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### INSERTION OF CERAMIC MEMBERS FOR GAS PATH ENDWALL CONTOURING

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#### Abstract

A method for providing endwall contouring in the manufacture of a ceramic matrix composite airfoil endwall for a gas turbine engine includes forming a ceramic insert having a contoured surface defining a desired endwall contouring, draping a first fiber ply over the contoured surface of the ceramic insert, and densifying the assembled ceramic insert and first fiber ply. The first fiber ply conforms to a shape of the contoured surface.

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#### Background/Summary

## BACKGROUND

[0001] The present disclosure relates generally to the manufacture of fiber-reinforced ceramic matrix composite (CMC) components and, more particularly, to CMC airfoil endwalls for use in a gas turbine engine.

[0002] Fiber-reinforced CMCs have been developed for the manufacture of components that are exposed to high temperatures, corrosive environments, and mechanical stress. CMCs are of particular interest in the aerospace industry and their use has been adopted for high temperature aircraft applications, including, but not limited to, gas path endwalls for blades and vanes of a gas turbine engine.

[0003] A typical gas turbine engine includes a turbine module with one or more turbine stages for extracting energy from a stream of working medium fluid. Each turbine stage has a hub capable of rotation about an engine axis. The hub includes peripheral slots for holding one or more arrays (i.e. rows) of blades. FIG. 1 shows a typical blade of a turbine section of a gas turbine engine. Each blade includes an attachment **12**, adapted to be received in a corresponding slot of a rotor disk, platform **14**, and an airfoil **16**. When the blades are installed in the hub the platforms **14** cooperate with each other to partially define the radially inner boundary of an annular working medium gas path. The airfoils span across the gas path so that the airfoil tips are in close proximity to a nonrotatable casing. The casing circumscribes the blade array to partially define the radially outer boundary of the gas path. Alternatively, a blade may have a radially outer platform or shroud **18** that partially defines the radially outer boundary of the gas path, as shown in FIG. 2. The radially inner platform **14** and the radially outer platform **18** (if present) partially define gas path endwalls. As used herein, “endwall” refers to a gas path boundary.

[0004] A typical turbine module also includes one or more arrays of vanes that are nonrotatable about the engine axis. As shown in FIG. 3, each vane has radially inner and outer platforms **20** that partially define the radially inner and outer gas path boundaries. An airfoil **22** spans across the gas path from the inner platform **20** to the outer platform **20**. The vane platforms partially define the gas path endwalls.

[0005] During engine operation, a stream of working medium fluid flows through the turbine gas path. Near the endwalls, the fluid flow is dominated by a vortical flow structure known as a horseshoe vortex. The vortex forms as a result of the endwall boundary layer which separates from the endwall as the fluid approaches the leading edges of the airfoils. The separated fluid reorganizes into the horseshoe vortex. There is a high loss of efficiency associated with the vortex. The loss is referred to as “secondary” or “endwall” loss. As much as 30% of the loss in a row of airfoils can be attributed to endwall loss. Aerodynamic loss reduction via changes in gas path contouring at airfoil endwalls has been previously documented, for example, in U.S. Pat. Nos. 7,887,297 and 8,511,978. Endwall contouring is typically cast and/or machined in conventional metallic materials.

[0006] Modifications which allow high precision contouring are non-trivial in ceramic matrix composite layouts. New methods are needed for the manufacture of CMC blades and vanes with endwall contouring.

## SUMMARY

[0007] A method for providing endwall contouring in the manufacture of a ceramic matrix composite airfoil endwall for a gas turbine engine includes forming a ceramic insert having a contoured surface defining a desired endwall contouring, draping a first fiber ply over the contoured surface of the ceramic insert, and densifying the assembled ceramic insert and first fiber ply. The first fiber ply conforms to a shape of the contoured surface.

[0008] A ceramic insert for an endwall of an airfoil of a gas turbine engine includes a first surface configured to face away from a gas path surface of the endwall and a second surface opposite the first surface. The second surface is contoured and configured to define a contour of the gas path

surface of the endwall.

[0009] An endwall assembly for an airfoil of a gas turbine engine includes a first fiber layer, a second fiber layer forming a gas path surface, and a contoured insert disposed between the first and second fiber layers, wherein the second fiber layer conforms to a contoured surface of the contoured insert such that the contoured surface defines a geometry of the gas path surface.

[0010] The present summary is provided only by way of example, and not limitation. Other aspects of the present disclosure will be appreciated in view of the entirety of the present disclosure, including the entire text, claims and accompanying figures.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 is a view of a prior art turbine engine blade having a single endwall.

[0012] FIG. 2 is a view of a prior art turbine engine blade having two endwalls.

[0013] FIG. 3 is a view of a prior art turbine engine vane having two endwalls.

[0014] FIGS. 4 is a plan view with topographic contours showing an airfoil with an elevation and trough used in combination on an endwall,

[0015] FIG. 5 is a perspective cross-sectional side view of a portion of the endwall of FIG. 4 taken along the line 5-5 of FIG. 4 and having endwall contouring defined by a contoured insert disposed between inner and outer endwall layers.

[0016] FIG. 6 is a perspective top view of the contoured insert of FIG. 5.

[0017] FIG. 7 is a cross-sectional side view of the endwall taken along the line 7-7 of FIG. 5.

[0018] FIG. 8 is a flowchart of a method for providing endwall gas path contouring in the manufacture of a CMC airfoil endwall.

[0019] While the above-identified figures set forth embodiments of the present invention, other embodiments are also contemplated, as noted in the discussion. In all cases, this disclosure presents the invention by way of representation and not limitation. It should be understood that numerous other modifications and embodiments can be devised by those skilled in the art, which fall within the scope and spirit of the principles of the invention. The figures may not be drawn to scale, and applications and embodiments of the present invention may include features, steps and/or components not specifically shown in the drawings.

### DETAILED DESCRIPTION

[0020] The present disclosure is directed to the manufacture of airfoil endwalls of a gas turbine engine and, specifically, the manufacture of ceramic matrix composite (CMC) endwalls with gas path endwall contouring. The present disclosure is directed to a method of providing endwall contouring in a CMC layup process. The disclosed method is not limited to a particular endwall contouring geometry. As will be understood by one of ordinary skill in the art, the disclosed method can be used to provide any endwall contouring determined suitable for a particular application.

[0021] FIG. 4 is a plan view of endwall **100** with topographic contours. FIG. 4 shows endwall **100**, airfoil **102**, leading edge **104**, trailing edge **106**, suction surface **108**, pressure surface **110**, protrusion **112**, apex **114**, depression **116**, base **118**, endwall leading edge **120**, endwall trailing edge **122**, and oppositely disposed matefaces **124** and **126**. Airfoil **102** projects radially from endwall **100** and includes leading edge **104**, trailing edge **106**, suction surface **108**, and pressure surface **110**. Endwall **100** has a perimeter defined by endwall leading edge **120**, endwall trailing edge **122**, and matefaces **124** and **126**. Endwall **100** includes protrusion **112** and depression **116**. Protrusion **112** projects radially from endwall **100** forming an outward extending bulge or elevation on a surface of endwall **100** with an apex **114**. Depression **116** extends into endwall **100** forming a trough or recess in endwall **100** with base or deepest point **118**. The endwall contouring shown in FIG. 4 is for illustrative purposes only and is not intended to depict gas path contouring suitable for

reducing aerodynamic loss in operation of a gas turbine engine. While endwall **100** shows combined use of protrusion **112** and depression **116**, it will be understood by one of ordinary skill in the art that endwalls formed using the disclosed method may include only a protrusion or only a depression or multiple protrusions and/or depressions. Furthermore, the disclosed method may be used to provide axisymmetric gas path contouring.

[0022] FIG. 5 is a perspective cross-sectional side view of a portion of endwall **100** of FIG. 4 taken along the line 5-5 of FIG. 4 and having endwall contouring defined by a contoured endwall insert disposed between inner and outer endwall layers. FIG. 5 shows protrusion **112**, apex **114**, depression **116**, base **118**, endwall leading edge **120**, endwall trailing edge **122**, inner fiber layer **130**, outer fiber layer **132**, contoured insert **134**, inner surface **135**, outer surface **136**, and opening **137**. A portion of outer fiber layer **132** has been removed to show inner fiber layer **130**. Inner fiber layer **130** can form a base of endwall **100**. Outer fiber layer **132** forms a gas path surface of endwall **100**. Contoured insert **134** is disposed between inner fiber layer **130** and outer fiber layer **132**. Opening **137** represents the position of airfoil **102**. Opening **137** is provided for illustrative purposes only. As will be understood by one of ordinary skill in the art, airfoil **102** can be formed with endwall **100**. For example, in some embodiments, outer fiber layer **132** can form a portion of airfoil **102**.

[0023] Inner fiber layer **130** can have a substantially uniform thickness and can comprise one or more fiber plies provided in a stacked arrangement. As used herein, the term “substantially uniform thickness” refers to the thickness of single fiber ply (e.g., 2D woven or braided fabric sheet) forming the fiber layer, or a stack of fiber plies forming the fiber layer, which may include fiber tows of non-uniform diameter, as will be understood by one of ordinary skill in the art, but generally does not contribute to the defined gas path contouring of endwall **100** (thicknesses shown in FIG. 7). Outer fiber layer **132** can have a substantially uniform thickness and can comprise one or more fiber plies provided in a stacked arrangement. Fibers can be formed from silicon carbide (SiC) or other suitable ceramic material. Fibers can be arranged in woven or braided architectures, including, for example, 2D woven or braided fiber plies, e.g., fabric sheets, as known in the art. As discussed further herein, inner fiber layer **130** and outer fiber layer **132** can be undensified prior to assembly with contoured insert **134**.

[0024] Contoured insert **134** has a non-uniform thickness with an inner surface **135** configured to face away from the gas path surface and an outer surface **136** opposite inner surface **135** and characterized by one or more protrusions and/or depressions. Contoured outer surface **136** is configured to face the gas path surface and define a contour of the gas path surface in combination with outer fiber layer **132**. As illustrated, contoured outer surface **136** of contoured insert **134** defines the shape of protrusion **112** with apex **114** and depression **116** with base **118**.

[0025] Contoured insert **134** can be formed of a fiber-reinforced CMC material or a monolithic ceramic body. As discussed further herein, contoured insert **134** formed of a CMC can be partially or fully densified prior to assembly with inner and outer fiber layers **130** and **132**. Contoured insert **134** has contoured outer surface **136** designed for gas path endwall contouring. The shape of contoured insert **134** is not limited to the surface geometry shown. As will be understood by one of ordinary skill in the art, contoured insert **134** can be formed to provide any endwall contouring determined suitable for a specific application.

[0026] Outer fiber layer **132** can be closely draped over contoured insert **134** such that outer fiber layer **132** conforms to contoured outer surface **136** of contoured insert **134** and such that contoured outer surface **136** defines a geometry of the endwall gas path surface.

[0027] FIG. 5 shows a portion of the endwall gas path surface provided by outer fiber layer **132**. A portion of outer fiber layer **132** is omitted to show inner fiber layer **130**. As illustrated, contoured insert **134** and outer fiber layer **132** are disposed on a pressure side of the airfoil with outer fiber layer **132** extending from endwall leading edge **120** to endwall trailing edge **122**. As will be understood by one of ordinary skill in the art, outer fiber layer **132** fully covers inner fiber layer

**130** to form the gas path surface of endwall **100**. As discussed further herein, contoured insert **134** can cover any portion of inner fiber layer **130** as necessary for providing the desired endwall contouring.

[0028] FIG. **6** is a perspective top view of contoured insert **134** disposed on inner fiber layer **130** in a partial assembly of endwall **100**. FIG. **6** shows endwall leading edge **120**, trailing edge **122**, matefaces **124** and **126**, inner fiber layer **130**, contoured insert **134**, opening **137**, insert layers **134A-134G**, insert layer cutouts or openings **140**, **141**, and **142**, locating feature **144**, and mating edges **145**. FIG. **7** is a cross-sectional view of endwall **100** taken along the line 7-7 of FIG. **5**. FIG. **7** shows contoured insert **134**, insert layers **134A-134G**, inner surface **135**, contoured outer surface **136**, insert layer cutouts or openings **140**, **141**, and **142**, inner fiber layer **130**, outer fiber layer **132**, protrusion **112**, depression **116**, tapered edges **146** and **148**, nominal gas path surface **150**, and thicknesses **T1**, **T2**, and **T3**. FIGS. **6** and **7** are discussed together herein.

[0029] As illustrated in FIGS. **6** and **7**, in some embodiments, contoured insert **134** can comprise a laminated structure formed from stacked insert layers **134A-134G**. Each insert layer **134A-134G** can have a substantially uniform thickness **T1** and can comprise one or more fiber plies provided in a stacked arrangement. The thickness **T1** of each insert layer **134A-134G** can vary. Fibers can be formed from silicon carbide (SiC) or other suitable ceramic material. Fibers can be arranged in woven or braided architectures, including, for example, 2D woven or braided fiber plies, e.g., fabric sheets, as known in the art. The laminated structure illustrated in FIGS. **6** and **7** is a non-limiting example of a laminated construction of contoured insert **134**. It will be understood by one of ordinary skill in the art that the number, shape, and arrangement of insert layers **134A-134G** will vary according to application to provide a desired endwall contouring. Contoured insert **134** is disposed between inner fiber layer **130** and outer fiber layer **132** as discussed with respect to FIG. **5**.

[0030] Insert layer **134A** is a base layer configured to be disposed on inner fiber layer **130**. Inner fiber layer **130** can have a substantially uniform thickness **T2**. Insert layers **134B-134G** are disposed in sequence on insert layer **134A**, with insert layer **134G** forming the outermost layer of contoured insert **134**. Insert layer **134A** in combination with outer fiber layer **132** can define the nominal gas path surface **150** of endwall **100**, which can generally be defined by an arc of a circle circumscribing a longitudinal axis of the gas turbine engine and defining a circumferential contour of endwall **100**. The arrangement of insert layers **134B-134G** can define contoured outer surface **136** of contoured insert **134** and, in combination with outer fiber layer **132**, can define the contoured gas path surface of endwall **100**. Outer fiber layer **132** can have a substantially uniform thickness **T3** such that the contour of the gas path surface of endwall **100** follows contoured outer surface **136** of contoured insert **134**. The thicknesses illustrated in FIG. **7** are not drawn to scale nor intended to be limiting.

[0031] Insert layers **134B-134G** can have different geometries such that the stacking of insert layers **134B-134G** produces one or more protrusions that extend outward from the base insert layer **134A**. One or more insert layer **134A-134G** can include cutouts or openings to provide depressions or recesses from a surface of one or more insert layers, including the surface of the base insert layer **134A**. As illustrated in FIGS. **6** and **7**, insert layer **134A** includes cutout **140**, insert layer **134B** includes cutout **141**, and insert layer **134C** includes cutout **142**. Cutouts **140**, **141**, and **142** can have substantially similar shapes and can be aligned in a stacked arrangement to form a depression extending inward from insert layer **134C** to inner fiber layer **130** and defining depression **116**. As shown in FIG. **7**, cutouts **140**, **141**, and **142** can increase in size outward from insert layer **134A** to insert layer **134C** to form a tapered edge, which in combination with outer fiber layer **132** can define tapered edge **146** of depression **116**.

[0032] Insert layers **134E-134G** can be configured to form a portion of protrusion **112**. Insert layers **134E-134G** have substantially similar shapes but can decrease in size outward from insert layer **134E** to insert layer **134G** to form a tapered edge, which in combination with outer fiber layer **132**

can define tapered edge **148** of protrusion **112**. As shown in FIG. 7, a nominal surface **150** can be defined by outer fiber layer **132** disposed directly on insert layer **134A**. Protrusion **112** extends outward from nominal surface **150**, following a contour of stacked insert layers **134B-134G**. Depression **116** extends inward from nominal surface **150**, following a contour of cutouts **140**, **141**, and **142** formed in insert layers **134A**, **134B**, and **134C**, respectively.

[0033] Base insert layer **134A** can provide support for insert layers **134B-134G**, set a nominal gas path surface for endwall **100**, and help correctly locate contoured insert **134** on inner fiber layer **130** with respect to airfoil **102**. Base insert layer **134A** can include multiple fiber plies with cutouts **140** in applications where deep depressions in the endwall gas path surface are required.

[0034] The shapes and arrangements of insert layers disposed on base insert layer **134A** (e.g., insert layers **134B-134G**) can vary according to the application. Any number of insert layers can be provided in a stacked arrangement on base insert layer **134A** and can have any geometry to provide protrusions of a desired height and shape. Furthermore, multiple groups of insert layers provided in stacked arrangements can be disposed on base insert layer **134A** to form multiple protrusions on the endwall gas path surface. Similarly, any insert layer can include multiple cutouts to form multiple depressions on the endwall gas path surface. Edges of insert layers can be aligned or significantly aligned to provide steep walls of protrusions or depressions or can be significantly offset to provide gradual changes in elevation.

[0035] One or more contoured inserts **134** can be provided in a single endwall assembly. In some embodiments, use of multiple contoured inserts **134** may be preferable for case of manufacture. Each contoured insert **134** can be configured with locating features **144** to ensure proper assembly. For example, each contoured insert **134** can have a locating feature **144** corresponding to a contour or position of airfoil **102**. As illustrated in FIG. 6, contoured insert **134** can be a first contoured insert configured to be disposed on a first side of airfoil **102** having an outer perimeter with a contoured portion (locating feature **144**) corresponding to a suction side surface of airfoil **102** (illustrated by opening **137**). A second contoured insert (not shown) can be configured to be disposed on the opposite side of endwall **100** and airfoil **102**, having an outer perimeter with a contoured portion (locating feature) corresponding to a pressure side surface of airfoil **102** (illustrated by opening **137**). Contoured inserts **134** can additionally include one or more mating edges **145** having a geometry configured to mate with a corresponding mating edge of an adjacent contoured insert.

[0036] In alternative embodiments, contoured insert **134** can be formed of a monolithic ceramic or a 3D woven fiber-reinforced CMC of desired shape. As discussed further herein, contoured insert **134** can be formed as a unitary body separately from other portions of endwall **100** and airfoil **102** and subsequently assembled therewith. In some embodiments, it may be desirable to provide adjacent endwalls of uniform size and configuration with different gas path contouring. This can be accomplished readily in a CMC layup process by providing prefabricated contoured inserts of different geometry.

[0037] FIG. 8 is a flowchart of method **200** for providing endwall gas path contouring in the manufacture of a CMC airfoil endwall. In step **202**, a contoured insert having a contoured surface defining a desired gas path endwall contouring is formed. A fiber preform of the contoured insert can be formed by stacking one or more groups of fiber plies of desired shapes on a base ply using a known fiber layup process. Each fiber ply can have a substantially uniform thickness. As previously discussed, the base fiber ply (e.g., insert layer **134A**) and any fiber ply disposed thereon can include one or more cutouts (e.g., cutout **140**). Fiber plies can have any shape needed to provide the desired gas path endwall contouring. Fiber plies can be cut to a desired shape using any known cutting techniques or tools. Multiple fiber plies can be cut together. Patterns can be used to cut and assemble fiber plies into shapes providing a desired surface contouring. Fiber plies can include a tackifier as known in the art to stabilize the fiber plies and assembled preform layup.

[0038] Following layup, the fiber preform of the contoured insert can be fully or partially densified

with a matrix material, such as SiC, as known in the art to produce the contoured insert. Densification can be achieved using CVI, polymer infiltration and pyrolysis, slurry infiltration, melt infiltration, and combinations thereof as known in the art. Densification can be carried out until the resulting CMC contoured insert has reached a desired residual porosity. Prior to densification, one or more fiber interface coatings (e.g., boron nitride) can be applied to fibers as known in the art. Additional finishing processes, as known in the art, may be conducted following densification to smooth portions of the contoured surface or further define contours, if necessary. [0039] In an alternative embodiment, the contoured insert can be formed from a 3D woven fiber preform having the desired contoured surface. The 3D woven fiber preform can be partially or fully densified with a ceramic matrix as described above. In yet another embodiment, a monolithic ceramic contoured insert can be cast having the desired contoured surface.

[0040] Multiple contoured inserts can be formed according to the above methods for each endwall. Each contoured insert can have a different contoured surface and can be configured to form a different portion of the endwall gas path surface.

[0041] In step **204**, one or more contoured inserts are disposed on an inner fiber layer configured to form an inner surface of the endwall (opposite the gas path). As previously described, the inner fiber layer can have a substantial uniform thickness and can comprise one or more fiber plies. The one or more contoured inserts can be positioned on the inner fiber layer using one or more locating features, as previously described, to ensure proper arrangement in the endwall. In embodiments having more than one contoured insert, contoured inserts can include edges having a geometry configured to mate with an adjacent contoured insert. Mating edges can provide a substantially uniform or otherwise desired transition between adjacent contoured inserts and can additionally ensure proper placement of contoured inserts in the endwall.

[0042] In step **206**, an outer fiber layer, as previously described, is positioned on or draped over the contoured surface of the contoured insert. The outer fiber layer forms the gas path surface of the endwall and can comprise one or more fiber plies. The outer fiber layer can have a substantially uniform thickness and substantially conforms to the contoured surface of the contoured insert, such that the contoured surface of the contoured insert substantially defines the contours of the gas path surface of the endwall.

[0043] Both the inner and outer fiber layers can include a tackifier to stabilize the endwall assembly. Layup and sizing of the inner fiber layer, contoured insert, and outer fiber layer can be conducted in a tooling, as known in the art, to form an endwall preform.

[0044] In step **208**, the endwall preform is densified with a matrix material, such as SiC, as known in the art, to produce the final endwall component. Densification can be achieved using CVI, polymer infiltration and pyrolysis, slurry infiltration, melt infiltration, and combinations thereof as known in the art. Densification can be carried out until the resulting CMC endwall has reached a desired residual porosity. In embodiments in which the contoured insert is fully densified prior to assembly in the endwall preform, densification can fill in gaps between the contoured insert and the inner and outer fiber layers including gaps formed between ends of insert fiber plies and the outer fiber layer. Prior to densification, one or more fiber interface coatings (e.g., boron nitride) can be applied to fibers of the inner and outer fiber layers as known in the art. Additional finishing processes, as known in the art, may be conducted following densification to smooth portions of the gas path contoured endwall surface or further define contours, if necessary.

[0045] Modifications which allow high precision contouring are non-trivial in CMC layups. The disclosed inserts comprised of monolithic ceramic or CMC preforms of a predefined shape can be used to provide predefined gas path endwall contouring in a CMC layup.

[0046] The embodiments disclosed herein are intended to provide an explanation of the present invention and not a limitation of the invention. The present invention is not limited to the embodiments disclosed. It will be understood by one skilled in the art that various modifications and variations can be made to the invention without departing from the scope and spirit of the

invention.

## Discussion of Possible Embodiments

[0047] The following are non-exclusive descriptions of possible embodiments of the present invention.

[0048] An endwall assembly for an airfoil of a gas turbine engine includes a first fiber layer, a second fiber layer forming a gas path surface, and a contoured insert disposed between the first and second fiber layers, wherein the second fiber layer conforms to a contoured surface of the contoured insert such that the contoured surface defines a geometry of the gas path surface.

[0049] The apparatus of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations, and/or additional components:

[0050] In an embodiment of the preceding endwall assembly, the contoured insert can include a fiber-reinforced ceramic matrix composite.

[0051] In an embodiment of the endwall assembly of any of the preceding paragraphs, the contoured insert can be partially densified with the ceramic matrix.

[0052] In an embodiment of the endwall assembly of any of the preceding paragraphs, the second fiber layer can have a substantially uniform thickness.

[0053] In an embodiment of the endwall assembly of any of the preceding paragraphs, the contoured surface can include a protrusion and/or a depression.

[0054] In an embodiment of the endwall assembly of any of the preceding paragraphs, the contoured surface can include a nominal surface, a protrusion extending outward from the nominal surface, and a depression extending inward from the nominal surface.

[0055] In an embodiment of the endwall assembly of any of the preceding paragraphs, the contoured insert can include a locating feature corresponding to a contour or position of the airfoil.

[0056] In an embodiment of the endwall assembly of any of the preceding paragraphs, the contoured insert can be a first contoured insert and wherein the endwall assembly can further include a second contoured insert disposed between the first and second fiber layers.

[0057] In an embodiment of the endwall assembly of any of the preceding paragraphs, the contoured surface of each of the first and second contoured inserts can include a protrusion and/or a depression.

[0058] In an embodiment of the endwall assembly of any of the preceding paragraphs, the first contoured insert can be disposed adjacent to the second contoured insert and can include a first mating edge having a geometry configured to mate with a corresponding second mating edge of the second contoured insert.

[0059] In an embodiment of the endwall assembly of any of the preceding paragraphs, the first contoured insert can include a protrusion and the second contoured insert comprises a depression.

[0060] In an embodiment of the endwall assembly of any of the preceding paragraphs, the contoured insert can include a plurality of fiber layers provided in a stacked arrangement and at least partially densified with a ceramic matrix.

[0061] In an embodiment of the endwall assembly of any of the preceding paragraphs, wherein each fiber layer of the plurality of fiber layers can include one or more fiber plies.

[0062] In an embodiment of the endwall assembly of any of the preceding paragraphs, wherein the contoured insert can be a monolithic ceramic body.

[0063] A ceramic insert for an endwall of an airfoil of a gas turbine engine includes a first surface configured to face away from a gas path surface of the endwall and a second surface opposite the first surface. The second surface is contoured and configured to define a contour of the gas path surface of the endwall.

[0064] The apparatus of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations, and/or additional components:



[0065] The ceramic insert can include a plurality of fiber plies densified with a ceramic matrix.

[0066] In an embodiment of any of the preceding ceramic inserts, the second surface can include a nominal surface defined by an arc of a circle and at least one of a protrusion extending outward from the nominal surface and a depression extending inward from the nominal surface.

[0067] In an embodiment of any of the preceding ceramic inserts, the second surfaces can include a protrusion and a depression.

[0068] An embodiment of any of the preceding ceramic inserts can further include a locating feature corresponding to a contour or position of the airfoil.

[0069] In an embodiment of any of the preceding ceramic inserts, the ceramic insert can be a monolithic ceramic body.

[0070] A method for providing endwall contouring in the manufacture of a ceramic matrix composite airfoil endwall for a gas turbine engine includes forming a ceramic insert having a contoured surface defining a desired endwall contouring, draping a first fiber ply over the contoured surface of the ceramic insert, and densifying the assembled ceramic insert and first fiber ply. The first fiber ply conforms to a shape of the contoured surface.

[0071] The method of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations, additional components, and/or steps:

[0072] In an embodiment of the preceding method, the ceramic insert can be a fiber-reinforced ceramic matrix composite.

[0073] In an embodiment of any of the preceding methods, forming the ceramic insert can include forming a fiber preform and at least partially densifying the fiber preform with a ceramic matrix.

[0074] In an embodiment of any of the preceding methods, forming the ceramic insert can include forming a fiber preform having an outer surface having a protrusion and/or a depression.

[0075] In an embodiment of any of the preceding methods, forming the ceramic insert can include at least partially densifying the fiber preform.

[0076] In an embodiment of any of the preceding methods, the fiber preform can include a plurality of fiber layers assembled in a stacked arrangement, the plurality of fiber layers having differing shapes and/or sizes.

[0077] In an embodiment of any of the preceding methods, the plurality of fiber layers can have differing thicknesses.

[0078] In an embodiment of any of the preceding methods, each fiber layer of the plurality of fiber layers can include one or more fiber plies.

[0079] In an embodiment of any of the preceding methods, at least one fiber layer of the plurality of fiber layers can include a cutout, the cutout forming at least a portion of a depression of the fiber preform.

[0080] In an embodiment of any of the preceding methods, the plurality of fiber plies can be stacked to form a protrusion on the outer surface of the preform, wherein a shape of the plurality of fiber plies in the stacked arrangement decreases in size from an innermost fiber layer to an outermost fiber layer to form tapered walls of the protrusion.

[0081] In an embodiment of any of the preceding methods, the ceramic insert can include a plurality of fiber plies densified with a ceramic matrix.

[0082] In an embodiment of the method of any of the preceding paragraphs, the ceramic insert can be a monolithic ceramic body.

[0083] An embodiment of any of the preceding methods can further include positioning the ceramic insert between the first fiber ply and a second fiber ply, wherein the second fiber ply is densified with the first fiber ply.

[0084] In an embodiment of any of the preceding methods, the ceramic matrix composite insert can include a locating feature corresponding to a contour or position of the airfoil.

[0085] An embodiment of any of the preceding methods can further include forming at least one

additional ceramic insert having a contoured surface defining a desired endwall contouring and joining the ceramic insert and the at least one additional ceramic insert. The first fiber ply can be draped over each of the ceramic insert and the at least one additional ceramic insert.

[0086] In an embodiment of any of the preceding methods, the ceramic insert can be a monolithic ceramic body.

[0087] In an embodiment of any of the preceding methods, each ceramic insert can be a fiber-reinforced ceramic matrix composite.

[0088] In an embodiment of any of the preceding methods, each ceramic insert can comprise a plurality of fiber plies.

[0089] While the invention has been described with reference to an exemplary embodiment(s), 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(s) disclosed, but that the invention will include all embodiments falling within the scope of the appended claims.

## Claims

1. A method for providing endwall contouring in the manufacture of a ceramic matrix composite airfoil endwall for a gas turbine engine, the method comprising: forming a ceramic insert having a contoured surface defining a desired endwall contouring; draping a first fiber ply over the contoured surface of the ceramic insert, the first fiber ply conforming to a shape of the contoured surface; and densifying the assembled ceramic insert and first fiber ply.
2. The method of claim 1, wherein the contoured surface comprises a protrusion and/or a depression.
3. The method of claim 1, wherein forming the ceramic insert comprises: forming a fiber preform; and at least partially densifying the fiber preform with a ceramic matrix.
4. The method of claim 1, wherein forming the ceramic insert comprises forming a fiber preform having an outer surface having a protrusion and/or a depression.
5. The method of claim 4, wherein forming the ceramic insert comprises at least partially densifying the fiber preform.
6. The method of claim 4, wherein the fiber preform comprises a plurality of fiber layers assembled in a stacked arrangement, the plurality of fiber layers having differing shapes and/or sizes.
7. The method of claim 6, wherein the plurality of fiber layers have differing thicknesses.
8. The method of claim 7, wherein each fiber layer of the plurality of fiber layers comprises one or more fiber plies.
9. The method of claim 4, wherein at least one fiber layer of the plurality of fiber layers comprises a cutout, the cutout forming at least a portion of a depression of the fiber preform.
10. The method of claim 4, wherein the plurality of fiber plies are stacked to form a protrusion on the outer surface of the preform, wherein a shape of the plurality of fiber plies in the stacked arrangement decreases in size from an innermost fiber layer to an outermost fiber layer to form tapered walls of the protrusion.
11. The method of claim 1, wherein the ceramic insert is monolithic ceramic body.
12. The method of claim 1 and further comprising positioning the ceramic insert between the first fiber ply and a second fiber ply, wherein the second fiber ply is densified with the first fiber ply.
13. The method of claim 1 and further comprising: forming at least one additional ceramic insert having a contoured surface defining a desired endwall contouring; and joining the ceramic insert and the at least one additional ceramic insert; wherein the first fiber ply is draped over each of the ceramic insert and the at least one additional ceramic insert.

- 14.** The method of claim 13, wherein joining the ceramic insert and the at least one additional ceramic insert comprises aligning mating edges of the respective ceramic inserts.
- 15.** The method of claim 13, wherein each ceramic insert comprises a fiber-reinforced ceramic matrix composite.
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