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(54) CERAMIC MATRIX COMPOSITE COMPONENT INCLUDING COOLING CHANNELS AND METHOD OF PRODUCING

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C04B 35/71	(2006.01)
F01D 25/12	(2006.01)

(52) **U.S. Cl.**

CPC ***F01D 5/18*** (2013.01); ***C04B 35/71*** (2013.01); ***F01D 25/12*** (2013.01); *F05D 2260/221* (2013.01); *F05D 2300/6033* (2013.01)

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CPC C04B 35/62844; C04B 35/63468; C04B 35/638; C04B 35/64; C04B 35/71; C04B 35/80; F01D 5/186; F01D 9/065; F05D 2230/10; F05D 2300/6033

See application file for complete search history.

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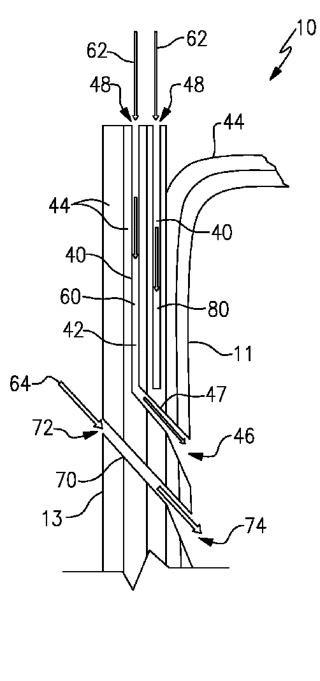
(57) **ABSTRACT**

A ceramic matrix composite component and method of fabrication including a plurality of longitudinally extending ceramic matrix composite plies in a stacked configuration forming a densified body and one or more elongate functional features formed therein and in alignment with the plurality of longitudinally extending ceramic matrix composite plies. Each of the elongate functional features includes an inlet configured to be in fluid communication with a flow of cooling fluid from a fluid source. One or more bores cut through the plurality of ceramic matrix composite plies from at least one of the one or more elongate functional features to an outlet proximate to an outer surface of the ceramic matrix composite component. One or more film cooling throughholes cut through the ceramic matrix composite plies from an inner surface of the ceramic matrix composite component to an outlet proximate to the outer surface of the ceramic matrix composite component.

9 Claims, 5 Drawing Sheets



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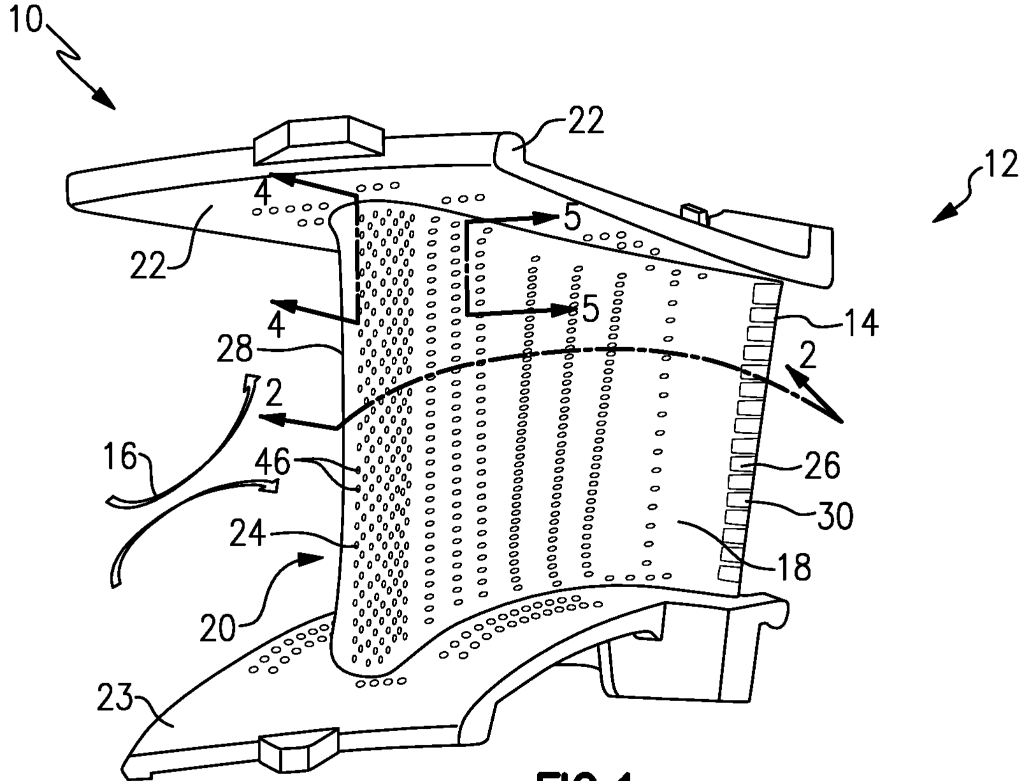
10
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12
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FIG.1

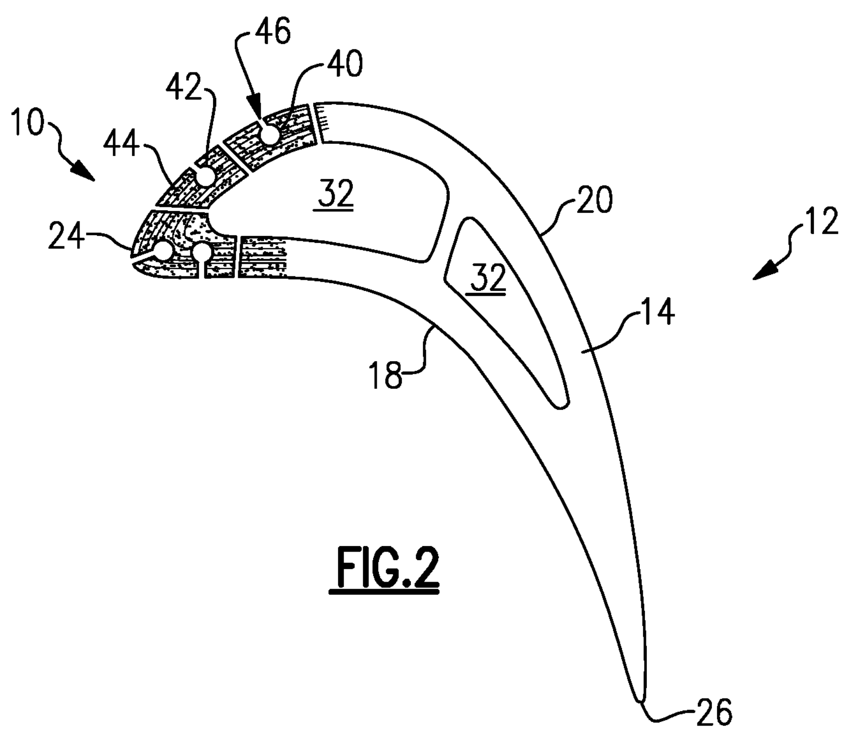
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FIG.2

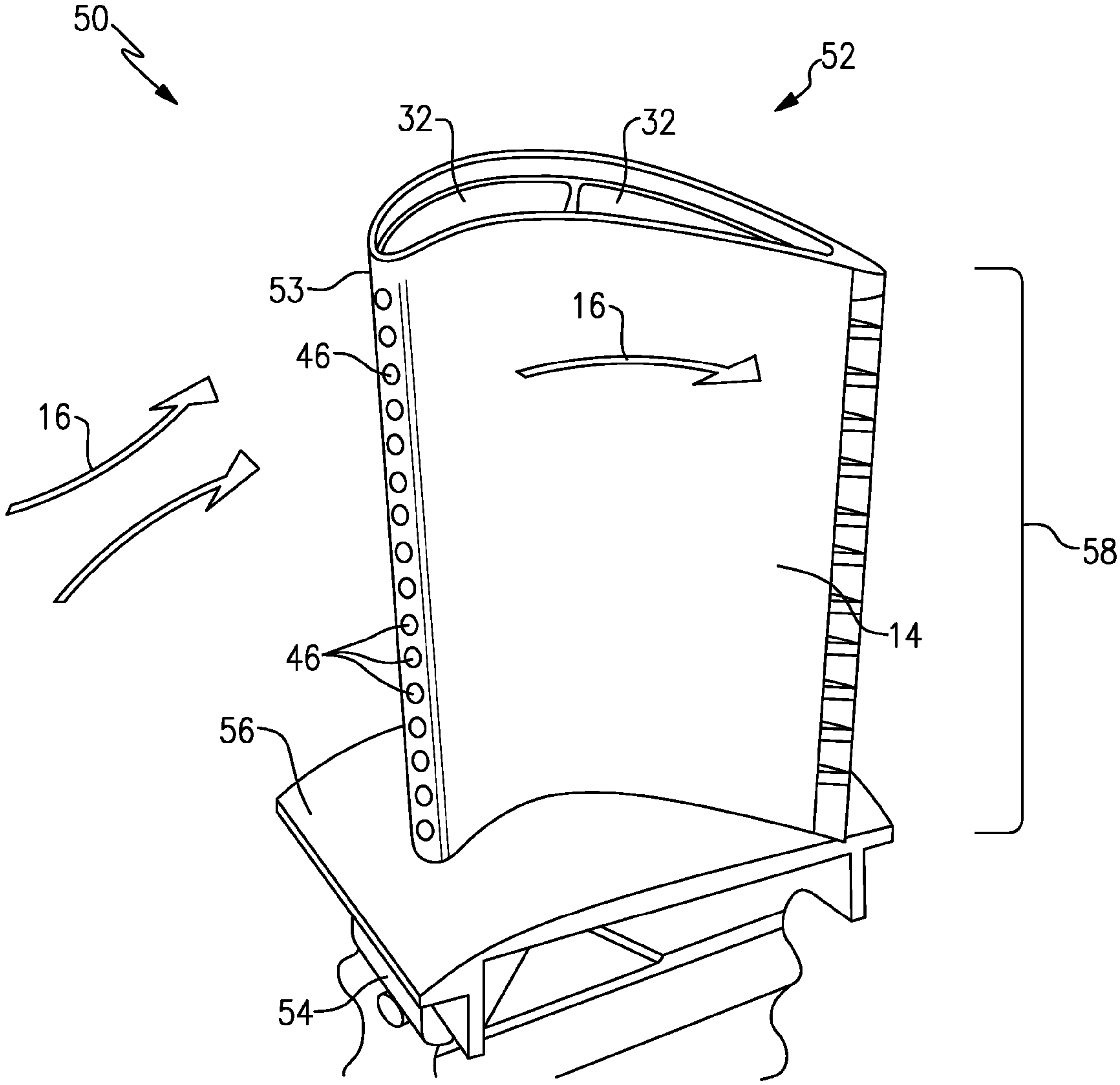
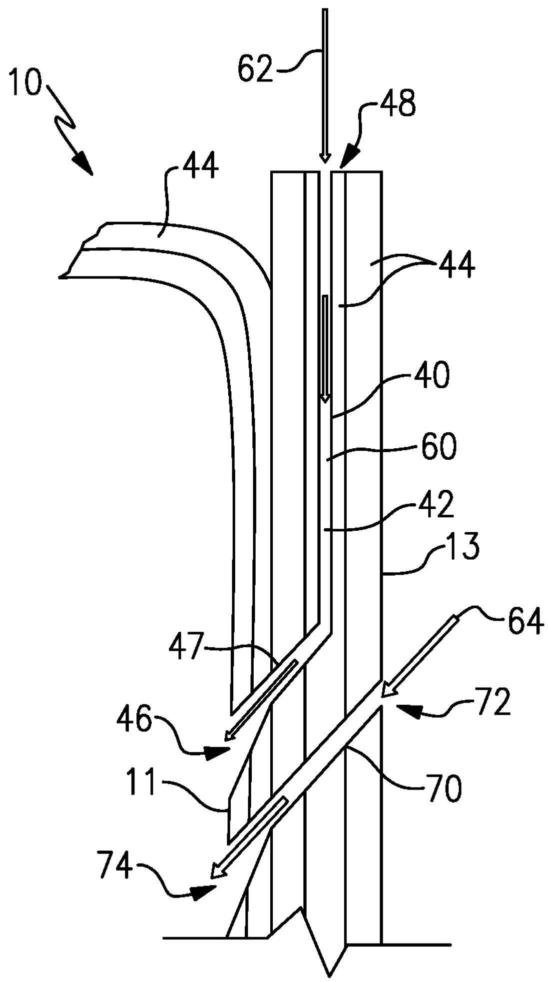


FIG.3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62
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44
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64
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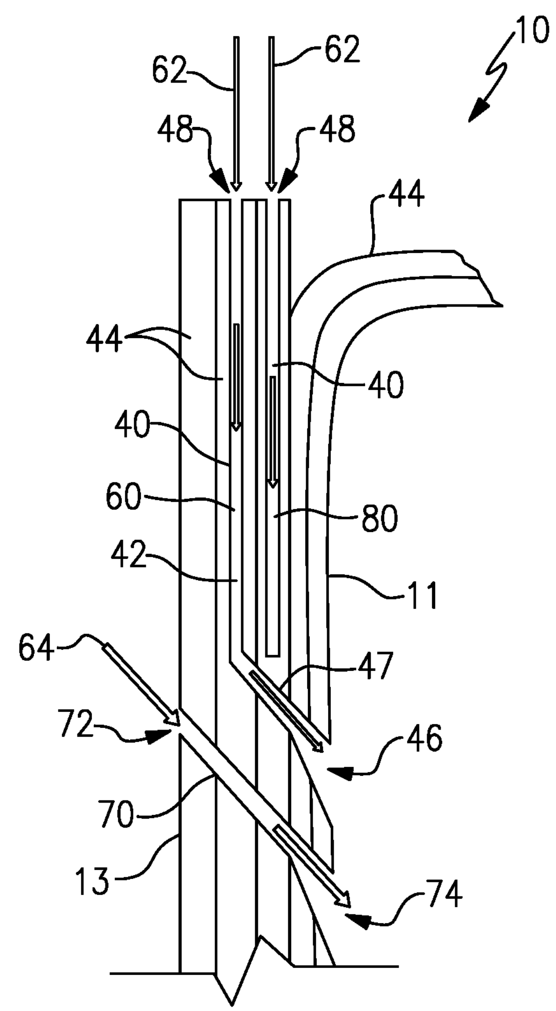
11
70
74

FIG.4


10
62
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44
44
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80
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11
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47
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46
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13
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FIG.5

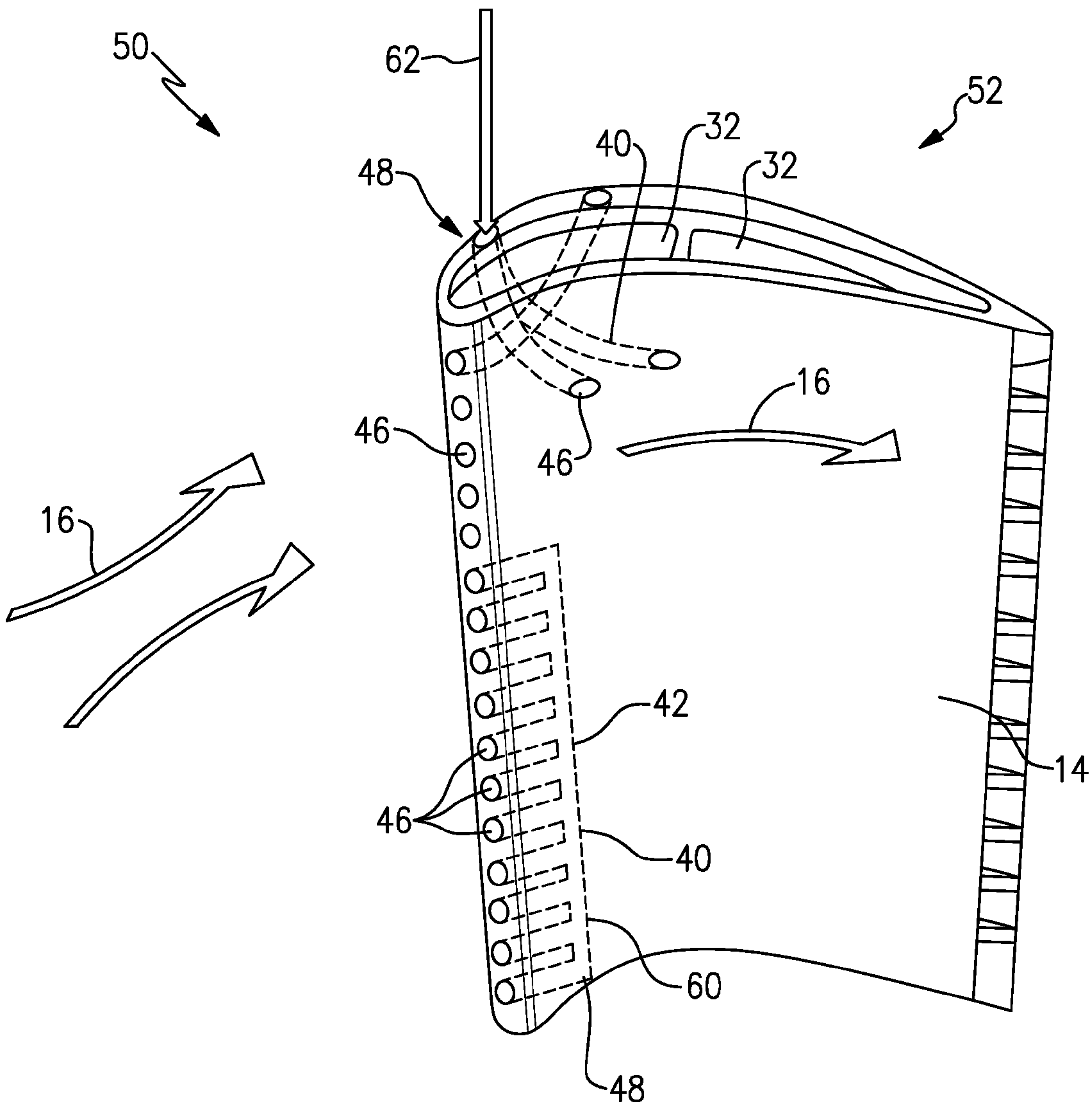

FIG.6

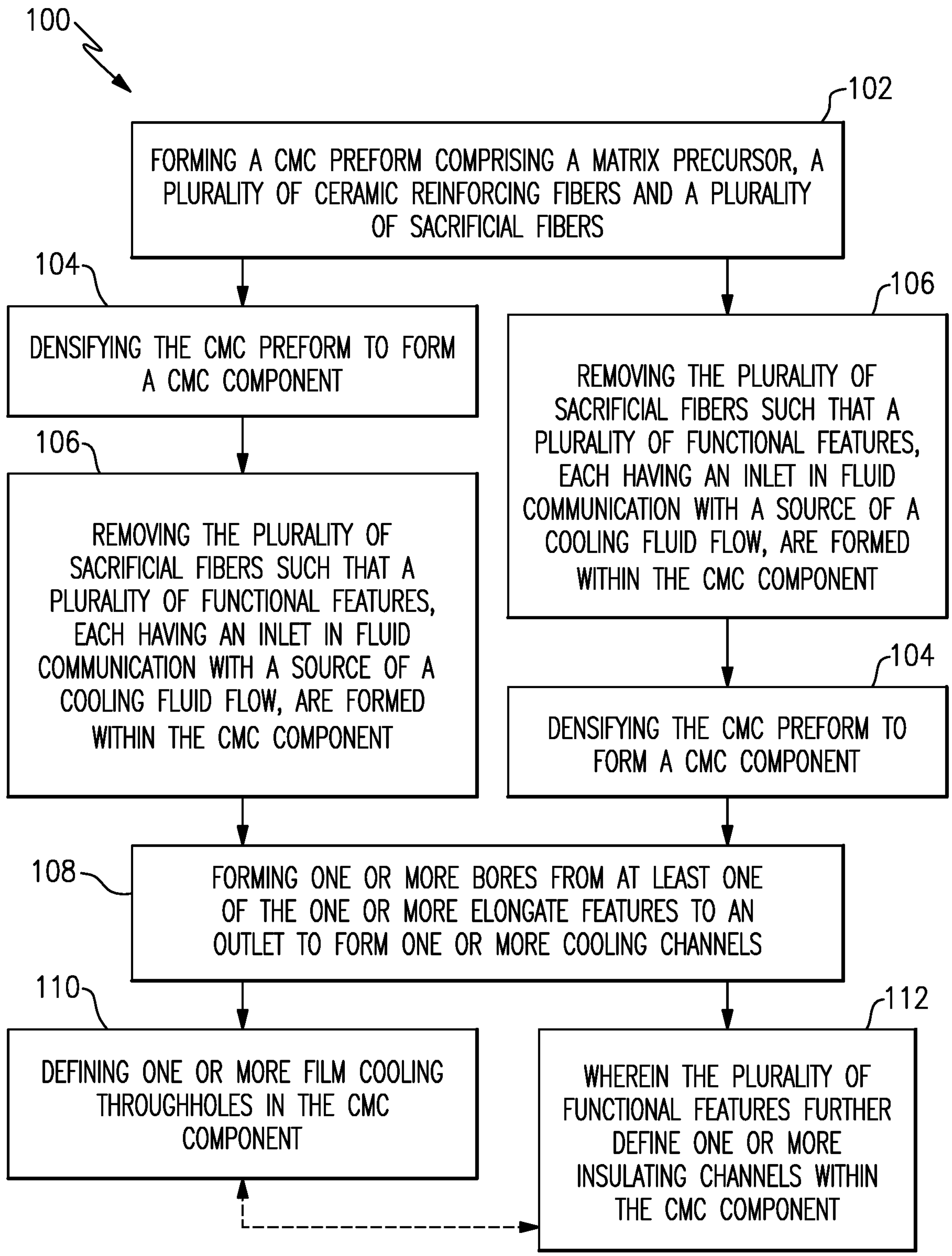
100
102
FORMING A CMC PREFORM COMPRISING A MATRIX PRECURSOR, A PLURALITY OF CERAMIC REINFORCING FIBERS AND A PLURALITY OF SACRIFICIAL FIBERS
104
DENSIFYING THE CMC PREFORM TO FORM A CMC COMPONENT
106
REMOVING THE PLURALITY OF SACRIFICIAL FIBERS SUCH THAT A PLURALITY OF FUNCTIONAL FEATURES, EACH HAVING AN INLET IN FLUID COMMUNICATION WITH A SOURCE OF A COOLING FLUID FLOW, ARE FORMED WITHIN THE CMC COMPONENT
106
REMOVING THE PLURALITY OF SACRIFICIAL FIBERS SUCH THAT A PLURALITY OF FUNCTIONAL FEATURES, EACH HAVING AN INLET IN FLUID COMMUNICATION WITH A SOURCE OF A COOLING FLUID FLOW, ARE FORMED WITHIN THE CMC COMPONENT
104
DENSIFYING THE CMC PREFORM TO FORM A CMC COMPONENT
108
FORMING ONE OR MORE BORES FROM AT LEAST ONE OF THE ONE OR MORE ELONGATE FEATURES TO AN OUTLET TO FORM ONE OR MORE COOLING CHANNELS
110
DEFINING ONE OR MORE FILM COOLING THROUGHHOLES IN THE CMC COMPONENT
112
WHEREIN THE PLURALITY OF FUNCTIONAL FEATURES FURTHER DEFINE ONE OR MORE INSULATING CHANNELS WITHIN THE CMC COMPONENT

FIG.7

CERAMIC MATRIX COMPOSITE COMPONENT INCLUDING COOLING CHANNELS AND METHOD OF PRODUCING

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation application of U.S. application Ser. No. 16/723,059 filed Dec. 20, 2019, which is hereby incorporated by reference in its entirety.

FIELD

The present invention relates generally to gas turbines for power generation and more specifically to methods of forming ceramic matrix composite components for hot gas path turbine components for gas turbines.

BACKGROUND

Silicon carbide (SiC)-based ceramic matrix composite (CMC) materials have been proposed as materials for certain components of gas turbine engines, such as the turbine blades, vanes, nozzles, shrouds and buckets. Various methods are known for fabricating SiC-based components, including Silicomp, melt infiltration (MI), chemical vapor infiltration (CVI), polymer inflation pyrolysis (PIP), and oxide/oxide methods. Though these fabrication techniques significantly differ from each other, each involves the use of hand lay-up and tooling or dies to produce a near-net-shape part through a method that includes the application of heat at various method stages.

As with turbine blades and vanes formed from more conventional superalloy materials, CMC blades, vanes and shrouds are primarily equipped with cavities and cooling voids to reduce weight, reduce centrifugal load, and reduce operating temperatures of the components. These features are typically formed in CMC components using a combination of removable and expendable tooling, drilling or the like. Internal cooling channels are advantageous for cooling the both metal and CMC hot-gas path hardware as they reduce cooling flow requirements and thermal gradients/stress.

In many instances, the CMC gas turbine components are subject to extreme conditions in the form of extreme thermal gradients and high temperatures. Even with the inclusion of cavities and cooling voids in the CMC component as previously described, the extreme conditions may drive crack formation, coating spallation, and recession in the CMC components. Reduced service life from these problems prevents CMC components from realizing their full potential.

Accordingly, there is a need for a ceramic matrix composite component and method of producing a ceramic matrix composite component that provide improved cooling to the CMC gas turbine components when subject to extreme conditions, such as extreme thermal gradients and high temperatures.

BRIEF DESCRIPTION

Aspects and advantages of the disclosure will be set forth in part in the following description, or may be obvious from the description, or may be learned through practice of the disclosure.

A ceramic matrix composite (CMC) component is generally provided, along with a method of forming the ceramic matrix composite component. In one embodiment, the ceramic matrix composite component includes: a plurality of longitudinally extending ceramic matrix composite plies in a stacked configuration forming a densified body; one or more elongate functional features formed therein the densified body, and in alignment with the plurality of longitudinally extending ceramic matrix composite plies, and one or more bores cutting through the plurality of longitudinally extending ceramic matrix composite plies from at least one of the one or more elongate functional features to an outlet proximate to an outer surface of the ceramic matrix composite component. Each of the one or more elongate functional features includes an inlet in fluid communication with a flow of cooling fluid from a fluid source; and

In an alternate embodiment, the ceramic matrix composite component includes a plurality of longitudinally extending ceramic matrix composite plies in a stacked configuration forming a densified body; one or more elongate functional features formed therein the densified body, and one or more bores cutting through the plurality of longitudinally extending ceramic matrix composite plies from at least one of the one or more elongate functional features to an outlet proximate to an outer surface of the ceramic matrix composite to form at least one cooling channel. Each of the one or more elongate functional features includes an inlet in fluid communication with a flow of cooling fluid from a fluid source. At least one of the one or more elongate functional features is configured to retain the flow of fluid from the fluid source in the elongate functional feature to form an insulating channel.

In yet another embodiment, the method of forming a ceramic matrix composite product includes forming a CMC preform comprising a matrix precursor, a plurality of reinforcing fibers and a plurality of sacrificial fibers; performing one of: removing the plurality of sacrificial fibers such that one or more elongate functional features are formed in the CMC preform in fluid communication with a source of cooling fluid flow; or applying a fluid infiltrant to the CMC preform thereby densifying the CMC preform, performing the other of: removing the plurality of sacrificial fibers such that one or more elongate functional features are formed in the CMC preform in fluid communication with a source of cooling fluid flow; or applying a fluid infiltrant to the CMC preform thereby densifying the CMC preform, and forming one or more bores cutting through the plurality of longitudinally extending ceramic matrix composite plies from at least one of the one or more elongate functional features to an outlet proximate to an outer surface of the ceramic matrix composite component to provide a flow of fluid from the fluid source to an exterior of the ceramic matrix composite component and form one or more cooling channels.

These and other features, aspects and advantages of the present disclosure will become better understood with reference to the following description and appended claims. The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the disclosure and, together with the description, serve to explain the principles of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

A full and enabling 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 drawings, in which:

FIG. **1** is a perspective view of a ceramic matrix component (CMC), and more particularly, a CMC nozzle, in accordance with one or more embodiments disclosed herein;

FIG. **2** is a sectional view taken in direction **2-2** of FIG. **1** of the ceramic matrix composite (CMC) component of FIG. **1**, in accordance with one or more embodiments disclosed herein;

FIG. **3** is a perspective view of another embodiment of a ceramic matrix component (CMC), and more particularly, a CMC blade, in accordance with one or more embodiments disclosed herein;

FIG. **4** is a schematic sectional view taken in direction **4-4** of FIG. **1** of a portion of the ceramic matrix composite (CMC) component of FIG. **1**, in accordance with one or more embodiments disclosed herein;

FIG. **5** is a schematic sectional view taken in direction **5-5** of FIG. **1** of a portion of the ceramic matrix composite (CMC) component of FIG. **1**, in accordance with one or more embodiments disclosed herein;

FIG. **6** is a schematic view of a portion of the ceramic matrix composite (CMC) component of FIG. **3**, illustrating one or more functional features in hidden line, in accordance with one or more embodiments disclosed herein; and

FIG. **7** schematically shows a method for forming a CMC component, in accordance with one or more embodiments disclosed herein.

Wherever possible, the same reference numbers will be used throughout the drawings to represent the same parts.

DETAILED DESCRIPTION

Embodiments of the present disclosure, for example, in comparison to concepts failing to include one or more of the features disclosed herein, enable the formation of one or more cooling channels in a CMC airfoil component, wherein the channels are configured in alignment with the one or more CMC layers. The inclusion of the cooling channels in alignment with the one or more CMC layers provides for maintenance of the component structural integrity. The CMC airfoil component further includes one or more insulating channels or one or more film cooling holes. The method, according to the present disclosure, has decreased complexity with low cost, and more efficient cooling with the ability to reduce the cooling demand and flow-rate of the part

When introducing elements of various embodiments of the present invention, the articles "a," "an," "the," and "said" are intended to mean that there are one or more of the elements. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements. Reference now will be made in detail to embodiments of the disclosure, one or more examples of which are illustrated in the drawings. Each example is provided by way of explanation of the disclosure, not limitation of the disclosure. In fact, it will be apparent to those skilled in the art that various modifications and variations can be made in the present disclosure without departing from the scope or spirit of the disclosure. For instance, features illustrated or described as part of one embodiment can be used with another embodiment to yield a still further embodiment. Thus, it is intended that the present disclosure covers such modifications and variations as come within the scope of the appended claims and their equivalents.

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.

Chemical elements are discussed in the present disclosure using their common chemical abbreviation, such as commonly found on a periodic table of elements. For example, Hydrogen would be represented by its common chemical abbreviation H; Helium would be represented by its common chemical abbreviation He; and so forth.

As used herein, the "average particle diameter" or "average fiber diameter" refers to the diameter of a particle or fiber such that about 50% of the particles or fibers have a diameter that is greater than that diameter, and about 50% of the particles or fibers have a diameter that is less than that diameter.

As used herein, "substantially" refers to at least about 90% or more of the described group. For instance, as used herein, "substantially all" indicates that at least about 90% or more of the respective group have the applicable trait and "substantially no" or "substantially none" indicates that at least about 90% or more of the respective group do not have the applicable trait. As used herein, the "majority" refers to at least about 50% or more of the described group. For instance, as used herein, "the majority of" indicates that at least about 50% or more of the respective group have the applicable trait.

A ceramic matrix composite product (a "CMC product"), particularly a ceramic matrix composite product formed from melt infiltration, is generally provided herein, along with methods of forming such product. The CMC product is formed a plurality of ply layers including one or more elongated functional features formed in alignment with the plurality of ply layers, in combination with one or more insulating channels formed in alignment with the plurality of ply layers, or one or more film cooling holes, in combination enhancing the function of the CMC component.

Systems used to generate power include, but are not limited to, gas turbines, steam turbines, and other turbine assemblies, such as land based aero-derivatives, used for power generation. In certain applications, the power generation systems, including the turbomachinery therein (e.g., turbines, compressors, and pumps) and other machinery, may include components that are exposed to heavy wear conditions. For example, certain power generation system components, such as blades, buckets, casings, rotor wheels, shafts, shrouds, nozzles, and so forth, may operate in high heat and/or high revolution environments. These components are manufactured using ceramic matrix composites and these components may also include cooling passages and insulating passages. The present disclosure provides a CMC component including one or more cooling passages or channels, and a method of forming the ceramic matrix composite (CMC) components. An exemplary embodiment of the disclosure is shown in FIGS. **1-6** as a turbine airfoil, and more particularly a nozzle or turbine blade, but the present disclosure is not limited to the illustrated structures.

Referring now to FIGS. **1** and **2**, illustrated in FIG. **1** is a perspective view of a component **10**, such as, but not limited to, a turbine nozzle segment **12**, including a turbine airfoil **14**. Illustrated in FIG. **2** is a side cross-sectional view of the nozzle segment **12** taken through line **2-2** of FIG. **1**, Although FIGS. **1** and **2** show a turbine nozzle segment **12**, other suitable components, according to the present disclosure, include, but are not limited to, a combustor liner, a blade, a nozzle end wall/band, a blade platform, a shroud or other hot gas path component. Component **10** is preferably formed of a ceramic matrix composite (CMC) material.

As used herein, ceramic matrix composite or "CMCs" refers to composites comprising a ceramic matrix reinforced by ceramic fibers. Some examples of CMCs acceptable for use herein can include, but are not limited to, materials having a matrix and reinforcing fibers comprising oxides, carbides, nitrides, oxycarbides, oxynitrides and mixtures thereof. Examples of non-oxide materials include, but are not limited to, CMCs with a silicon carbide matrix and silicon carbide fiber (when made by silicon melt infiltration, this matrix will contain residual free silicon); silicon carbide/silicon matrix mixture and silicon carbide fiber; silicon nitride matrix and silicon carbide fiber; and silicon carbide/silicon nitride matrix mixture and silicon carbide fiber. Furthermore, CMCs can have a matrix and reinforcing fibers comprised of oxide ceramics. Specifically, the oxide-oxide CMCs may be comprised of a matrix and reinforcing fibers comprising oxide-based materials such as aluminum oxide (Al_2O_3), silicon dioxide (SiO_2), aluminosilicates, and mixtures thereof. Accordingly, as used herein, the term "ceramic matrix composite" includes, but is not limited to, carbon-fiber-reinforced carbon (C/C), carbon-fiber-reinforced silicon carbide (C/SiC), and silicon-carbide-fiber-reinforced silicon carbide (SiC/SiC). In one embodiment, the ceramic matrix composite material has increased elongation, fracture toughness, thermal shock, and anisotropic properties as compared to a (non-reinforced) monolithic ceramic structure.

There are several methods that can be used to fabricate SiC—SiC CMCs. In one approach, the matrix is partially formed or densified through melt infiltration (MI) of molten silicon or silicon containing alloy into a CMC preform. In another approach, the matrix is at least partially formed through chemical vapor infiltration (CVI) of silicon carbide into a CMC preform. In a third approach, the matrix is at least partially formed by pyrolizing a silicon carbide yielding pre-ceramic polymer. This method is often referred to as polymer infiltration and pyrolysis (PIP). Combinations of the above three techniques can also be used.

In one example of the MI CMC process, a boron-nitride based coating system is deposited on SiC fiber. The coated fiber is then impregnated with matrix precursor material in order to form prepreg tapes. One method of fabricating the tapes is filament winding. The fiber is drawn through a bath of matrix precursor slurry and the impregnated fiber wound on a drum. The matrix precursor may contain silicon carbide and or carbon particulates as well as organic materials. The impregnated fiber is then cut along the axis of the drum and is removed from the drum to yield a flat prepreg tape where the fibers are nominally running in the same direction. The resulting material is a unidirectional prepreg tape. The prepreg tapes can also be made using continuous prepregging machines or by other means. The tape can then be cut into shapes, layed up, and laminated to produce a preform. The preform is pyrolyzed, or burned out, in order to char any organic material from the matrix precursor and to create porosity. Molten silicon is then infiltrated into the porous preform, where it can react with carbon to form silicon carbide. Ideally, excess free silicon fills any remaining porosity and a dense composite is obtained. The matrix produced in this manner typically contains residual free silicon.

The prepreg MI process generates a material with a two-dimensional fiber architecture by stacking together multiple one-dimensional prepreg plies where the orientation of the fibers is varied between plies. Plies are often identified based on the orientation of the continuous fibers. A zero degree orientation is established, and other plies are designed based on the angle of their fibers with respect to the zero degree direction. Plies in which the fibers run perpendicular to the zero direction are known as 90 degree plies, cross plies, or transverse plies.

The MI approach can also be used with two-dimensional or three-dimensional woven architectures. An example of this approach would be the slurry-cast process, where the fiber is first woven into a three-dimensional preform or into a two-dimensional cloth. In the case of the cloth, layers of cloth are cut to shape and stacked up to create a preform. A chemical vapor infiltration (CVI) technique is used to deposit the interfacial coatings (typically boron nitride based or carbon based) onto the fibers. CVI can also be used to deposit a layer of silicon carbide matrix. The remaining portion of the matrix is formed by casting a matrix precursor slurry into the preform, and then infiltrating with molten silicon.

An alternative to the MI approach is to use the CVI technique to densify the Silicon Carbide matrix in one-dimensional, two-dimensional or three-dimensional architectures. Similarly, PIP can be used to densify the matrix of the composite. CVI and PIP generated matrices can be produced without excess free silicon. Combinations of MI, CVI, and PIP can also be used to densify the matrix.

Component **10**, and more particularly the nozzle segment **12**, includes a plurality of circumferentially spaced airfoil shaped hollow vanes, of which only one is illustrated and referred to herein as airfoil **14**, that are supported between arcuate, segmented outer bands **22** and inner bands **23** (of which only one of each is shown), also referred to herein as endwalls. The airfoil **14**, the outer band **22** and the inner band **23** are arranged into a plurality of circumferentially adjoining nozzle segments **12** that collectively form a complete 360° assembly.

It should be noted that the construction of the nozzle segment **12** is used merely as an example, and the principles of the present invention are applicable to any turbine airfoil. As indicated, FIG. **1** illustrates a single nozzle segment **12**, including a single airfoil **14** against which a flow of hot exhaust gas **16** is directed. The airfoil **14** includes widthwise spaced apart airfoil pressure and suction sides **18**, **20** extending heightwise or spanwise and outwardly between opposed nozzle end walls, or bands, **22** and **23**. The exemplary airfoil pressure and suction sides **18**, **20** illustrated herein may be concave and convex respectively. The airfoil **14** includes lengthwise or chordwise spaced apart airfoil leading and trailing edges **24**, **26** at or near forward and aft ends **28**, **30** of the airfoil **14**. A chord C (not shown) is defined between the airfoil leading edge **24** and the airfoil trailing edge **26** of the airfoil cross section.

FIG. **2** is a sectional view of the component **10** taken in direction **2-2** of FIG. **1** showing one or more functional features **40**, described presently, and more particularly one or more cooling channels **42** formed in the component **10**. A plurality of ceramic matrix composite (CMC) plies **44** (only a few have been shown for clarity) are illustrated. The plurality of functional features **40** extend in alignment with the ceramic matrix composite plies **44** (described presently). Each functional feature **40** is in fluid communication (described presently with a source of cooling fluid via an inlet (described presently) and exterior the component **10** via an outlet **46** (FIG. **1**). In an alternate embodiment, at least one of the plurality of functional features **40** may be in fluid communication with a plenum **32** defined within the airfoil **14**.

Referring now to FIG. **3**, illustrated is an alternate embodiment of the CMC component described herein. It again is noted, the same reference numbers will be used throughout the drawings to represent the same parts. In the embodiment of FIG. **3**, illustrated is a component **50**, such as, but not limited to, a turbine rotor segment **52**, including an airfoil **14**. Although FIG. **3** shows a turbine rotor segment **52**, as previously stated, other suitable components, according to the present disclosure, include, but are not limited to, a combustor liner, a blade, a nozzle end wall/band, a blade platform, a shroud or other hot gas path component. Similar to the component **10** of FIGS. **1** and **2**, the component **50** is preferably formed of a ceramic matrix composite (CMC) material.

In the embodiment of FIG. **3**, the CMC component **50** includes an airfoil **14** against which a flow of hot exhaust gas **16** is directed. The airfoil **14** extends from a tip **53** to a dovetail **54**. Component **50** is mounted to a turbine disk (not shown) by the dovetail **54** which extends downwardly from the airfoil **14** and engages a slot on the turbine disk. A platform **56** extends laterally outwardly from the area where the airfoil **14** is joined to the dovetail **54**. The component **50** includes at least one plenum **32** extending along the interior of the airfoil **14**. During operation of a power generation system, a flow of cooling air (not shown) is directed through the plenum **32** to reduce the temperature of the airfoil **14**.

The component **10**, and more specifically the airfoil **14**, includes widthwise spaced apart airfoil pressure and suction sides **18**, **20** extending heightwise or spanwise and outwardly from the airfoil platform **56** along an airfoil span **58** to the airfoil tip **53**. Similar to the airfoil **14** of FIGS. **1** and **2**, the airfoil pressure and suction sides **18**, **20** illustrated in this particular embodiment may be concave and convex respectively. The airfoil **14** includes a lengthwise or chordwise spaced apart airfoil leading edge **24** and a trailing edge **26** at or near a forward **28** and an aft end **30**, respectively, of the airfoil **14**. It should be noted herein that a first edge of the airfoil **14** to contact the incoming gases **16** is referred to herein as the leading edge **24** and a second edge that contacts the hot exhaust gas **16** as the hot exhaust gas **16** flows past the airfoil **14** is referred to as the trailing edge **26**. A chord C (not shown) is defined as a line between the airfoil leading edge **24** and trailing edge **26** of a cross section of the airfoil **14**.

Similar to the previous embodiment, the component **50** includes one or more functional features (not shown), and more particularly one or more cooling channels formed in the component **50**. The component **50** is comprised of a plurality of ceramic matrix composite (CMC) plies **44** with the plurality of functional features **40** extending in alignment with the ceramic matrix composite plies **44**. Each functional feature is in fluid communication (described presently with the plenum **32** defined within the airfoil **14** via an inlet (described presently) and exterior the component **50** via an outlet **46**. In an alternate embodiment, at least one of the plurality of functional features **40** may be in fluid communication with an alternative source of a cooling fluid.

Referring now to FIG. **4**, illustrated is a schematic sectional view of a portion of the component **10** taken through line **4-4** in FIG. **1**, illustrating the plurality of CMC plies **44**. In this disclosed embodiment, one or more of the plurality of CMC plies **44** has formed therein one or more functional features **40** (of which only one is illustrated in FIG. **4**). In an embodiment, the functional feature **40** is an elongate channel that serves as a cooling manifold **60** for the passage therethrough of a cooling fluid flow **62**, also referred to herein as fluid flow **62**.

During the process of laying down the plurality of CMC plies **44** and fabrication of the functional features **40** (described presently), the inlet **48** for each functional feature **40** is formed. Each of the plurality of functional features **40** extends from a respective inlet **48** through the CMC plies **44**, and in alignment therewith the CMC plies **44**. The inlet **48** provides for an input of the cooling fluid flow **62**.

Subsequent to laying down the plurality of CMC plies **44** and fabrication of the functional features **40**, the outlet **46** for each functional feature **40** is formed proximate to an outer surface **11** of the ceramic matrix composite component **10**, such as by drilling a bore **47** through the plurality of CMC plies **44**, in a substantially cut-ply configuration, so as to cut through the plurality of CMC plies **44** and fluidly couple the functional feature **40** to an exterior of the ceramic matrix composite component **10**. The inlet **48**, the functional feature **40**, the bore **47** and the outlet **46** define a cooling channel **42** through the CMC plies **44** sufficient to permit flow of the cooling fluid flow **62** therethrough.

In addition, and optionally, one or more film cooling throughholes **70** (of which only one is illustrated) are formed, such as by drilling through the plurality of CMC plies **44**, so as to cut through the plies **44** and to provide additional cooling of the component surface. Each of the one or more film cooling throughholes **70** extends from an inlet **72** disposed flush at an inner surface **13** of the ceramic matrix composite component **10** to an outlet **74** disposed flush at the outer surface **11** of the ceramic matrix composite component **10**. A portion of the pressurized air from the compressor is directed through the one or more film cooling throughholes **70**, entering through the inlet **72**, as an additional cooling fluid flow **64**, and exiting at the outlet **74**. Each of the plurality of film cooling throughholes **70** forms an opening through the plurality of CMC plies **44** of sufficient dimension to permit the flow of additional cooling fluid flow **64** therethrough. In an embodiment, the plurality of film cooling throughholes **70** can be interleaved with the functional features **40** that form cooling channels **42** having warmer air to mitigate cold spots caused by the film cooling throughholes **70**. Additionally, the functional features **40** that form cooling channels **42** may be sufficiently sized to feed multiple outlets **46** (described presently). By carefully laying out the position of the cooling channel outlets **46** and the plurality of film cooling throughholes **70**, a surface film temperature can be made more uniform. More specifically, colder film cooling fed by the plurality of film cooling throughholes **70** (shorter paths) can configured downstream of hotter film cooling, fed by the plurality of cooling channels **42**, producing an overall film temperature that is more even.

In the illustrated embodiment, each of the functional features **40** and the plurality of film cooling throughholes **70** are open to and fluidly communicate with a source of cooling fluid flow, and to the exterior of the component **10**. In contrast to known prior art, by forming the plurality of functional features **40**, and more specifically, the plurality of cooling channels **42** between the plurality of CMC plies **44**, the overall strength of the CMC plies **44** and resultant component **10** is not weakened and allows finer control of local cooling rates than traditional cooling features. In addition, relatively small cooling channels, such as cooling channels **42**, having longer flow-paths than traditional film cooling holes, such as the plurality of film cooling throughholes **70**, make use of more of the available heat capacity in the cooling fluid flow **62**, allowing reduction of flows. Routing the cooling fluid flow **62** from the cooling source through the regions of the airfoil **14** that experience the greatest thermal gradient induced stresses, and placement of the plurality of functional features **40** as disclosed herein helps to balance surface temperatures and provide novel means of gradient/stress mitigation.

In the embodiment of FIG. **4**, the arrangement of ceramic matrix composite plies **44**, the functional feature **40**, the cooling channel **32**, the inlet **48**, the outlet **46** and the film cooling throughhole **70** are schematic and have been enlarged for illustration purposes. The size and geometry of the CMC plies and voids are not limited to those shown in FIG. **4**.

Referring now to FIG. **5**, illustrated is a schematic sectional view of another portion of the component **10** taken through line **5-5** in FIG. **1**, illustrating the plurality of CMC plies **44**. In this disclosed embodiment, one or more of the plurality of CMC plies **44** has formed therein one or more functional features **40** (of which two are illustrated in FIG. **5**). In an embodiment, the one or more functional features **40** are configured as elongate channels. More specifically, in the illustrated embodiment, the one or more functional features **40** include a cooling channel **42** that serves as a cooling manifold **60** for the passage therethrough of a cooling fluid flow **62** and an insulating channel **80** that is not in fluid communication with the hot gas path flow **16**.

Similar to the embodiment of FIG. **4**, during the process of laying down the plurality of CMC plies **44** and fabrication of the functional features **40** (described presently), an inlet **48** for each functional feature **44** is formed. Each of the plurality of functional features **40** extends from a respective inlet **48** through the CMC plies **44**, and in alignment therewith the CMC plies **44**. The inlet **48** provides for an input of the cooling fluid flow **62**.

Subsequent to laying down the plurality of CMC plies **44** and fabrication of the functional features **40**, an outlet **46** for each of the functional features **40** that serve as a cooling channel **42**, is formed such as by drilling a bore **47** through the plurality of CMC plies **44** so as to cut through the plurality of CMC plies **44**, in a substantially cut-ply configuration, and fluidly couple the functional feature **40** to an exterior of the ceramic matrix composite component **10** via the outlet **46**. Similar to the embodiment of FIG. **4**, the inlet **48**, the functional feature **40**, the bore **47** and the outlet **46** define a cooling channel **42** through the CMC plies **44** sufficient to permit flow of the cooling fluid flow **62** therethrough. The functional features **40** that serve as insulating channels **80** do not include an outlet and therefore do not provide for the passage therethrough of the cooling fluid **62** to the exterior of the component **10**.

In an embodiment, the insulating channels **80** may be formed in different plies **44**, providing management of heat pick-up of the cooling fluid low **62** in the cooling channels **42**. The insulating channels **80**, also described herein as "dead" channels, may also provide a mitigation for EBC spallation/damage. More particularly, configuring an insulating channel **80** very near the hot gas path **16** would cause them to be exposed quickly in the event of a spall. A new path would then become available for the cooling fluid flow **62** reducing the temperature and extending the life of the damaged airfoil **14** until it could be replaced.

In this embodiment, one or more of the plurality of functional features **40** extends from a source of cooling fluid through the CMC plies **44**, and in alignment therewith the CMC plies **44**, to the outlet **46**, and forms the cooling channel **42** through the CMC plies **44** sufficient to permit flow of the cooling fluid flow **62** therethrough. In addition, one or more of the plurality of functional features **40** extends from the source of cooling fluid through the CMC plies **44**, and in alignment therewith the CMC plies **44**, and does not include the formation of an outlet, and forms the insulating channel **80**. Similar to the previous embodiment, optionally one or more film cooling throughholes **70** (of which only one is illustrated) may optionally be formed, such as by drilling through the plurality of CMC plies **44**, so as to cut through the plies **44** and to provide sufficient cooling of the airfoil surface. Each of the one or more film cooling throughholes **70** extends from an inlet **72** disposed flush at an inner surface **13** of the ceramic matrix composite component **10** to an outlet **74** disposed flush at the outer surface **11** of the ceramic matrix composite component **10**. A portion of the pressurized air from the compressor is directed through the one or more film cooling throughholes **70**, entering through the inlet **72**, as an additional cooling fluid flow **64**, and exiting at the outlet **74**. Each of the plurality of film cooling throughholes **70** forms an opening through the plurality of CMC plies **44** of sufficient dimension to permit the flow of additional cooling fluid flow **64** therethrough. In an embodiment, the plurality of film cooling throughholes **70** can be interleaved with the functional features **40** that form the cooling channels **42** and the insulating channel **80** having warmer air to mitigate cold spots caused by the film cooling throughholes **70**. As in the previous embodiment, the functional features **40** that form the cooling channels **42** may be sufficiently sized to feed multiple outlets **46** where desired.

In the embodiment of FIG. **5**, the arrangement of ceramic matrix composite plies **44**, the functional features **40**, the cooling channel **42**, the outlet **46**, the inlets **48**, the insulating channel **80**, the film cooling throughholes **70**, and respective inlet **72** and outlet **74** are schematic and have been enlarged for illustration purposes. The size and geometry of the CMC plies and voids are not limited to those shown in FIG. **5**.

Referring now to FIG. **6**, illustrated is a portion of the airfoil **14** of FIG. **3**, illustrating alternative layouts for the one or more functional features **40**, and more particularly the cooling channels **42**. As illustrated, the functional features **40** may be configured with one or more turns connecting to the platform **56** (FIG. **3**), or bands, such as the outer band **22** (FIG. **1**) and/or inner band **23** (FIG. **1**) of the nozzle segment **12**. The functional features **40** configured as such may be formed by laying curved or angled slots in the plies **44**, forming the functional features in multiple layers or drilling openings to intersect with pre-formed channels. Forming the functional features **40** in multiple layers provides the cooling channels **42** to cover more hot area from the limited surface access in the platform **56**, and/or bands **22**, **23**. Fabrication of functional features in multiple layers are discussed in U.S. patent spplication Ser. No. 16/723,011, filed Dec. 20, 2019, T. Dyson, et al., "Ceramic Matrix Composite Component Including Cooling Channels in Multiple Layers and Method of Producing", filed simultaneous herewith, and which is incorporated herein in its entirety.

In addition, as illustrated in FIG. **6**, the functional features **40** that form the cooling channels **42** may be sufficiently sized to feed multiple outlets **46**, thereby acting as a cooling manifold **60**. More specifically, each cooling channel **42**, having a single inlet **48** may be fluidly coupled to a plurality of outlets **46**.

In the embodiment of FIG. **6**, the arrangement of the functional features **40**, the cooling channels **42**, the outlets **46**, the inlets **48** and the film cooling throughholes **70** are schematic and have been enlarged for illustration purposes.

The size and geometry of the CMC plies and voids are not limited to those shown in FIG. **6**.

FIG. **7** schematically shows a method **100** of forming the CMC component **10**, **50** according to the present disclosure, having one or more elongate functional features **40** defined therein, and more specifically, one or more cooling channels **42** formed within the plies of the CMC component. Component **10**, **50** is formed using a lay-up technique. Method **100** includes initially forming a CMC preform comprising a matrix precursor, a plurality of ceramic reinforcing fibers and a plurality of sacrificial fibers, in a step **102**. Forming the CMC preform includes initially providing a plurality of ceramic matrix composite plies **44**, such as a series of plies **44** formed into a laminate stack. An example of material for plies **44** includes, but is not limited to, pre-preg composite plies including, for example, woven carbon fiber, binder material and coated SiC fibers, as previously described.

As previously described, the method, and more particularly step **102** of forming the CMC preform, includes a means for defining one or more elongate functional features within the plies **44**, such as by using a plurality of sacrificial fibers. The sacrificial fibers enable the forming of the one or more elongate functional features **40** for enhancing the function of the CMC, such as one or more cooling channels **42** and/or the plurality of insulating channels **80** in the CMC preform. Fabrication of elongate functional features using sacrificial fibers are discussed in commonly assigned, U.S. Pat. No. 10,384,981, by D. Hall et al., entitled "Methods of Forming Ceramic Matrix Composites Using Sacrificial Fibers and Related Products," which is incorporated herein in its entirety and U.S. patent application Ser. No. 16/722,896, filed Dec. 20, 2019, filed simultaneously herewith, by D. Dunn et al., and entitled "Methods of Forming Ceramic Matrix Composites Using Sacrificial Fibers and Non-Wetting Coating", which is incorporated herein in its entirety. The geometry of the one or more elongate functional features **40** defined therein the CMC preform includes any suitable geometry including a rounded, curved, elliptical, rectilinear or other suitable geometry.

Additional plies **44** are disposed to enclose the sacrificial fibers. The preform component is placed in an autoclave and an autoclave cycle is completed to form the CMC preform comprising the matrix precursor, the plurality of ceramic reinforcing fibers and the plurality of sacrificial fibers. The preform component is subject to typical autoclave pressures and temperature cycles used in the industry for ceramic composite materials. Autoclaving pulls out any volatiles remaining in the plies and autoclave conditions can be varied depending on the ply material. After autoclaving, a burn-out method is performed to remove any remaining material or additional binders in the pre-form component. The burn-out method is generally conducted at a temperature of approximately 426-648° C. (approximately 800-1200° F.).

After burn-out, the preform component is placed in a vacuum furnace for densification, in a step **104**. Densification is performed using any known densification technique including, but not limited to, Silicomp, melt infiltration (MI), chemical vapor infiltration (CVI), polymer inflation pyrolysis (PIP), and oxide/oxide methods. Densification can be conducted in a vacuum furnace having an established atmosphere at temperatures above 1200° C. to allow Silicon or other infiltrant materials to melt-infiltrate into the preform component. One suitable method of densification is melt infiltration wherein molten matrix material is drawn into the plies **44** and permitted to solidify. After densification, the densified preform component or densified body includes the plurality of sacrificial fibers disposed therein, as shown in step **104**, and forms at least a portion of the component **10**, **50**.

Subsequent to densification, the one or more elongate functional features **40** are further formed by removing the sacrificial fibers, to leave one or more elongate channels, in a step **106**. The removal of the sacrificial fibers to form the elongate channels is discussed in the above-referenced commonly assigned, U.S. Pat. No. 10,384,981 and U.S. patent application Ser. No. 16/722,896.

In an alternate embodiment, the one or more elongate functional features **40** are further formed by removing the plurality of sacrificial fibers prior to densification, as described in step **104**.

In an embodiment, an internal hollow portion of each of the one or more elongate functional features **40** is sufficiently large and open in the component **10**, **50** such that a coolant or other fluid can be directed therethrough to provide cooling, and optionally insulating, to component **10**, **50**. In an embodiment, during the layup of the sacrificial fibers, one or more fibers are laid up in a manner to form the inlet **48** for the input of the cooling fluid. The densified matrix material formed at the ceramic matrix composite ply **44** forms a blockage opposed to the inlet formation that substantially prevents flow of coolant or other fluids and more particularly, forms the one or more elongate functional features **40** as a closed structure at an end opposed to the inlet **48** that is internal to the component **10**, **50**. In an embodiment, openings are machined or otherwise formed into the component **10**, **50**, in a step **108**, to provide outlets **46** to the one or more elongate functional features **40** to permit flow therethrough and form the cooling channels **42**. In an embodiment, the blockage remains in place to form the one or more insulating channels **80**, in a step **112**. In an optional step **110**, one or more film cooling throughholes **70** are formed in the CMC component **10**, **50** to provide additional flow of a cooling fluid flow to the surface of the airfoil and provide additional cooling.

Accordingly, disclosed is a CMC component comprised of a CMC preform in which one or more functional features are formed. By forming the one or more functional features as described herein, a network of cooling channels, or a cooling circuit, is formed in the CMC plies, while limiting strength reduction of any given ply, and allowing the cooling channels to change orientation without cutting the CMC fibers. In addition, by forming the one or more functional features as described herein, a network of insulating channels, can be formed in the CMC plies. As previously indicated, the design of the cooling circuit provides greater robustness to recession and reduces thermal stresses by spreading out the cooling channels in the CMC preform. In addition, the incorporation of cooling channels provides a more uniform temperature distribution. The additional film cooling throughholes may be required to cool the surface sufficiently. The one or more functional features are formed in the CMC component during lay-up and aligned with the CMC fibers in a respective ply. In the simplest embodiment, the one or more functional features are aligned with the fibers, in a respective ply of a plurality of plies, that are arranged in alternating oriented plies. In more complex arrangements, the one or more functional features may form complex networks whereby the functional features are configured with one or more turns to connect to a respective platform or band, and/or configured to provide a single functional feature fluidly coupled to multiple outlets.

While the invention has been described with reference to one or more embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

What is claimed is:

1. A ceramic matrix composite component, comprising:

a plurality of longitudinally extending ceramic matrix composite plies in a stacked configuration forming a densified body;

one or more elongate functional features formed therein the densified body, wherein each of the one or more elongate functional features includes an inlet configured to be in fluid communication with a flow of cooling fluid from a fluid source;

one or more bores cutting through the plurality of longitudinally extending ceramic matrix composite plies from at least a first one of the one or more elongate functional features to an outlet proximate to an outer surface of the ceramic matrix composite component to form at least one cooling channel,

wherein at least a second one of the one or more elongate functional features is configured to retain the flow of cooling fluid from the fluid source in the second one of the one or more elongate functional features to form an insulating channel; and

one or more film cooling throughholes cutting through the plurality of longitudinally extending ceramic matrix composite plies from an inner surface of the ceramic matrix composite component to an outlet proximate to the outer surface of the ceramic matrix composite component, the one or more film cooling throughholes in fluid communication with the flow of cooling fluid from the fluid source;

wherein the one or more functional features are formed during lay-up of the plurality of longitudinally extending ceramic matrix composite plies.

2. The ceramic matrix composite component of claim **1**, wherein the one or more bores are formed via one or more of laser drilling, electrical discharge machining, cutting or machining the plurality of longitudinally extending ceramic matrix composite plies.

3. The ceramic matrix composite component of claim **1**, wherein the one or more film cooling throughholes is formed via one or more of laser drilling, electrical discharge machining, cutting or machining the plurality of longitudinally extending ceramic matrix composite plies.

4. The ceramic matrix composite component of claim **1**, wherein the ceramic matrix composite component is a hot gas path turbine component.

5. The ceramic matrix composite component of claim **4**, wherein the hot gas path turbine component is selected from the group consisting of a combustor liner, a blade, a shroud, a nozzle, a nozzle end wall, and a blade platform.

6. The ceramic matrix composite component of claim **1**, wherein the at least one insulating channel does not include an outlet proximate to the outer surface of the ceramic matrix composite component.

7. The ceramic matrix composite component of claim **1**, wherein each of the one or more elongate functional features extend in a lengthwise direction defined by the ceramic matrix composite component.

8. The ceramic matrix composite component of claim **1**, wherein the one or more elongate functional features are configured in multiple plies of the plurality of longitudinally extending ceramic matrix composite plies.

9. The ceramic matrix composite component of claim **1**, wherein the ceramic matrix composite component is a hot gas path turbine component for a gas turbine engine, the gas turbine engine defining a hot gas path flow, wherein the insulating channel is not in fluid communication with the hot gas path flow.

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