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(71) Applicant: **SIEMENS AKTIENGESELLSCHAFT**
[DE/DE]; Werner-von-Siemens-Straße 1, 80333 München
(DE).

(72) Inventor: **MARRA, John J.**; 1039 Westbury Way, Lake
Mary, Florida 32746 (US).

(74) Agent: **SCOTT, Mark W.**; Siemens Corporation- Intellect-
tual Property Dept., 3501 Quadrangle Blvd Ste 230, Orlan-
do, Florida 32817 (US).

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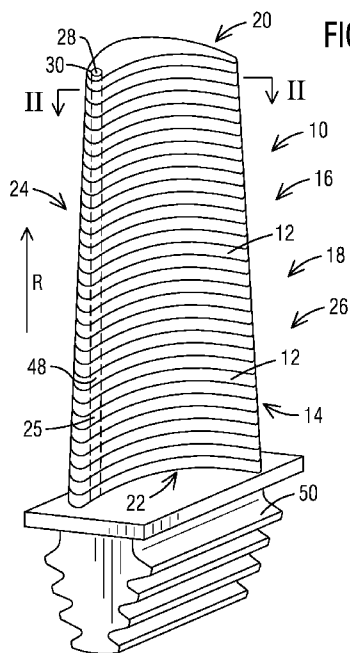


FIG. 1

(57) Abstract: There is provided a component (10) having a plurality of laminates (12) formed from a ceramic matrix composite material stacked on one another to form a stacked laminate structure (14). A seal (28) formed from a resolidifiable ductile and a thermally conductive metal material (25) is disposed adjacent stacked laminates (12) so as to reduce and/or eliminate air leakage therebetween. The seal (28) comprises a column (48) of the metal material (25) extending through corresponding openings (46) in the laminates (12) between a top end (20) and a bottom end (22) of the stacked laminate structure (14). The metal material (25) comprises an alloy of silver and copper.



SEALING SCHEMES FOR CERAMIC MATRIX COMPOSITE STACKED LAMINATE STRUCTURES

FIELD

5 The present invention relates to high temperature components, and more particularly to structures and processes for sealing ceramic matrix composite (CMC) stacked laminate structures.

BACKGROUND

10 Gas turbines comprise a casing or cylinder for housing a compressor section, a combustion section, and a turbine section. A supply of air is compressed in the compressor section and directed into the combustion section. The compressed air enters the combustion inlet and is mixed with fuel. The air/fuel mixture is then combusted to produce high temperature and
15 high pressure gas. This working gas then travels past the combustor transition and into the turbine section of the turbine.

 Generally, the turbine section comprises rows of vanes which direct the working gas to the airfoil portions of the turbine blades. The working gas travels through the turbine section, causing the turbine blades to rotate,
20 thereby turning the rotor. The rotor is also attached to the compressor section, thereby turning the compressor and also an electrical generator for producing electricity. High efficiency of a combustion turbine is achieved by heating the gas flowing through the combustion section to as high a temperature as is practical. The hot gas, however, may degrade the various
25 metal turbine components, such as the combustor, transition ducts, vanes, ring segments, and turbine blades that it passes when flowing through the turbine.

 For this reason, strategies have been developed to protect turbine components from extreme temperatures such as the development and
30 selection of high temperature materials adapted to withstand these extreme temperatures and cooling strategies to keep the components adequately

cooled during operation. State of the art superalloys with additional protective coatings are commonly used for hot gas path components of gas turbines. In view of the substantial and longstanding development in the area of superalloys, however, it figures to be extremely difficult to further increase the temperature capability of superalloys.

Accordingly, ceramic matrix composite (CMC) materials have been developed with a higher potential temperature resistance relative to superalloys. Such CMC materials may include a ceramic or a ceramic matrix material, either of which hosts a plurality of reinforcing fibers. Typically, the fibers may have a predetermined orientation to provide the CMC materials with additional mechanical strength. It has been found, however, that forming turbine components from CMC materials may be challenging due to, amongst other things, the difficulty in orientating fibers at edges of the component in the complex shapes typical of many turbine components.

For this reason, components formed from stacked CMC laminates have also been developed. The stacked CMC laminates comprise a plurality of laminates formed from a CMC material with fibers in a desired orientation. By including a plurality of flat laminates, each having a desired fiber orientation and shape, the overall composition and shape of the component may be better controlled with increased options. Still, while oxide and non-oxide CMC materials can survive high temperatures, they can only do so for limited time periods in a combustion environment without being cooled since external surfaces are typically exposed to gas path combustion gases that are substantially hotter than 1200° C.

For this reason further, cooling schemes have been developed within stacked laminates structures, wherein a cooling air flow is introduced into one or more cavities extending radially through the stack of laminates and into cooling channels formed in the individual laminates. The cooling air carries heat away from the CMC material by convection and is flowed out from the cooling channels. Because of the temperatures and pressures involved, however, even the slightest gap between adjacent laminates may result in

separation of the adjacent laminates and substantial leakage of the cooling air between adjacent laminates. While some solutions have been proposed, such as a retaining ring placed on top of the laminate stack which is tightened to place a compressive load on the stack, such solutions have been to be not fully effective in eliminating the separation of adjacent airfoils and substantial leakage of cooling fluid during operation. One issue is that the further away a given laminate is from the compressive load and the source thereof, the less effect the compressive load has on that distant area. Accordingly, improved solutions for sealing a stacked laminate structure are desired.

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SUMMARY

In accordance with an aspect of the present invention, there are provided solutions for sealing a stacked laminate structure, such as one made from ceramic matrix composite (CMC) fillets or laminates. Aspects of the present invention infiltrate a thermally conductive and ductile metal ("seal") material, such as a copper material, between the laminates in the stacked laminate structure in order to produce a seal between the laminates. In this way, when cooling air is provided to the stack laminate structure, the seal prevents cooling fluid (e.g., air) leakage and improves cooling efficiency in high temperature environments. In certain aspects, the seal material may be one that is highly malleable under high temperature conditions, thereby allowing it to maintain an effective seal under high temperature conditions, e.g., > 1200° C. In another aspect, the described sealing structures and processes may also aid in reducing a degree of necessary (compressive) pre-loading on the stacked laminates since the metal material used for the seal will actually pull the laminates together in its cooled state. In addition, in certain embodiments, the metal (seal) material will expand and re-anneal during operational cycles, thereby avoiding load transmission between laminates under high temperature conditions and relieving stresses that might otherwise induce cracks.

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In another aspect, the seal formed by the metal material may also aid in removing heat from CMC laminates, which is particularly useful since CMC materials are typically insulators. For example, the seal may be positioned throughout the stacked laminate structure to allow heat to be transferred via
5 conduction to interior areas of the structure where heat can be carried away via convection to a cooling fluid traveling through the component.

In accordance with another aspect, there is provided a component comprising a plurality of stacked laminates, a portion or all of which comprise a ceramic matrix composite material. The plurality of stacked laminates
10 define a stacked laminate structure. The component further includes a seal formed from a metal material disposed between adjacent stacked laminates in the stacked laminate structure. In an embodiment, the seal comprises a column of the resolidifiable ductile and conductive material which extends
15 through corresponding openings in the stacked laminates between a top end and a bottom end of the stacked laminate structure. In addition, the seal may be disposed within a plurality of sealing passages inboard of an exterior of the stacked laminate structure and between a leading edge and trailing edge thereof. The sealing passages are in fluid communication with the column
20 such that the metal material forming the seal may also be disposed within the sealing passages.

In accordance with another aspect, there is provided a process for sealing a stacked laminate structure comprising: stacking a plurality of laminates comprising a ceramic matrix composite material on one another to form the stacked laminate structure; forming a plurality of sealing passages
25 within an interior of the stacked laminate structure; filling the plurality of sealing passages with a molten metal material; and cooling the molten metal material within the sealing passages to form a seal for the stacked laminate structure in the sealing passages.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is explained in the following description in view of the drawings that show:

FIG. 1 illustrates a turbine component comprising a plurality of stacked laminates having a seal between the laminates in accordance with an aspect of the present invention.

FIG. 2 illustrates a laminate having a sealing channel formed therein in accordance with an aspect of the present invention.

FIG. 3 illustrates a seal passage formed between two laminates in accordance with an aspect of the present invention.

FIG. 4 illustrates another seal passage formed between two laminates in accordance with another aspect of the present invention.

FIG. 5 illustrates a laminate having a seal passage and a cooling passage in accordance with an aspect of the present invention.

FIG. 6 illustrates a seal passage and a cooling passage formed between two laminates in accordance with another aspect of the present invention.

FIG. 7 illustrates a metal support formed through the sealed stack of laminates in accordance with an aspect of the present invention.

FIG. 8 illustrates the formation of a laminate plate having a sealing channel and a cooling channel formed therein in accordance with an aspect of the present invention.

FIG. 9 illustrates the addition of a metal material to a laminate in accordance with an aspect of the present invention.

FIG. 10 illustrates the stacking of laminates to form the stacked laminate structure in accordance with an aspect of the present invention.

FIG. 11 illustrates the addition of seal material to the seal passages in accordance with an aspect of the present invention.

FIG. 12 illustrates a plug for a sealing passage in accordance with an aspect of the present invention.

FIG. 13 illustrates a stationary vane formed by a process in accordance with an aspect of the present invention.

DETAILED DESCRIPTION

5 Referring now to the Figures, FIG. 1 illustrates an exemplary component 10 formed by a plurality of stacked laminates 12 stacked on top of one another to form a stacked laminate structure 14 in accordance with an aspect of the present invention. In the illustrated embodiment, the component 10 comprises a gas turbine component (e.g., blade 16); however, it is
10 understood that the present invention is not so limited. The component 10 of FIG. 1 comprises an airfoil shape 18 having a top end 20, a bottom end 22, a leading edge 24, and a trailing edge 26. As will be described in detail below, the laminates 12 comprise a seal 28 formed from a metal (seal) material 25 that is infiltrated between the stacked laminates 12 and/or radially (R) through
15 the stacked laminate structure 14. In an aspect, the seal 28 is effective to prevent air leakage between adjacent laminates 12, as well as carry away heat from the laminates 12 in the stacked structure 14. In FIG. 1, a portion of the seal 28 is illustrated within a sealing passage 30 extending radially (R) toward the top end 20 of the component 20 from the bottom end 22. It is
20 understood that the seal 28 is typically also located within further internal sealing passages 30 between adjacent laminates 12 as will be described below and illustrated in additional figures.

FIG. 2 illustrates an exemplary laminate 12 in accordance with an aspect of the present invention for use in building the component 10. In an
25 aspect, a suitable number of laminates 12 are stacked on top of one another to form the stacked laminate structure 14, as well define sealing passages 30 within the structure 14. As shown, the laminate 12 comprises a body 32 having a top surface 34 and a bottom surface 36 extending between a leading edge 40 and a trailing edge 42. In addition, the laminate 12 comprises a
30 channel 38 (hereinafter sealing channel 38) defined within one or both of the top surface 34 and the bottom surface 36 of the body 32.

The sealing channel 38 may extend longitudinally between the leading edge 40 and the trailing edge 42 of the laminate 12 within an interior portion of the body 32. The illustrated embodiment shows the sealing channel 38 with a uniform distance between the sealing channel 38 and an exterior 44 of laminate 12. However, it is appreciated that the present invention is not so limited. In other embodiments, the distance between the sealing channel 38 and an exterior 44 or outer perimeter of the laminate 12 may vary depending on the particular application.

As shown in FIG. 2, in certain embodiments, the body 32 of the laminate 12 may comprise at least one opening 46 through the body 32 for the introduction of the molten metal (seal) material 25 therein (as will be explained below). The opening 46 may be within the sealing channel 38, or may be located adjacent thereto as shown, such that material which is flowed into the opening 46 is also able to flow into the sealing channel 38. In addition, the opening 46 may be sized such that the opening 46 on one laminate 12 at least partially overlaps a similar opening 46 on an abutting laminate 12 in the stack to form a sealing passage 30 in the form of a column 48 (shown by the dotted lines in FIG. 1) extending radially through the component 10. In this way, the metal (seal) material 25 can be introduced into the column 48 and distributed to the other sealing channels 38 throughout the stacked laminate structure 14 to form the seal 28. In an aspect, the column 48 and the sealing channels 38 collectively define sealing passages 30 for the component 10.

Each sealing channel 38 may be of any suitable dimension (e.g., depth and width) suitable for providing the desired degree of sealing for the laminates 12 and desired degree of thermal conductivity for the component 10. By way of example only, each channel 38 may comprise a depth of from about 0.25 to about 5 mm and a width of from about 0.25 mm to about 5 mm. As used herein, it is noted the term "about" refers to a value which may be \pm 5% of the stated value. In addition, each channel 38 may have any desired shape in cross-section, such as a polygonal shape or a curved (e.g., a

semicircle or a half-ellipse) shape. Further, a surface of each sealing channel 38 may have varying degrees of roughness or smoothness as desired.

Further, each laminate 12 is formed wholly or partially formed from a CMC material 47 as is known in the art. The CMC material 47 may include a ceramic or a ceramic matrix material, each of which hosts a plurality of reinforcing fibers. In certain embodiments, the CMC material 47 may be anisotropic, at least in the sense that it can have different strength characteristics in different directions. It is appreciated that various factors, including material selection and fiber orientation can affect the strength characteristics of a CMC material. In addition, the CMC material 47 may comprise oxide, as well as non-oxide CMC materials. In an embodiment, the CMC material 47 comprises an oxide-oxide CMC material as is known in the art.

In a particular embodiment, the CMC material 47 comprises a ceramic matrix (e.g., alumina) and the fibers may comprise an aluminosilicate composition consisting of alumina and silica (such as 3M's Nextel 720 high temperature oxide fibers). The fibers may be provided in various forms, such as a woven fabric, blankets, unidirectional tapes, and mats. A variety of techniques are known in the art for making a CMC material and such techniques may be used in forming the CMC material 47 for use herein. In addition, exemplary CMC materials are described in U.S. Patent Nos. 8,058,191, 7,745,022, 7,153,096; 7,093,359; and 6,733,907, the entirety of each of which is hereby incorporated by reference. As mentioned, the selection of materials may not be the only factor which governs the properties of the CMC material 47 as the fiber direction may also influence the mechanical strength of the material, for example. As such, the fibers for the CMC material 47 may have any suitable orientation, such as those described in U.S. Patent No. 7,153,096. In still other embodiments, the laminates 12 may be formed from a 3D printed ceramic matrix composite (CMC) material as set forth in PCT/US2016/059029 (the entirety of which is incorporated by

reference herein) where a ceramic material is loaded into a fiber, e.g., ceramic fiber, and 3D printed in a desired pattern.

Referring again to FIG. 1, a plurality of the laminates 12 are stacked on top of one another to form a component 10 having a plurality of seal passages 30 formed therein. In an embodiment, the component 10 formed from a stack of laminates 12 may comprise a rotating component for a gas turbine, such as a blade, which may be mounted on a platform 50 as shown in FIG. 1. In another embodiment, the component 10 may comprise a stationary component for a gas turbine, such as a vane, with the stacked laminate structure 14 disposed between an upper platform as well as a lower platform. In addition, the present invention is not so limited to gas turbine components and it is understood that any desired component may be formed by the processes described herein.

As mentioned, when the laminates 12 have an opening 46 therein, the opening 46 of one laminate 12 may overlay an opening 46 of the abutting (overlying or underlying) laminate 12 in the stacked laminate structure 14 such a sealing passage 30 in the form of a column 48 (FIG. 1) is formed which extends radially (R) through the body 32 of the structure 14. In addition, upon stacking of the laminates 12, a plurality of sealing passages 30 may be formed within the interior of the stacked laminate structure 14 extending between a leading edge 24 and a trailing edge 26 thereof. In one embodiment, a given laminate 12 may comprise a sealing channel 38 within both a top surface 34 and a bottom surface 36 of the laminate 12. Further, in an embodiment, to form a sealing passage 30, a sealing channel 38 in one laminate 12 may overlap with a sealing channel 38 in an abutting laminate 12 to form a sealing passage 30 as shown in FIG. 3. In other embodiments, selected ones of the laminates 12 comprise a channel 38 in only one of the top surface 34 and the bottom surface 36. In still other embodiments, the channel 38 is formed in only one of the laminates 12, but the other laminate 12 is utilized to close the sealing passage 30 as is shown in FIG. 4. The formed sealing passages 30 (via channels 38) may be in fluid communication

with the radial sealing passage 30 (column 48) (FIG. 1) such that metal (seal) material 25 may flow from the column 48 into the sealing passages 30 defined between the laminates 12 during assembly of the component 10.

In certain embodiments, the laminates 12 utilized in forming the desired component 10 may be substantially identical to one another. In other
5 embodiments, at least one laminate 12 may be different from another laminate 12 in terms of size, shape, density, fiber orientation, cooling channel dimensions, porosity, or the like. In addition, a portion or all of the laminates 12 may be in the form of a flat plate, and may have an airfoil shape, for
10 example. In other embodiments, selected ones or pairs of the laminates 12 may have substantially non-planar abutting surfaces.

The metal material (seal) material 25 may be any metal which can be heated and flowed into the passageways 30 between laminates 12 as described herein during assembly of the component 10, allowed to cool and
15 solidify, and act a seal between and for the laminates 12. In addition, as mentioned, the metal material 25 may be one which has a greater thermal conductivity than the CMC material 47 of the laminates 12. In this way, when the CMC material 47 of the laminates 12 is subjected to a high temperature environment (e.g., > 1200° C), heat may be transferred to the metal material
20 25 from the "hot" CMC material and aid in cooling the CMC material 47 to prevent thermal damage thereto.

In an embodiment, the metal material 25 may comprise a metal selected from the group consisting of aluminum, antimony, copper, silver, gold, tungsten, and zirconium. In certain embodiments, the metal material 25
25 may comprise an alloy formed from two or more of these elements (and optionally other additional components). In a particular embodiment, the metal material 25 comprises copper, which is highly advantageous as the material melts and resolidifies easily, is thermally conductive, and highly ductile. In an embodiment, the metal material 25 may comprise an alloy
30 comprising both copper and silver. The addition of silver will raise both the melting point and thermal conductivity of the alloy relative to copper alone.

In accordance with another aspect, the component 10 further comprises a plurality of cooling passages formed within an interior of the component 10 such that a cooling fluid may be flowed through the cooling passages to further draw heat from the component 10 during high
5 temperature operation. In an aspect, heat may be conducted to the metal (seal) material 25, which is then carried away by the cooling fluid. To accomplish this, as shown in FIG. 5, selected ones of the laminates 12 may further comprise a cooling channel 52 (distinct from sealing channel 38) formed on a top surface 34 and/or a bottom surface 36 of the laminate 12.

10 Each cooling channel 52 may also be of any suitable dimension (e.g., depth and width) suitable for providing the desired degree of cooling for the CMC component 10. By way of example only, each cooling channel 52 may comprises a depth of from about 0.25 to about 5 mm and a width of from about 0.25 mm to about 5 mm. In addition, each cooling channel 52 may
15 have any desired shape in cross-section, such as a polygonal or rounded shape, e.g., a semicircle. Further, a surface of the cooling channels 52 may have varying degrees of roughness or smoothness. In certain embodiments, one or more of the cooling channels 52 may include fins, stanchions, buttons, or the like to increase the heat transfer properties of the channels 52.

20 As was discussed above with respect to sealing passages 38 (see FIGS. 3-4), each cooling channel 52 may be also formed within a given laminate 12 and closed by stacking another laminate 12 over the top surface of the cooling channel 52 in order to define a cooling passage 54. Thus, in an embodiment, one laminate 12 without a cooling channel 52 may be stacked
25 over a corresponding abutting laminate 12 having a channel 52 to close the channel and form a cooling passage 54. In other embodiments, a given pair of laminates 12 may each comprise a cooling channel 52. When the laminates 12 are stacked, the cooling channels 52 overlap and define a cooling passage 54 having a depth which represents a combined depth of the
30 two channels 52. For example, two semi-circular cooling channels 52 may be combined in order to define a circular cooling passage 54 as shown in FIG.

6. In certain embodiments, when a laminate 12 comprises both a sealing channel 38 and a cooling channel 52, the cooling channel 52 may be disposed more inboard of an exterior of the laminate 12 relative to the sealing channel 38 as is also shown in FIG. 6.

5 Referring again to FIG. 5, to allow for delivery of a cooling fluid, e.g., air, to the component 10, each laminate 12 may have a (coolant) inlet 58 in fluid communication with the cooling channel 52. The inlet 58 is in fluid communication with a fluid, such as air, delivered from a suitable fluid source, such as an air compressor. In certain embodiments, the inlet 58 comprises
10 an opening 60 in the body 32 of the laminate 12 such that a cooling fluid flowed into the opening 60 will travel into the cooling channel 52 (and thus cooling passage 54 formed by one or more channels 52). As with the sealing passages 38, any suitable number of the cooling channels 52 and cooling passages 54 (in fluid communication with a coolant source) may be provided
15 in a given laminate 12 or in the component 10 as a whole, and in any desired shape or pattern. Moreover, it is understood that the opening(s) 60 of one laminate 12 may overlap with the opening(s) of another laminate 12 such that a radial cooling passage 54 is defined through the stacked laminate structure 14 in fluid communication with the cooling passages 54 defined between the
20 laminates 12.

In addition to the inlet 58, the laminate 12 may further include an outlet 62 for exit of the cooling fluid from the cooling passage 54. In an embodiment, the outlet 62 is disposed at a trailing edge 42 of the laminate 12; however, it is understood that the present invention is not so limited. In
25 certain embodiments, one or more columns 48 (filled with the molten metal material 25 and cooled to form a seal 28) extend radially through the stacked laminate structure 14. At least one of the columns 48 is positioned adjacent the ejecting coolant air flow from outlet 62 as shown in FIG. 5. In this way, the coolant air flow will tend to flow against the seal 28 versus flowing between
30 adjacent laminates 12. In an embodiment also, an end of the sealing

passages 30 between adjacent laminates 12 may terminate with the seal 28 via column 48 for greater sealing integrity.

In accordance with another aspect, while CMC materials provide excellent thermal protection properties, the mechanical strength of CMC materials is still notably less than that of corresponding high temperature superalloy materials. For this reason, in certain embodiments and as shown in FIG. 7, when the laminates 12 comprise a CMC material, the component 10 may further comprise at least one metal support 64 which extends radially through the stacked laminate structure 14 through additional respective openings in the laminates 12. In certain embodiments, more than one metal support 64 may be provided extending radially through the structure. In some embodiments, the metal support 64 may be pre-formed and the laminates 12 may be stacked over the metal support 64 akin to rings on a pole. In other embodiments, the metal support 64 may be formed by an additive manufacturing process as the laminates 12 are stacked to form the stacked laminate structure 14. In this way, the metal support 64 may comprise an optimal interface between the CMC material of the laminates 12 and the metal along an entire radial length of the component 10.

In addition, additively manufacturing the metal support as the laminates are added also allows for the possibility of varying a thickness of the support 14 along its radial length to account for differences in thermal exposure (if so desired). Exemplary additive manufacturing processes for producing a support 64 through the stacked laminate structure 14 are described in PCT Application No. PCT/US2015/023017, entitled "Hybrid Ceramic Matrix Composite Materials," the entirety of which is hereby incorporated by reference.

The metal support 64 may comprise any suitable metal material which will provide an added strength to the laminates 12 and component 10, as well as allow for cooling of the CMC material by being in contact therewith or by being in close proximity thereto such that the CMC material transfers heat to the metal support 64. In certain embodiments, the metal material may

comprise a superalloy material, such as a Ni-based or a Co-based superalloy material as are well known in the art. The term "superalloy" may be understood to refer to a highly corrosion-resistant and oxidation-resistant alloy that exhibits excellent mechanical strength and resistance to creep even at high temperatures. Exemplary superalloy materials are commercially available and are sold under the trademarks and brand names Hastelloy, Inconel alloys (e.g., IN 738, IN 792, IN 939), Rene alloys (e.g. Rene N5, Rene 41, Rene 80, Rene 108, Rene 142, Rene 220), Haynes alloys, Mar M, CM 247, CM 247 LC, C263, 718, X-750, ECY 768, 262, X45, PWA 1483 and CMSX (e.g. CMSX-4) single crystal alloys, GTD 111, GTD 222, MGA 1400, MGA 2400, PSM 116, CMSX-8, CMSX-10, PWA 1484, IN 713C, Mar-M-200, PWA 1480, IN 100, IN 700, Udimet 600, Udimet 500 and titanium aluminide, for example.

In accordance with another aspect, the laminates 12 may further include any suitable structure that facilitates positioning of a first laminate on a second laminate and so forth as the stacked laminate structure is built. Any suitable structure may be utilized for this purpose. For example, in an embodiment, a first laminate may comprise an indent which is dimensioned to receive a tab from a corresponding second laminate. Alternatively, any other suitable structure may be utilized for facilitating the positioning and stacking of the laminates.

In accordance with another aspect, there is described a process for sealing a component 10 comprising a stacked laminate structure 14. In certain embodiments, the processes may manufacture a gas turbine component as is known in the art, which may be a rotating or stationary component, such as a blade or vane. Referring now to FIGS. 8-13, a stationary vane is formed by the illustrated process, although it is understood that the present invention is not so limited to the processes described herein or the manufacture of stationary vanes or gas turbine components altogether. Alternatively, the component formed may comprise any other suitable structure.

First, as shown in FIG. 8, a substantially flat plate 66 comprising a CMC material may be provided. From the flat plate 66, a laminate 12 may be cut (e.g., laser cut) to a desired shape (e.g., an airfoil shape) with the desired features (e.g., channels 38, 52) and openings (e.g., 46, 60) therein. For example, a given laminate 12 may be provided with a sealing channel 38, a cooling channel 52, an opening 46 in fluid communication with the sealing channel 38 (FIG. 2), an opening 60 in fluid communication with the cooling channel 52 (FIG. 5), and an outlet 62 for the cooling channel 52 (FIG. 5). These features may be included on one or both sides of the formed laminate 12. In addition, the laminate 12 may include one or more openings (not shown) to accommodate a metal support 64 as described above. In an embodiment, the formation of the laminate 12 and the desired features therein may be accomplished by any suitable method, such as machining, water jet cutting, and/or laser cutting, or the like.

Forming the laminates 12 from flat plates 66 can provide numerous advantages. For one, a flat plate provides a strong, reliable, and statistically consistent form of the CMC material. As a result, the flat plate approach may avoid manufacturing difficulties that have arisen when fabricating tightly curved configurations. For example, flat plates may be unconstrained during curing, and thus do not suffer from anisotropic shrinkage strains. Further, utilizing flat plates reduces the criticality of delamination-type flaws, which are difficult to identify. Moreover, dimensional control is more easily achieved as flat plates may be accurately formed and machined to shape using cost-effective cutting methods. A flat plate construction also enables scaleable and automated manufacturing processes. Exemplary resulting laminates 12 from this process step are shown in FIGS. 2 and 5 as discussed previously.

Alternatively, the laminates 12 may initially be provided by first forming a substantially flat skeleton of a desired shape instead of in the form of a substantially flat plate, while still retaining a strong, reliable, and statistically consistent form of the CMC material. The flat skeleton technique involves drawing out or purchasing commercially drawn out fiber material such as

Nextel 610, 720 and 650. Depending on the particular application and desired component, the drawn fiber may have one or more certain intended thickness, size, shape, density, fiber orientation, fiber architecture, and the like. Next, the elongated drawn fiber is worked in any of a variety of ways, such as by
5 laying up, rolling, tacking, injecting, spraying and the like, to shape out a substantially flat skeleton of a desired shape.

After the flat skeleton has been shaped out, a ceramic material, such as an oxide material commercially available as Pritzkow FW12 (matrix is an alumina zirconia mixture), or those described in U.S. Patent Nos. 7,153,096;
10 7,093,359; and 6,733,907, may be deposited in and about the fiber skeleton, thereby interconnecting the fiber skeleton by any of a variety of ways, such as by injection, spraying, sputtering, melting, infiltration, melt slurry infiltration, and the like. Depending on the particular application and desired component, the resulting laminate 12 may have one or more certain intended thickness,
15 size, shape, density, porosity, pore characteristic and the like, if desired. Processes for carrying out these processes are set in forth in PCT Application No. PCT/US2015/060053, the entirety of which is also incorporated by reference herein. Thereafter, the produced laminate 12 may be provided with a sealing channel 38, a cooling channel 52, an opening 46 in fluid
20 communication with the sealing channel 38 (FIG. 2), an opening 60 in fluid communication with the cooling channel 52 (FIG. 5), and an outlet 62 for the cooling channel 52 (FIG. 5). These features again may be included on one or both sides of the formed laminate 12. Further alternatively, the laminates 12 may be provided with their desired features and obtained from a suitable
25 commercial source.

Referring now to FIG. 9, a base member 68 may be provided on which to stack the plurality of laminates 12. The base member 68 may comprise any suitable substrate, such as a first laminate 12 in the stack, a plain laminate with no features incorporated therein, or an element of the
30 component, e.g., a platform 50, on which the stack may begin. In certain embodiments, the laminates 12 are placed individually on the base member to

build the stacked laminate structure 14. As mentioned, at selected portions of the stacked laminate structure 14, embedded sealing passages 30 and optionally also cooling passages 54 will be formed. This may be accomplished by stacking at least a pair of laminates 12 such that they define one or more enclosed sealing passages 30 and cooling passages 54 in the stack 14 (due to the channels 38, 52 formed therein and openings 46).

In certain embodiments, one or more metal supports 64 (or portions thereof) are also provided, each of which extends radially from the base member 68 as was shown in FIG. 7. In an embodiment, the individual laminates 12 or laminate groups are stacked sequentially over the metal support 64 until the completed stacked laminate structure 14 is formed. In an embodiment, the metal support structure 64 may thus be pre-fabricated and dimensioned so as to accommodate placement of the laminates 12 thereon. In other embodiments, the metal support 64 may instead be built in situ via additive manufacturing as the laminates 12 are stacked to form the complete stacked laminate structure 14.

For example, as shown in FIG. 9, a metal source material 70 may be added within corresponding openings of one or more laminates 12 from a suitable metal source 72. In an embodiment, the metal material 70 is provided from a suitable metal source, such as a hopper or the like, in powdered form at a predetermined volume and feed rate. Following deposition of the metal material 70, an energy source 74, such as a laser source, focuses an amount of energy 76 on the metal material 70 to form molten metal within the respective opening. To accomplish the above, the energy source 74 may be moved with respect to the subject laminate(s) 12, or vice-versa, to position the energy source 74 at a desired location over the subject laminate(s) 12 to melt the metal material 70. The molten metal will be allowed to cool actively or passively to provide a corresponding segment of the metal support 64.

Thereafter, one or more additional laminates 12 may be added to the laminate stack, and an additional portion of the metal support 64 formed. The

process of building segments of the metal support(s) 64 may be repeated several times until the stacked laminate structure 14 is fully formed with the desired metal support(s) 64 therein. These and other methods for forming a metal support within a plurality of stacked laminates are set forth in PCT
5 Application No. PCT/US2015/023017, the entirety of which is hereby incorporated by reference.

In accordance with another aspect, once the desired number of laminates 12 are stacked, the laminates 12 may undergo heat treatment, e.g., a sintering process, in order to sinter/fuse the laminates together. In other
10 embodiments, two or more laminates 12 forming a respective internal sealing passage 30 or cooling passage 54 may be sintered in a separate location (away from the stack) so as to fuse the laminates together as a laminate group having two or more laminates. Thereafter, the sintered group of laminates 12 may then be placed on the stack. In any case, sintering may be
15 done at any suitable temperature and a for a suitable duration to join two or more adjacent laminates to one another, and in one embodiment, may be done at a temperature of about 500 to 1000° C for a period of 1 to 24 hours.

Referring now to FIG. 11, the stacking of the laminates 12 also facilitates the formation of the sealing passages 30, including a passage 30 in
20 the form of a column 48 extending radially through the stacked laminate structure 14. This column 48 will be utilized as a "fill port" to distribute molten seal material 25 to other corresponding interior sealing passages 30 which extend longitudinally through the body 32 of the stacked laminate structure 14 as is shown by arrows 78. To accomplish this, a suitable amount of the metal
25 (seal) material 25 may be delivered from a suitable source to the column 48 in order to fill the column 48 with the molten metal material 25. In an embodiment, prior to addition to the sealing passages 30, the metal material 25 is heated to such an extent as to give the metal material 25 a degree of viscosity and allow flow of the metal material 25 into the passages 30,
30 including column 48.

In certain embodiments, the base member 68 may be outfitted with a plug 80 or the like to provide for sealed closure of the passages 30 as shown in FIG. 12. FIG. 12 represents an underside of the base member (inner shroud) 68 shown in FIG. 11. Alternatively or in addition, a laminate 12 or other structure which closes off the column 48 at a bottom or top portion thereof may also be provided. In addition, when the component 10 is a vane 84, an additional platform, e.g., outer shroud 82, may be fixed to the laminate stacked structure 14 as is conventional in the art and as is shown in FIG. 13 to complete production of the component 10. Although one column 48 is illustrated, it is appreciated that multiple fill ports (radial sealing passages 30 or columns 48) may be provided through the stacked laminate structure 14 to distribute the molten metal material 25 to the sealing passages 30 formed between adjacent laminates 12.

Returning to the process, after sufficient molten metal material 25 has been added to the sealing passages 30 (including column 48), the molten seal material 25 is allowed to cool within the passages 30 in order to form the seal 28 for the stacked laminates 12. When cooling passages 54 are provided as described herein, the seal 28 will act to prevent leakage of cooling fluid from the component (typically between the laminates 12 in the stack), thereby improving cooling efficiency and high temperature capabilities of the component 10. Moreover, during high temperature operation, the seal material 25 may, in fact, become molten to at least an extent. In this way, the seal material 25 is able to reform (at least to an extent) during and following operational cycles, thereby relieving stresses that otherwise might induce cracks. In this way also, the integrity of the seal 28 may remain intact even after several operational cycles.

In any of the embodiments described herein, prior to, concurrent with, or following the stacking of the laminates 12 and sintering, the laminates 12 may also be retained/compressed via a retaining structure or other structure that compresses the stack of laminates 12 and maintains the laminates in a compressed state. For example, in an embodiment, a metal plate (not shown)

may be disposed as a top member in the stacked laminate structure 14. A threaded bolt or the like may be driven down into the metal plate and/or metal support 64 (when present) in order to provide a desired degree of compression to the stacked laminate structure 14. In an aspect, the amount of compressive force is determined by the materials present, the size and number of laminates in the stack, the presence of a metal support or not, and the like.

In embodiments where a metal support 64 is provided, for example, the metal will likely have a significantly greater coefficient of thermal expansion relative to the CMC material 47 of the laminates 12. Thus, as the operating temperature increases, the metal support 64 will expand and the compressive force on the laminates 12 will be reduced. In order to ensure that the sufficient compressive force remains is in place during operation (where the component 10 is subjected to high temperatures, e.g., > 1200° C) and to prevent cooling fluid leakage from the stacked laminate structure 14, there must be a significantly higher loading on the laminates 12 in their cold (non-operating) state relative to their operating (high temperature) state. Prior to this disclosure, this significant preload was often too great for the laminates 12, which are prone to cracking and breaking with significant compressive loads.

In accordance with an aspect, the disclosed sealing structures and sealing processes allow for reduced compression or preloading on the top of the stacked laminates and/or the metal support 64, and thus a reduced cold crushing load on the laminates 12 since the metal (seal) material 25 will conform to the laminates 12 when hot. To accomplish this, in an embodiment, when the molten metal material 25 is introduced into the sealing passages 30, the CMC laminates 12 are also heated to prevent premature solidification of the molten metal material 25. Next, the sealing passages 30 are filled with the molten metal material 25, and the molten metal material 25 is allowed to cool. In this way, when the metal solidifies (having shrunk more than the CMC), the infiltrated metal material 25 may pull the laminates 12 together,

thereby reducing the compressive force needed on the laminates 12 in a cold state. The formed seal 28 from the cooled metal material 25 is thus in tension throughout the stacked laminate structure 14, but that tension may be reduced or eliminated as the associated component 10 is heated back to
5 operating temperature (e.g., > 1200° C). The latter is of benefit since it is preferred that the seal does not transfer any load to the laminates 12 during operation, but rather solely acts to seal the laminates 12 and prevent cooling fluid (e.g., air) from escaping between the laminates 12.

10 While various embodiments of the present invention have been shown and described herein, it will be obvious that such embodiments are provided by way of example only. Numerous variations, changes and substitutions may be made without departing from the invention herein. Accordingly, it is intended that the invention be limited only by the spirit and scope of the appended claims.

15

CLAIMS

What we claim is:

1. A component (10) comprising:
5 a plurality of laminates (12) comprising a ceramic matrix composite material (47) stacked on one another to define a stacked laminate structure (14); and
a seal (28) comprising a metal material (25) disposed between adjacent stacked laminates in the stacked laminate structure (14).
10
2. The component (10) of claim 1, wherein the seal (28) comprises a column (48) of the metal material (25) extending through corresponding openings (46) in the laminates (12) between a top end (20) and a bottom end (22) of the stacked laminate structure (14).
15
3. The component (10) of claim 2, wherein the stacked laminate structure (14) comprises a plurality of sealing passages (30) inboard of an exterior (44) thereof and extending between a leading edge (24) and a trailing edge (26) of the stacked laminate structure (14), wherein the plurality of
20 sealing passages (30) are in fluid communication with the column (48), and wherein the seal (28) further comprises the metal material (25) within the sealing passages (30).
4. The component (10) of claim 3, wherein the plurality of sealing
25 passages (30) are defined by a sealing channel (38) formed in selected ones of the stacked laminates (12).

5 5. The component (10) of claim 4, wherein at least a portion of the plurality of sealing passages (30) are defined by a first sealing channel (38) formed in a first stacked laminate (12) which at least partially overlaps a second sealing channel (38) formed in an abutting second stacked laminate (12).

10 6. The component (10) of claim 5, wherein the first sealing channel (38) and the second sealing channel (38) each have at least one of a semi-circular or a rectangular shape.

15 7 The component (10) of claim 3, wherein selected ones of the laminates (12) further comprise a plurality of cooling passages (54) spaced apart from the sealing passages (30) inboard of an exterior of the stacked laminate structure (14), the cooling passages (54) defined within an interior of the stacked laminate structure (14) and extending longitudinally between the leading edge (24) and the trailing edge (26) of the stacked laminate structure (14).

20 8. The component (10) of claim 10, wherein the cooling passages (54) are disposed more inboard from an exterior of the stacked laminate structure (14) relative to a plurality of the sealing passages (30).

25 9. The component (10) of claim 10, wherein the cooling passages (54) are defined by a first cooling channel (52) formed in a first stacked laminate (12) which at least partially overlaps a second cooling channel (52) formed in an abutting second stacked laminate (12).

10. The component (10) of claim 1, wherein, upon exposure to heat, the metal material (25) is effective to remove heat from the ceramic matrix composite material (47) of the stacked laminate structure (14) and to provide the seal (28) between adjacent stacked laminates (12) in the stacked laminate structure (14).
5

11. The component (10) of claim 1, wherein the metal material (25) comprises an element selected from the group consisting of aluminum, antimony, copper, gold, silver, tungsten, zirconium, and alloys comprising at least one of the elements.
10

12. The component (10) of claim 11, wherein the metal material (25) comprises an alloy of silver and copper.

13. The component (10) of claim 1 further comprising a metal support (64) extending through corresponding openings in the laminates (12) and the stacked laminate structure (14).
15

14. The component (10) of claims 1 to 13, wherein the component (10) comprises a stationary (84) or rotating component (26) of a gas turbine engine.
20

15. A process for sealing a stacked laminate structure (14) comprising:

stacking a plurality of laminates (12) comprising a ceramic matrix composite material (47) on one another to form the stacked laminate structure (14);

forming a plurality of sealing passages (30) within an interior of the stacked laminate structure (40);

filling the plurality of sealing passages (30) with a molten metal material (25); and

cooling the metal material (25) within the sealing passages (30) to form a seal (25) for the stacked laminate structure (14) in the sealing passages (30).

16. The process of claim 15, wherein a portion of the sealing passages (30) are defined by channels (38) formed in a surface of selected ones of the stacked laminates (12).

17. The process of claim 15, wherein the sealing passages (30) are formed by at least partially overlapping a first sealing channel (38) of a first stacked laminate (12) with a second sealing channel (38) of an adjacent second stacked laminate (12).

18. The process of claim 15, wherein the plurality of sealing passages (30) comprise a column (48) extending radially through the stacked laminate structure (14) and a plurality of longitudinal sealing passages (30) disposed between adjacent stacked laminates (12) and extending between a leading edge (24) and trailing edge (26) of the stacked laminate structure (14),
5 wherein the plurality of longitudinal sealing passages (30) are in fluid communication with the column (48).

19. The process of claim 15, wherein the metal material (25)
10 comprises an element selected from the group consisting of aluminum, antimony, copper, gold, silver, tungsten, zirconium, and alloys comprising at least one of the elements.

20. The process of claim 15, further comprising forming a plurality of
15 cooling passages (54) inboard of an exterior of the stacked laminate structure (14) and extending between a leading edge (40) and a trailing edge (42) of the stacked laminate structure (14).

FIG. 1

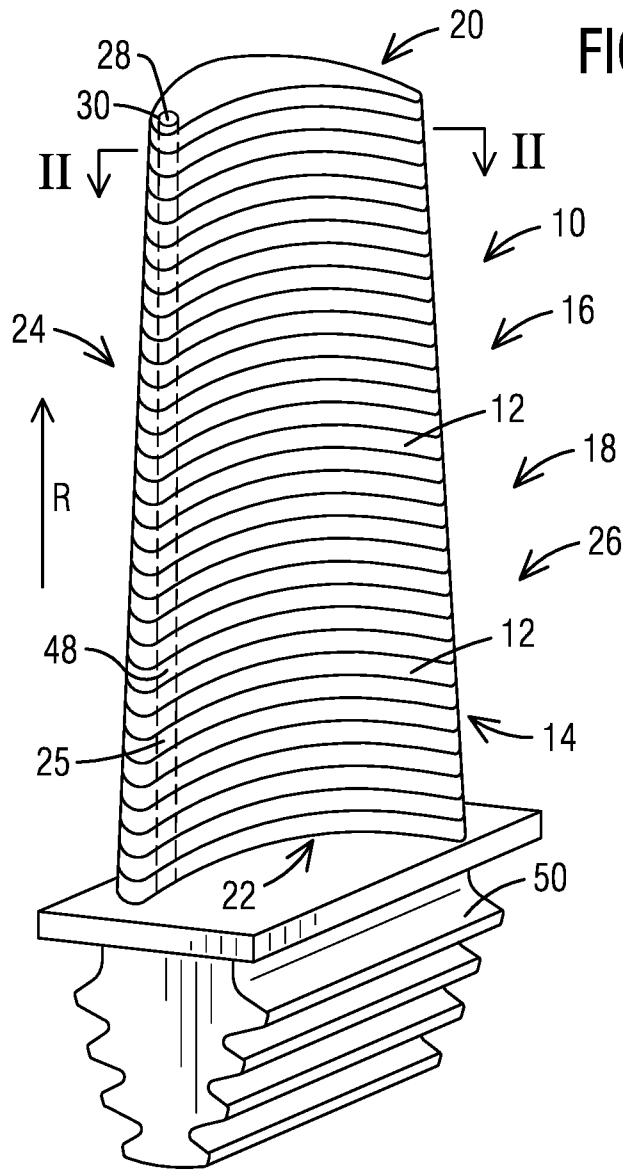
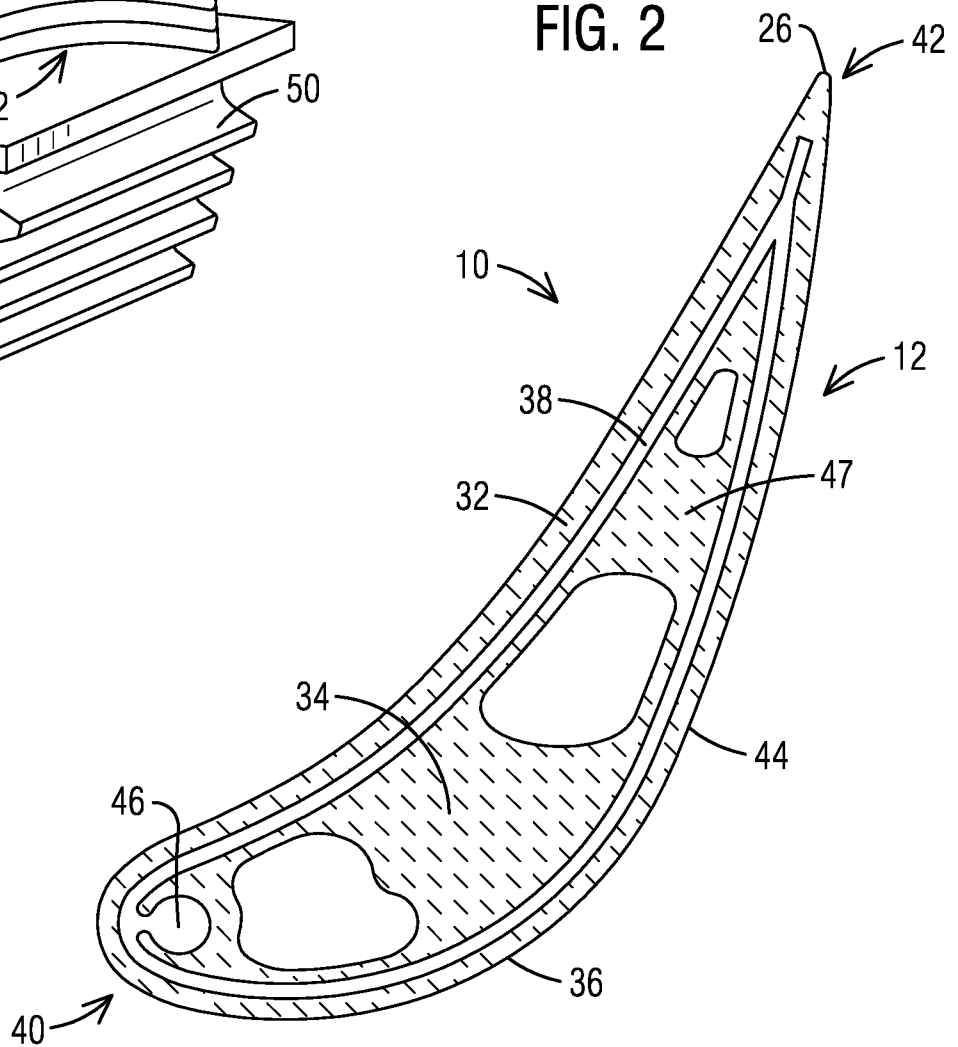


FIG. 2



2/6

FIG. 3

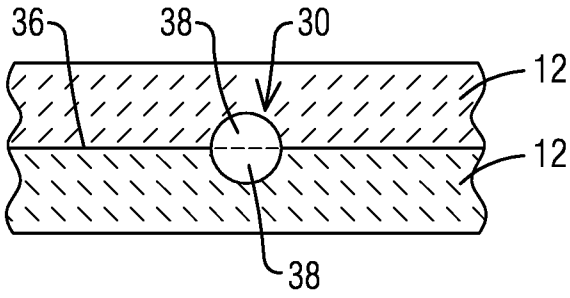


FIG. 4

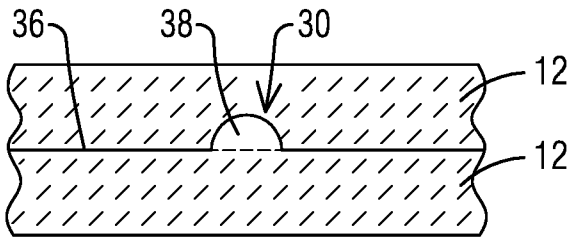


FIG. 5

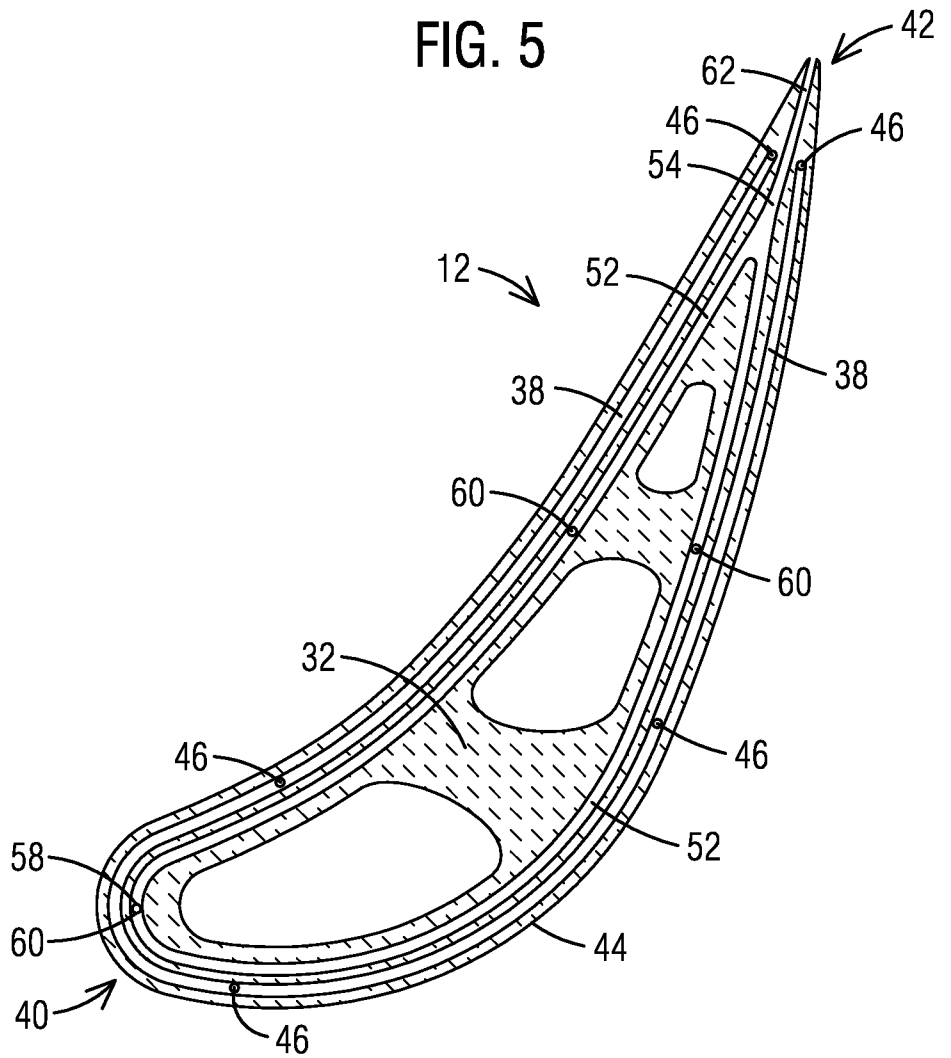


FIG. 6

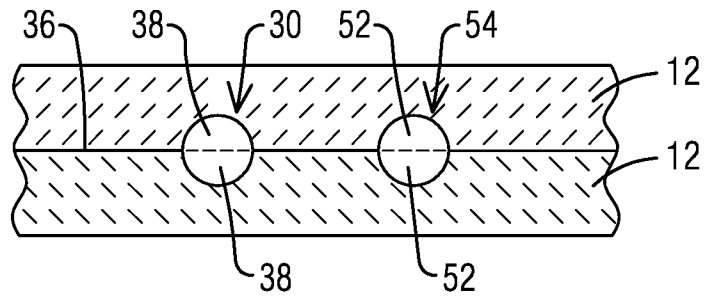


FIG. 7

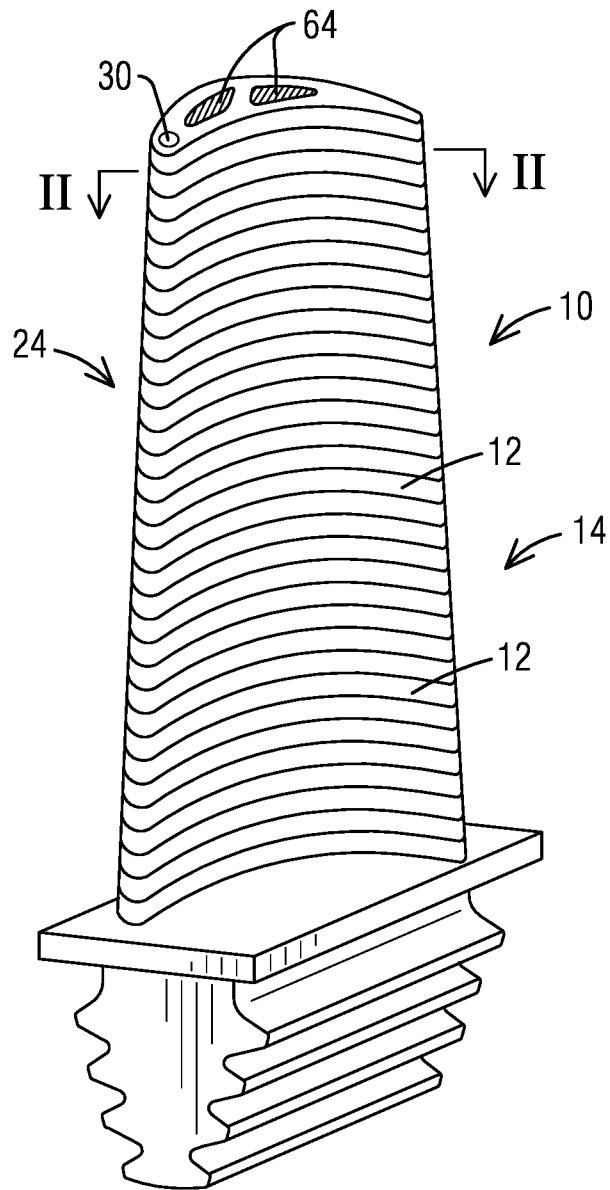


FIG. 8

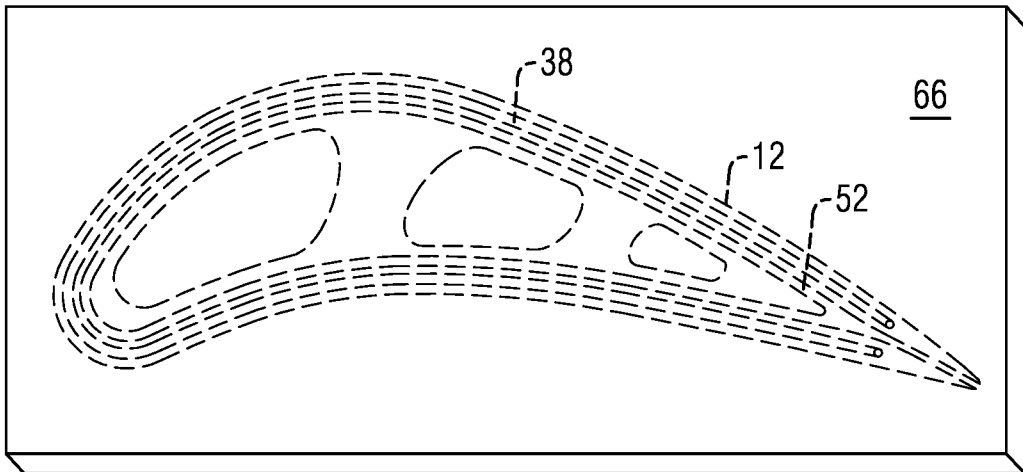


FIG. 9

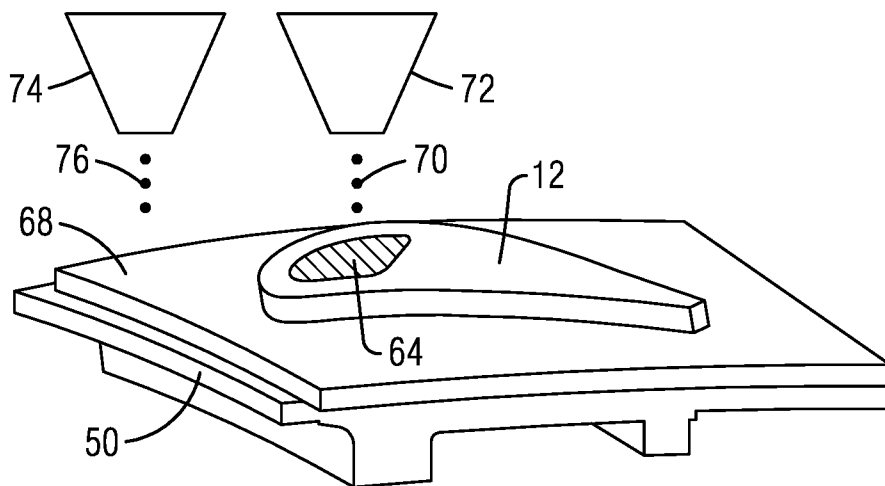


FIG. 10

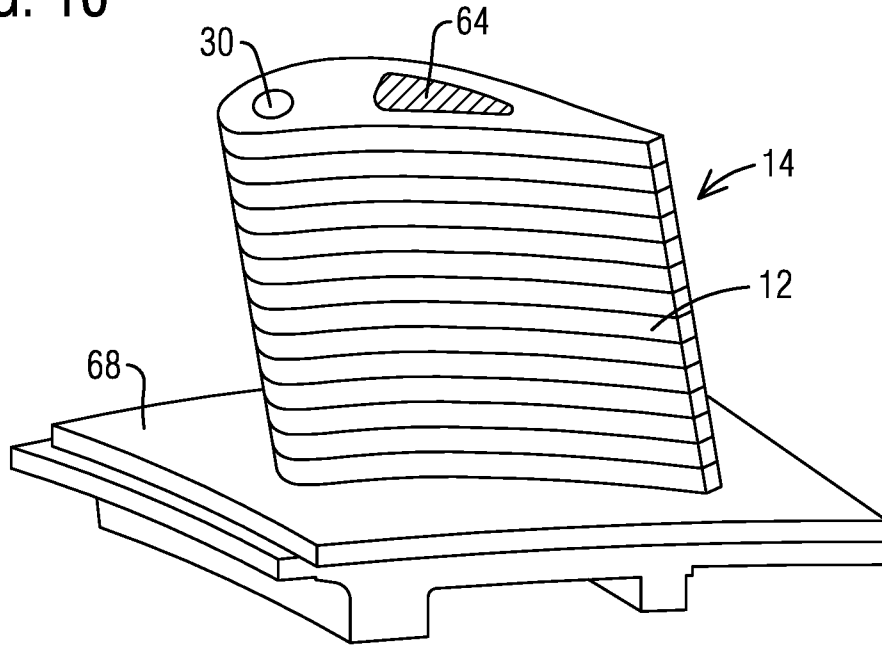


FIG. 11

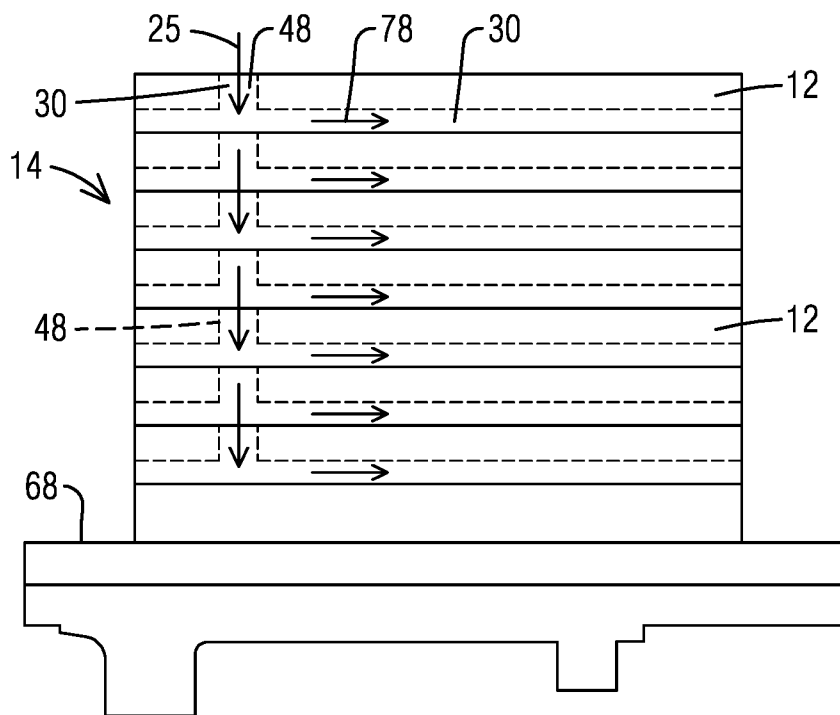


FIG. 12

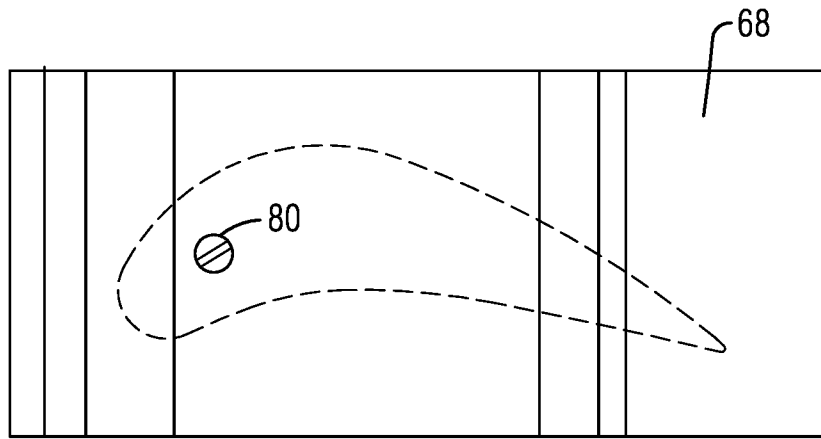
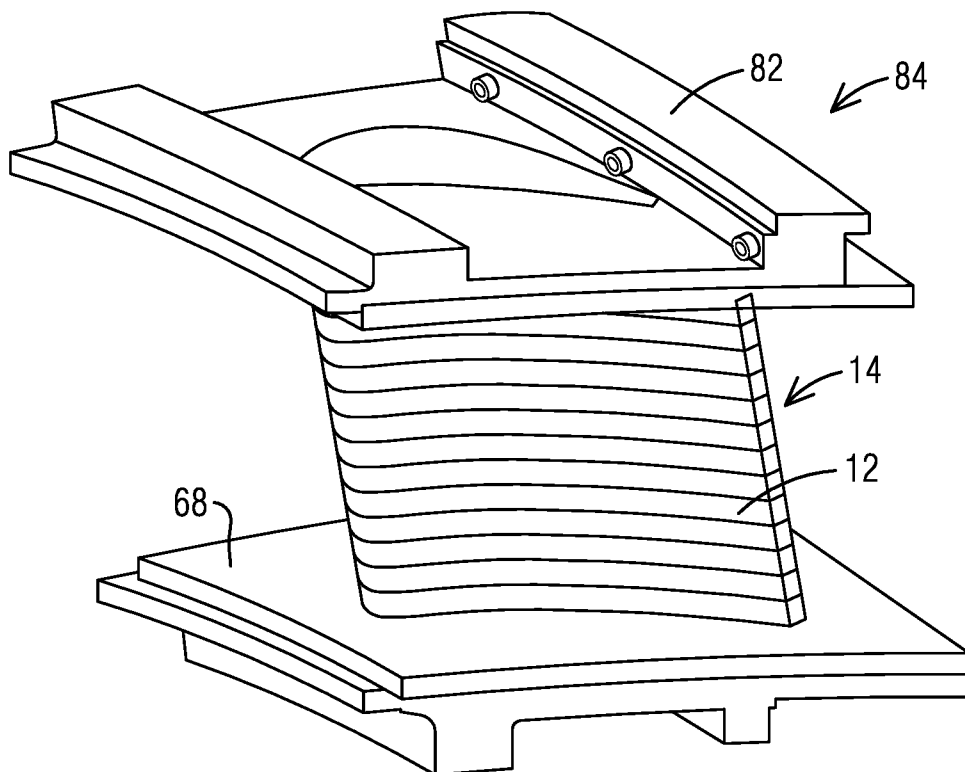


FIG. 13



INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/017547

A. CLASSIFICATION OF SUBJECT MATTER					
INV.	B32B7/04	B32B7/08	B32B18/00	B32B3/06	B32B3/08
	B32B3/26	F01D5/14	B23P15/04	F01D5/18	F01D5/28
	F01D9/04	F01D9/06			

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
B32B C04B F01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2016/159933 A1 (SIEMENS AG [DE]; SIEMENS ENERGY INC [US]) 6 October 2016 (2016-10-06)	1-4, 10, 11, 13, 14
Y	page 10, line 15 - line 30; claims 1, 2, 8, 9; figures 9-16	5-9, 15-20
A		12
Y	US 2006/121265 A1 (THOMPSON DANIEL G [US] ET AL) 8 June 2006 (2006-06-08)	5-9, 15-20
A	paragraph [0069] - paragraph [0072]; claim 7; figures 6, 8a	12

Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents :

<p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p>	<p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&" document member of the same patent family</p>
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Date of the actual completion of the international search 28 September 2017	Date of mailing of the international search report 10/10/2017
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Raming, Tomas
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2017/017547

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2016159933	A1	06-10-2016	NONE

US 2006121265	A1	08-06-2006	NONE
