponding arrow **128** illustrated in FIG. **2** and FIG. **4**. The tow **108** is twisted with an S twist to form the twisted tow **242**. The twisted tow **242** is then impregnated with a matrix slurry **130** having a ceramic matrix precursor **138** to form an impregnated set of tows **238**. The impregnated set of tows **238** are wound around a drum **132** to form a prepreg **204**.

(50) FIG. **5** illustrates a third optional step (denoted "B**2**" in FIG. **2**) for forming the twisted tow **242** from the process **120** described herein. The process **120** can continue from corresponding arrow **128** illustrated in FIG. **2** and FIG. **5**. The tow **108** is twisted to form the twisted tow **242**. The twisted tow **242** can also undergo a right-hand twist, or regular twist, so known as a "Z" twist (denoted "Z"). The twisted tow **242** is then woven **134**. The woven twisted tow **242** can form a woven matrix **136**. Resin transfer molding (RTM) can be used to form the prepreg **204**. The woven matrix **136** can be placed in a mold **139** of ceramic matrix slurry **138** to form the prepreg **204**.

(51) The twisted tows **242**, **242***u* described herein can be twisted between 1 turn/meter and up to and including 20 turns/meter during the first, second, or third optional part of the process **120**. It is further contemplated that the twisted tows **242**, **242***u* can be twisted between and including 5 turns/meter and up to and including 10 turns/meter. The turns/meter occur about an axis defined by the direction, for example either the first or second directions **124**, **125**, along which the fibers **206** extend.

(52) FIG. **6** is a schematic cross-sectional view of a component **200** according to an aspect of the disclosure herein. The component **200** is similar to the component **100**; therefore, like parts will be identified with like numerals increased by 100, with it being understood that the description of the like parts of the component **100** applies to the component **200**, except where noted.

(53) The component **200** is made of a CMC material where a ceramic matrix **210** encases a set of tows **212** to form the ply **202**. At least one tow **208** of the set of tows **212** is the twisted tow **242** described herein. Multiple plies **202** can be stacked and debulked to form a laminate preform **214**. A top of the component can define a laminar plane P extending into and out of the page. Each stacked ply **202** meets a consecutive ply along first, second, and third planes (denoted "P**1**", "P**2**", and "P**3**" respectively) each parallel to laminar plane P. The planes P**1**, P**2**, P**3** can define intralaminar spaces between consecutive stacked plies **202**. A plurality of fibers **206** defines at least one tow **208** in the set of tows **212**. It is further contemplated that all of the tows **208** in the set of tows **212** are twisted tows **242**. The set of tows **212** can also be the impregnated set of tows **238**.

(54) A middle ply **202***m* abuts both the first and second planes P**1**, P**2** extending therebetween to define a thickness (denoted "T"). The twisted tow **242** can be located in the middle ply **202***m*. The plurality of fibers **206** defining the twisted tow **242** can include at least one bridging fiber **240**. The at least one bridging fiber **240** can include a first portion **240***a*, a second portion **240***b*, and a third portion **240***c*. The first portion **240***a* can extend in a direction parallel to and along the first plane P**1**. The second portion **240***b* can extend in a direction parallel to and along the second plane P**2**. The third portion **240***c* can extend between the first and second portions **240***a*, **240***b* across the middle ply **202***m* from the first plane P**1** toward the second plane P**2**. The third portion **240***c* can

bend away from the first and second portions **240***a*, **240***b* at a fiber angle θ relative to the first and second planes P**1**, P**2** respectfully. The third portion **240***c* can have a length (denoted "L"). It should be understood that the fiber angle θ, thickness T, and length L are all related to each other by the expression: ($\sin \theta = T/L$). For example a bridging angle of 10° for a ply with a thickness of 0.30 mm would have a length of 1.72 mm.

(55) Twisting the tows **208** described herein increases the presence of bridging fibers **240**. Too many turns can cause impregnation and spreading issues, while too few turns can decrease the intralaminar toughness for the ply. It was found that between 1 and 20 turns/meter resulted in an increased intralaminar toughness for the ply **202**. A balance between a full impregnation with increased intralaminar toughness was found at and between 5 turns/meter and up to 10 turns/meter. A process including between 2 and 7 turns/meter provides sufficient impregnation with increased intralaminar toughness when compared to a process utilizing zero twists/meter.

(56) FIG. **7** illustrates a component **300** according to an aspect of the disclosure herein. The component **300** is similar to the component **200**; therefore, like parts will be identified with like numerals increased by 100, with it being understood that the description of the like parts of the component **200** applies to the component **300**, except where noted.

(57) The component **300** is defined by multiple plies **302** stacked and debulked to form a laminate preform **314**. Each ply **302** can define an individual row **344** of twisted tows **342**. Each individual row **344** can have a pattern **345** of left-hand twisted tows **342**L or right-hand twisted tows **342**R, or both left-hand twisted tows **342**L and right-hand twisted tows **342**R. The pattern **345** can include various twisted tows **342** or many of the same twisted tows **342**. Further, every other row **344** can have at least one row of left-hand twisted tows **342**L and at least one row of right-hand twisted tows **342**R.

(58) FIG. **8** illustrates a component **400** according to an aspect of the disclosure herein. The component **400** is similar to the component **300**; therefore, like parts will be identified with like numerals increased by 100, with it being understood that the description of the like parts of the component **300** applies to the component **400**, except where noted.

(59) The component **400** is defined by multiple plies **402** stacked and debulked to form a laminate preform **414**. Each ply **402** can define an individual row **444** of tows **408**. Each individual row **444** can have a pattern **445** of left-hand twisted tows **442**L or right-hand twisted tows **442**R, or both left-hand twisted tows **442**L and right-hand twisted tows **442**R. The pattern **445** can include various twisted tows **442** or many of the same twisted tows **442**. A set of rows **446** can include at least one row with the pattern **445**. Every other set of rows **446** can include the pattern **445**. It is further contemplated that each set of rows **446** includes multiple rows **444** of the pattern **445** with left-hand twisted tows **442**L or multiple rows of the pattern **445** with right-hand twisted tows **442**R. By way of non-limiting example, one set of rows **446** can have consecutive plies **402** formed with left-handed twisted tows **442**L where a plurality of fibers **406** in a first row **444***a* are oriented at an angle with respect to an abutting second row **444***b*.

(60) It should be understood that any combination of patterns of tows and twisted tows defining the laminate preforms described herein is contemplated where at least one row includes a twisted tow.

(61) FIG. **9** is a flow chart illustrating a method **500** of processing ceramic fiber, by way of non-limiting example the plurality of fibers **206**, for the manufacture of a ceramic matrix composite component, by way of non-limiting example the component **200**. The method includes at block **502** bundling the plurality of fibers **206** to form the set of tows **212**. At block **504**, the method includes twisting at least one tow **208** from the set of tows **212** through at least one turn/meter to define at least one twisted tow **242**. The twisted tow **242** can be twisted between 1 and up to and including 20 turns/meter. It is further contemplated that the twisted tow **242** is twisted between and including 5 turns/meter and up to and including 10 turns/meter. At block **506**, the method includes impregnating the set of tows **212** with a binder including the ceramic matrix precursor **138** to define an impregnated set of tows **238**. At block **508**, the method includes forming the prepreg **204**

from the impregnated set of tows **238** and at block **510**, the method includes forming the ply **202** from the prepreg **204**.
(62) The method **500** can include impregnating multiple sets of tows **208**, each set of tows **208** including at least one twisted tow **242**, to define a plurality of prepregs **204**, forming multiple plies **202** from the plurality of prepregs **204**, and stacking the multiple plies **202** to define the laminate preform **214**.
(63) The method **500** can further include forming rows **344** of left-hand twisted tows **442**L or right-hand twisted tows **442**R. The set of rows **446** described herein can be multiple rows of left-hand twisted tows **442**L or right-hand twisted tows. It is further contemplated that every other row **344** is a right-hand twisted tow **442**R and a left-hand twisted tow **442**L.
(64) The method **500** can include any of the optional steps A, B, C described herein with respect to FIGS. **2-5**. It is also contemplated that the method **500** includes a combination or parts of the optional steps A, B, C described herein with respect to FIGS. **2-5**.
(65) Benefits to the disclosure include stronger bridging with an increase in the number of bridging fibers in the ply. The greater the fiber angle the better the chance of a particular fiber participating in bridging between layers. Intentionally forming bridging fibers reinforces the through thickness "T". An improved intralaminar toughness due to slightly misaligned fibers relative to the in-plane direction increases intralaminar resistance. Intentionally misaligning fibers in order to achieve more robust fiber angle bridging enables a higher intralaminar toughness. Twisting the tow enables this intentional misalignment.
(66) An additional benefit of the present disclosure relates to the handling and manufacturability of a CMC tow. As the tow is transported in both batch and continuous processes, separated filaments, sometimes referred to as "fuzz", can cause difficulty for both operators and equipment. Twisting the tow at the previously discussed stages of processing binds the individual filaments into a tighter, more consistent bundle. This improvement to the tow increases control over the size of the tow and the manner in which the tow deforms as the prepreg tape is formed. The twisted tow will also possess increased resistance to individual filaments separating from the bundle.
(67) It should be appreciated that application of the disclosed design is not limited to turbine engines with fan and booster sections, but is applicable to turbojets and turbo engines as well.
(68) To the extent not already described, the different features and structures of the various aspects can be used in combination, or in substitution with each other as desired. That one feature is not illustrated in all of the examples is not meant to be construed that it cannot be so illustrated, but is done for brevity of description. Thus, the various features of the different aspects can be mixed and matched as desired to form new aspects, whether or not the new aspects are expressly described. All combinations or permutations of features described herein are covered by this disclosure.
(69) This written description uses examples to describe aspects of the disclosure described herein, including the best mode, and also to enable any person skilled in the art to practice aspects of the disclosure, including making and using any devices or systems and performing any incorporated methods. The patentable scope of aspects of the disclosure is defined by the claims, and can 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 have 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.
(70) Further aspects of the disclosure are provided by the subject matter of the following clauses:
(71) A method of processing ceramic fiber for manufacturing of a ceramic matrix composite (CMC) component, comprising bundling a plurality of fibers to form at least one tow; twisting the at least one tow through at least one turn/meter to define at least one twisted tow; forming a set of tows including the at least one twisted tow; impregnating the set of tows with a binder including a ceramic matrix precursor to form an impregnated set of tows; forming a prepreg from the impregnated set of tows; and forming a laminate preform from the prepreg.

(72) The method of any preceding claim wherein twisting the at least one tow comprises twisting the at least one tow between 1 turn/meter and up to and including 20 turns/meter.
(73) The method of any preceding claim wherein twisting the at least one tow comprises twisting the at least one tow between and including 5 turns/meter and up to and including 10 turns/meter.
(74) The method of any preceding claim wherein twisting the at least one tow comprises twisting the at least one tow between and including 2 turns/meter and up to and including 7 turns/meter.
(75) The method of any preceding claim further comprising impregnating multiple sets of tows, each set of tows including at least one twisted tow, to form a plurality of prepregs, forming multiple plies from the plurality of prepregs, and stacking the multiple plies to form the laminate preform.
(76) The method of any preceding claim wherein each ply comprises a row of twisted tows, and the row of twisted tows is formed with a pattern consisting of at least one of left-hand twisted tows, and right-hand twisted tows.
(77) The method of any preceding claim wherein the pattern includes left-hand twisted tows and right-hand twisted tows.
(78) The method of any preceding claim wherein every other tow is a left-hand twisted tow.
(79) The method of any preceding claim wherein every other tow is a right-hand twisted tow.
(80) The method of any preceding claim wherein multiple rows define a set of rows and every other set of rows includes the pattern.
(81) The method of any preceding claim wherein forming the prepreg comprises wrapping the impregnated set of tows around a drum.
(82) The method of any preceding claim further comprising depositing a coating on the plurality of fibers via a chemical vapor deposition (CVD) process to form a coated plurality of fibers prior to bundling the plurality of fibers.
(83) The method of any preceding claim wherein impregnating the at least one twisted tow with a binder comprises impregnating the at least one twisted tow with a matrix slurry.
(84) The method of any preceding claim further comprising depositing a coating on the plurality of fibers via a chemical vapor deposition (CVD) process to form a coated plurality of fibers after twisting the at least one tow.
(85) The method of any preceding claim wherein impregnating the at least one twisted tow with a binder comprises impregnating the at least one twisted tow with a matrix slurry.
(86) The method of any preceding claim wherein forming the prepreg comprises weaving or braiding the set of tows prior to impregnating the set of tows.
(87) The method of any preceding claim further comprising depositing a coating on the plurality of fibers via a chemical vapor deposition (CVD) process to form a coated plurality of fibers prior to bundling the plurality of fibers.
(88) A laminate preform for a ceramic matrix composite (CMC) component, the laminate preform comprising at least one ply including a prepreg formed with an impregnated set of tows, at least one tow in the impregnated set of tows twisted through at least one turn/meter, and having at least one bridging fiber extending between adjacent plies.
(89) The laminate preform of any preceding claim wherein the at least one ply comprises multiple plies stacked to define the laminate preform.
(90) The laminate preform of any preceding claim wherein at least one tow in the impregnated set of tows is twisted between 1 turn/meter and up to and including 20 turns/meter.
(91) The laminate preform of any preceding claim wherein at least one tow in the impregnated set of tows is twisted between 5 turns/meter and up to and including 10 turns/meter.
(92) The laminate preform of any preceding claim wherein at least one tow in the impregnated set of tows is twisted between 2 turns/meter and up to and including 7 turns/meter.
(93) The laminate preform of any preceding claim wherein at least one tow in every other ply in the multiple plies includes a pattern with one of a left handed twisted tow and a right handed twisted tow.

(94) The laminate preform of any preceding claim wherein the at least one tow is every tow in the impregnated set of tows.

Claims

1. A laminate preform for a ceramic matrix composite (CMC) component, the laminate preform comprising at least one ply including a prepreg formed with an impregnated set of tows, at least one tow in the impregnated set of tows twisted through at least one turn/meter, and having at least one bridging fiber extending between adjacent plies.
2. The laminate preform of claim 1, wherein the at least one ply comprises multiple plies stacked to define the laminate preform.
3. The laminate preform of claim 2, wherein the at least one tow in the impregnated set of tows is twisted between 1 turn/meter and up to and including 20 turns/meter.
4. The laminate preform of claim 3, wherein the at least one tow in the impregnated set of tows is twisted between 5 turns/meter and up to and including 10 turns/meter.
5. The laminate preform of claim 2, wherein at least one tow in every other ply in the multiple plies includes a pattern with one of a left handed twisted tow and a right handed twisted tow.
6. The laminate preform of claim 2, wherein the at least one tow is every tow in the impregnated set of tows.
7. The laminate perform of claim 1, wherein the impregnated set of tows at least one twisted tow.
8. The laminate preform of claim 7, wherein each set of tows include at least one twisted tow to form a plurality of prepregs.
9. The laminate perform of claim 8, further comprising multiple plies formed by the plurality of prepregs, the multiple plies being stacked to form the laminate preform.
10. The laminate preform of claim 9, wherein each ply comprises a row of twisted tows, and the row of twisted tows is formed with a pattern consisting of at least one of left-hand twisted tows, and right-hand twisted tows.
11. The laminate preform of claim 10, wherein the pattern includes left-hand twisted tows and right-hand twisted tows.
12. The laminate preform of claim 10, wherein multiple rows define a set of rows and every other set of rows includes the pattern.
13. The laminate preform of claim 1, wherein the impregnated set of tows are wrapped around a drum.
14. The laminate preform of claim 13, wherein the impregnated set of tows are formed by a plurality of fibers that are bundled together.
15. The laminate preform of claim 14, further comprising a coating deposited on the plurality of fibers via a chemical vapor deposition (CVD) process to form a coated plurality of fibers prior to bundling the plurality of fibers.
16. The laminate preform of claim 1, wherein the impregnated set of tows include a binder including a ceramic matrix precursor.
17. The laminate preform of claim 16, wherein the impregnated set of tows at least one twisted tow, and the at least one twisted tow is impregnated with a binder being a matrix slurry.
18. The laminate preform of claim 1, wherein the impregnated set of tows are formed by a set of tows that are woven or braided prior to impregnating the impregnated set of tows.
19. The laminate preform of claim 1, wherein the impregnated set of tows are formed by a plurality of fibers that are bundled together, and wherein the impregnated set of tows are formed by a plurality of fibers that are bundled together further comprising depositing a coating on the plurality of fibers via a chemical vapor deposition (CVD) process to form a coated plurality of fibers prior to

bundling the plurality of fibers.
20. The laminate preform of claim 1, wherein the laminate perform is used within a turbine engine.