(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
**06 June 2019 (06.06.2019)**

WIPO | PCT

(10) **International Publication Number**
**WO 2019/108220 A1**

(51) **International Patent Classification:**
*F01D 5/28* (2006.01) *C04B 35/82* (2006.01)
*C04B 35/653* (2006.01) *F01D 5/14* (2006.01)
*B32B 3/30* (2006.01) *F23R 3/00* (2006.01)

(21) **International Application Number:** PCT/US2017/064170

(22) **International Filing Date:** 01 December 2017 (01.12.2017)

(25) **Filing Language:** English

(26) **Publication Language:** English

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

(71) **Applicant** *(for BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW only)*: **SIEMENS ENERGY, INC.** [US/US]; 4400 Alafaya Trail, Orlando, Florida 32826-2399 (US).

(72) **Inventors: MERRILL, Gary B.**; 847 Post Lane, Orlando, Florida 32804 (US). **MORRISON, Jay A.**; 2885 Kingfisher Way, Mims, Florida 32754 (US).

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

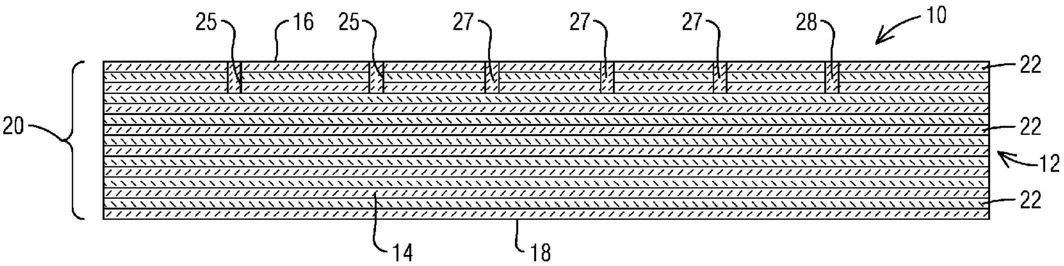
(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

**Published:**
— *with international search report (Art. 21(3))*

(54) **Title:** CERAMIC MATRIX COMPOSITE COMPONENTS WITH CRYSTALLIZED GLASS INSERTS

FIG. 1




(57) **Abstract:** There is provided a ceramic matrix composite component (10) having a body (12) comprising a ceramic matrix composite material (14) and a plurality of grooves (24, 25, 26) extending from a top surface (16) of the body (12) and into the body (12). An insert (27, 30, 32) of a crystallized glass material (28) is disposed within respective ones of the plurality of grooves (24, 25, 26). The inserts (27, 30, 32) of crystallized glass material (28) are effective to at least increase an interlaminar strength of the ceramic matrix composite material (14).

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# CERAMIC MATRIX COMPOSITE COMPONENTS WITH CRYSTALLIZED GLASS INSERTS

## FIELD

The present invention relates to systems and processes for improving thermal protection for high temperature components, including gas turbine components. More particularly, the present invention relates to a ceramic matrix composite (CMC) component having an engineered surface comprising inserts of crystallized glass formed within grooves of the CMC component.

## BACKGROUND

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 high pressure (working) 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, thereby causing the turbine blades to rotate, and thereby turning a rotor associated therewith. 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 various 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 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.

For this reason, ceramic matrix composite (CMC) materials have been developed and increasingly utilized. Typically, CMC materials include a ceramic or a ceramic matrix material, either of which hosts a plurality of reinforcing fibers. While such materials provide potentially higher temperature resistance relative to superalloy materials, there remain issues with such CMC materials in high temperature environments. For one, components made of CMC materials typically exhibit relatively poor interlaminar tensile and shear strength. As a result, the CMC material is prone to delamination at high temperature operation (e.g., 1600-1700° C) due to mechanical and thermal stresses. In addition, fiber grains of the CMC material may coarsen at such temperatures and lead to crack propagation at the fiber/matrix interface as firing temperatures increase. Accordingly, there is a need for CMC materials with improved structural integrity.

To provide the CMC material with further thermal protection, a thermal barrier coating (TBC) may be applied to the CMC substrate surface. Once applied, the TBC provides an insulating layer over the component surface, which may reduce the temperature the substrate is subjected to in a high temperature environment. A number of methods have been developed for applying a TBC coating to a CMC material, such as by (hot) thermal spraying or vapor deposition (e.g., electron beam physical vapor deposition (EB-PVD)). In thermal spraying (e.g., plasma spraying), for example, ceramic particles are heated to an elevated temperature to form a molten material, and the molten material is directed at the component surface and allowed to cool to form the desired coating.

Although techniques for the deposition of TBCs on a CMC material have improved and provide added thermal protection to the CMC material, the application of TBCs on CMC materials provides numerous challenges. For one, depending on the local macro-roughness of the ceramic fibers and matrix infiltration characteristics of the substrate CMC material, the adhesion of thermally sprayed TBCs to the CMC substrate may be poor. In addition, other coating methods, such as vapor deposition, may result in insufficient deposition, uneven distribution, and inadequate bonding of the TBC to the desired CMC substrate. Further, the TBC and the CMC material tend to have a thermal expansion mismatch where the TBC tends to expand more than the underlying CMC material. Thus, as the TBC heats, the TBC tends to lose adhesion with and delaminate from the CMC surface. As a result, the TBC coating on a CMC substrate is especially prone to rapid crack propagation and spallation issues. While workable solutions have been provided which mechanically interlock the TBC to the CMC surface (due to the lack of possible chemical bonding to the CMC surface), there still remain issues in sufficiently securing the TBC to the CMC surface. For one, the CMC material has weak interlaminar strength and is still prone to delamination, particularly in the event of failure of the TBC. Accordingly, CMC components having improved TBC adhesion to the underlying CMC substrate, as well as improved structural integrity are needed.

## BRIEF DESCRIPTION OF THE DRAWINGS

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

FIG. 1 is a cross-sectional view of a CMC component comprising inserts of crystallized glass therein in accordance with an aspect of the present invention.

FIG. 2 is a cross-sectional view of a CMC component comprising inserts of crystallized glass of varying depths in accordance with another aspect of the present invention.

FIG. 3 is a cross-sectional view of a CMC component comprising inserts of crystallized glass and a thermal barrier coating (TBC) thereover in accordance with an aspect of the present invention.

FIG. 4 is a cross-sectional view of a CMC component comprising inserts of crystallized glass, a TBC, and a bond coat in accordance with an aspect of the present invention.

FIGS. 5-7 illustrate steps in a process for making a CMC component in accordance with an aspect of the present invention.

FIG. 8 illustrates varying depths of the three inserts into plies of CMC material in accordance with an aspect of the present invention.

DETAILED DESCRIPTION

In accordance with an aspect, there is provided a component comprising a ceramic matrix composite (CMC) which is surface modified by having a plurality of grooves or channels formed therein, and which is processed to provide inserts of a crystallized glass material within the grooves. The resulting CMC component has increased interlaminar strength as a result of the crystallized glass penetrating a depth of the ceramic matrix composite. In addition, the modified CMC component comprises a stabilized surface for improved attachment of a thermal barrier coating (TBC) thereto. When utilized in a gas turbine engine, for example, the components described herein allow for increased firing temperatures, which, in turn, results in increased engine efficiency. In addition, due to the stabilized surface and increased local interply strength, the components described herein may exhibit longer lifetimes and time before repair, thereby reducing component costs, maintenance costs, and down time.

In accordance with one aspect of the present invention, there is provided a ceramic matrix composite component comprising: a body comprising a ceramic matrix composite material; a plurality of grooves extending from a top surface of the body and into the body; and an insert of a crystallized glass material disposed within respective ones of the plurality of grooves, wherein the insert of the crystallized glass material are effective to at least increase an interlaminar strength of the ceramic matrix composite material.

In accordance with another aspect of the present invention, there is provided a process for making a ceramic matrix composite component. The process comprises forming a plurality of grooves within a body of a ceramic matrix composite material, the grooves extending from a top surface of the and into the body; and forming a plurality of inserts of a crystallized glass material within the plurality of grooves, wherein the inserts of the crystallized glass material are effective to at least increase an interlaminar strength of the ceramic matrix composite material.

Now referring to the drawings, FIG. 1 illustrates a component 10 having a body 12 (CMC body 12) comprising a ceramic matrix composite material 14. The body 12 comprises a top surface 16, a bottom surface 18, and a through thickness 20 extending between the top surface 16 and the bottom surface 18. For purposes of illustration only, the CMC body 12 comprises a plurality of fibers in the form of plies 22 to which ceramic or ceramic matrix material may be added/impregnated in the formation of the CMC material 14. Alternate embodiments for the structure of the body 12 of CMC material 14 are set forth below. As shown in FIG. 1, a plurality of grooves 25 are provided that extend from the top surface 16 down into a through thickness 20 of the CMC body.

Within the grooves 25, there are provided inserts 27 of a crystallized glass or glass-containing material (hereinafter “crystallized glass material 28” or “glass material 28”). In one aspect, the inserts 27 of crystallized glass material 28 increase an interlaminar strength of the CMC material 14. In a particular embodiment, when the CMC material 14 comprises a plurality of plies as described herein, the inserts increase the interlaminar strength of the first few plies of the CMC material 14, thereby preventing delamination of the CMC material upon the application of stresses thereto (thermal or mechanical). In addition, when a TBC is utilized, the inserts 27 provide a more consistent surface for TBC adhesion relative to a CMC material alone. A CMC surface (without the inserts 27) will typically contain areas of exposed fiber and exposed matrix, which is a comparatively inconsistent and inhomogeneous surface. In addition to providing the CMC material 14 with the glass inserts 27, in certain embodiments, the CMC surface of the body 12 may be subjected to a surface roughening process (e.g., grit blasting) prior to deposition of a TBC thereon. This will further provide the body 12 with a further consistent surface for improved TBC adhesion.

In the embodiment shown in FIG. 1, the grooves 25 and corresponding inserts 27 have the same length such that they extend the same depth into the through thickness 20 of the CMC body. However, it is understood that the present invention is not so limited. In certain embodiments and as shown in FIG. 2, the grooves 25 may instead comprise a plurality of first grooves 24 and second grooves 26, and the inserts 27 comprise a plurality of first inserts 30 disposed within respective ones of the first grooves 24 and a plurality of second inserts disposed within respective ones of the second grooves 26. The first grooves 24, second grooves 26, first inserts 30, and second inserts 32 each extend from the top surface 16 down into the through thickness 20 of the body 12, and are spaced apart from one another. In this embodiment, the second grooves 26 and second inserts 32 have a longer length and thus extend deeper into the through thickness 20 compared to the first grooves 24 and first inserts 30. In this way, the first grooves 24 and first inserts 30 do not have an end which terminates in the same plane into the through thickness 20 as the second grooves 26 and second inserts 32. As a result, the likelihood of delamination or other structural damage to the CMC material 14, particularly at high temperatures, e.g., > 1200° C, is substantially reduced. Further, if a delamination defect is formed, then the grooves 24, 26 and inserts 30, 32 may act as an arresting feature of that delamination.

As referred to herein, the second grooves 26 and second inserts 32 refer to the grooves and inserts, respectively, that extend the furthest into the CMC body 12. In an embodiment, the first grooves 24 all have the same depth, e.g., extend from the top surface 16 into the body 12 to the same degree (but less than the second grooves 26). In other embodiments (*see e.g.,* FIG. 2), the first grooves 24 may comprise grooves of two or more different depths (lengths), each of which have a depth that is less than a depth of the second grooves 26.

Within the grooves 24, 26, there are provided corresponding first inserts and second inserts 30, 32 of a crystallized glass or glass-containing material (hereinafter “crystallized glass material 28” or “glass material 28”). Since the grooves and inserts have corresponding dimensions, it is understood that any description of the grooves 24, 25, 26 described herein may also be applicable to the inserts 27, 30, 32. For example, the first inserts 30 will also extend into a depth of the CMC body 12 to a lesser extent relative to the second inserts 32. In one aspect, the grooves 24, 25, 26 and inserts 27, 30, 32 reduce strain surface sintering of the CMC body 12, increase an interlaminar strength as a result of the crystallized glass penetrating a depth of the ceramic matrix composite, and provide a stabilized surface for improved attachment of a thermal barrier coating (TBC) thereto.

To reiterate, the glass material 28 provides the body 12 with a degree of added reinforcement and interlaminar strength to the CMC body 12. The glass material 28 may be formed within the grooves 24, 25, 26 via any suitable process known in the art. In an embodiment, to produce the inserts 27, 30, 32 of crystallized glass material 28, ingredient(s) for glass and a nucleating agent are thoroughly mixed together, and then the mixture is heated for a time and at a temperature effective to melt the mixture. The molten material may then be added to the grooves 24, 25, 26 and allowed to cool. The resolidified material may then be crystallized by heat-treating the resolidified material and thereafter cooling the material to provide the inserts 27, 30, 32 of glass material 28 (corresponding to a size and depth of the grooves 24, 25, 26).

The glass material 28 may comprise any suitable glass-containing material known in the art which can provide an added degree of interlaminar strength to the body 12. In an embodiment, the glass material 28 is one formed from one or more oxide materials, such as one or more of silica, sodium oxide (soda ash), calcium oxide, lead oxide, and potassium oxide. In addition, one or more additives may be provided in the manufacture of the glass material 28. In certain embodiments, the glass material 28 contains no pores or has a porosity of less than 5%.

In another embodiment, the glass material 28 comprises a glass-ceramic material as is known in the art. Glass-ceramic materials comprise an amorphous phase and can be heat-treated to produce one or more crystalline phases. In certain embodiments, the glass-ceramic material comprises between 30% [m/m] and 90% [m/m] crystallinity and may comprises properties such as little or no porosity, relatively low thermal expansion, and high durability. In this way, the glass-ceramic material may have the strength of a ceramic material, but also the hermetic sealing properties of glass. The glass-ceramic material may comprise any known material system in the art. In a particular embodiment, the glass material 28 comprises one of a $Li_2O \times Al_2O_3 \times nSiO_2$ system (LAS system); a $MgO \times Al_2O_3 \times nSiO_2$ system (MAS system); a $ZnO \times Al_2O_3 \times nSiO_2$ system (ZAS system), combinations thereof, and the like as are known in the art. By way of example, the LAS system refers to a mix of lithium, silicon, and aluminum oxides with additional components, e.g., glass-phase-forming agents such as $Na_2O$, $K_2O$ and CaO, and refining agents (if necessary). To provide the desired crystallization of the glass material 28, nucleating agents, such as zirconium(IV) oxide alone or in combination with titanium(IV) oxide, may be used in the above systems.

The component 10 may comprise any desired component comprising a CMC material 14 having grooves 24, 25, 26, and inserts 27, 30, 32 of glass material 28, as described herein. In an embodiment, the component 10 may comprise a turbine component as is known in the art for use at high temperatures (e.g., > 1200° C). In a particular embodiment, the component 10 may comprise a gas turbine component, e.g., an airfoil structure configured for use in a combustor turbine hot gas section. By way of example, the component 10 may be a stationary part or a rotating part of a gas turbine, such as one of a transition duct, an exhaust cone, a blade, a vane, or the like.

The CMC material 14 may comprise a fiber reinforced matrix material or metal reinforced matrix material as may be known or later developed in the art, such as one commercially available from the COI Ceramics Co. under the name AS-N720. If a fiber reinforced material is used, the fibers may comprise oxide ceramics, non-oxide ceramics, or a combination thereof. For example, the oxide ceramic fiber composition can include those commercially available from the Minnesota Mining and Manufacturing Company under the trademark Nextel, including Nextel 720 (alumino-silicate), Nextel 610 (alumina), and Nextel 650 (alumina and zirconia). For another example, the non-oxide ceramic fiber composition can include those commercially available from the COI Ceramics Company under the trademark Sylramic (silicon carbide), and from the Nippon Carbon Corporation, Limited under the trademark Nicalon (silicon carbide).

The matrix material composition that surrounds the fibers may be made of an oxide or non-oxide material, such as alumina, mullite, aluminosilicate, ytrria alumina garnet, silicon carbide, silicon nitride, silicon carbonitride, and the like. The CMC material 14 may combine a matrix composition with a reinforcing phase of a different composition (such as mullite/silica), or may be of the same composition (alumina/alumina or silicon carbide/silicon carbide). The fibers may be continuous or long discontinuous fibers, and may be oriented in a direction generally parallel, perpendicular, or otherwise disposed relative to the major length of the CMC material 14. The matrix composition may further contain whiskers, platelets, particulates, or fugitives, or the like. The reinforcing fibers may be disposed in the matrix material in layers, with the plies of adjacent layers being directionally oriented to achieve a desired mechanical strength.

The fibers may be provided in various forms, such as a woven fabric, blankets, unidirectional tapes, and mats. In an embodiment, the CMC material 14 is formed from a plurality of plies 22 of the fiber material (as shown in the figures), which are infused with a ceramic material and subjected to a suitable heat treatment, e.g., sintering, process. A variety of techniques are known in the art for making a CMC material and such techniques can be used in forming the CMC material 14 for use herein. In addition, exemplary CMC materials 14 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.

It is appreciated that the selection of materials may not be the only factor which governs the properties of the CMC material 14 as the fiber direction may also influence the mechanical strength of the material, for example. As such, the fibers for the CMC material 14 may have any suitable orientation, such as those described in U.S. Patent No. 7,153,096. In still another embodiment, the body 12 of CMC material 14 may be manufactured by a process as disclosed in PCT/US2016/059029, wherein a ceramic material is injected into a fiber material to form a ceramic fiber composite which is then 3D printed in a desired pattern to form the CMC body 12.

The grooves 24, 25, 26 and corresponding inserts 27, 30, 32 may be of any particular size, shape, and dimension for the intended purpose of the component 10. In an embodiment, the inserts 27, 30, 32 (and thus grooves 24, 25, 26) comprise a polygonal shape in cross-section. In another embodiment, one or both of the inserts 27, 30, 32 (and thus grooves 24, 25, 26) comprise a rounded cross-sectional profile. Further, the inserts 27, 30, 32 may be provided at any suitable angle relative to the top surface 16. The inserts 27, 30, 32 may also be wholly solid or define one or more cavities therein along a length thereof.

In addition, the inserts 27, 30, 32 of glass material 28 may be disposed in any suitable number, pattern, and location on the body 12. In accordance with an aspect, therefore, the selection of the placement strategy for the glass inserts 27, 30, 32, including but not limited to the angle, dimensions, number, and location of the grooves, may vary in accordance with the intended use of the component 10. In an embodiment, the inserts 27, 30, 32 are arranged in random pattern. In other embodiments, the inserts 27, 30, 32 are arranged in a predetermined pattern into the top surface 16 of the CMC body 12. In an embodiment, the predetermined pattern comprises a grid pattern. Due to the fact the grooves and inserts correspond to each other in terms of width, depth, and location, it is appreciated that any description herein which is applicable to a size (width, depth, etc.) and location of the inserts 27, 30, 32 is also applicable to the grooves 24, 25, 26.

When grooves 24, 26 and inserts 30, 32 of differing depths are provided, in an embodiment, the first inserts 30 have a depth of from about 0.5 mm to about 1.0 mm and a width from about 0.3 mm to about 1.0 mm, and in a particular embodiment have a depth of from about 0.6 mm to about 0.8 mm and a width from about 0.5 mm to about 0.7 mm. In addition, the second inserts 32 may have a depth of from about 1.0 mm to about 2.0 mm and a width from about 0.3 mm to about 1.0 mm, and in a particular embodiment have a depth of from about 1.4 mm to about 1.6 mm and a width from about 0.5 mm to about 0.7 mm. The inserts 30, 32 may be of similar dimensions. It is understood, however, that the present invention is not so limited to these values. As used herein, the term “about” refers to a value that it is within ± 1% of the stated value.

When the body 12 of the CMC material 14 comprises a plurality of plies 22, the inserts 27, 30, 32 may extend into extend into the plies 22 to a desired depth. In an embodiment, the inserts 27, 30, 32 may each extend into the plies 22 to a depth which is at a minimum of greater than one ply 22 and to a maximum of ten plies 22 (> 1 to 10 plies). The most common failure of TBC on CMC is delamination of the CMC in the first or second ply. It is thus desirable that the inserts have a depth of at least >1 ply to provide at least a degree of interlaminar strength improvement. In a particular embodiment, the inserts 27, 30, 32 extend to a depth of from 1.5 to 3.5 plies. By providing inserts 27, 30, 32 at these specified depths (> 1 – 10 plies), the interlaminar strengthening effect discussed herein may be achieved while also minimizing any in-plane strength reduction due to cutting the reinforcing fibers of the CMC material 14.

In an embodiment, the inserts 27 each extend to the same depth into the CMC body 12. In accordance with another aspect, first and second inserts are provided (inserts 30, 32) which extend to different depths into the CMC body 12 (within grooves 24, 26). In certain embodiments, the first and second inserts 30, 32 extend into two different plies 22 of the CMC body 12. For example, FIG. 2 illustrated a CMC material 14 having first inserts 30 and second inserts 32 extending down into different plies 22. In further embodiments, the provided inserts may extend into three or more different plies of the body 12. For example, in FIG. 8, there is shown a body 12 of a CMC material 14 having first inserts 30A, 30B and second inserts 32. In this embodiment, the first inserts 30A, 30B comprise inserts having two different depths which extend into different plies of the plurality of plies 22. At least one second insert 32 which extends deeper into the body 12 and plies 22 than the first inserts 30A, 30B. For ease of illustration, there are shown four (4) plies (P1-P4) of the CMC body 12 into which the inserts 30A, 30B, 32 extend. By way of example only, the four plies may have a total depth of 1-2 mm.

In one aspect, a decreasing stress state corresponds with a greater depth of the grooves 24, 25, 26 and inserts 27, 30, 32 into the CMC body 12. However, the inventors have found that not all inserts need extend to the deepest extent to obtain the desired reduced stress effect. Accordingly, when inserts of differing depths are utilized, the number of inserts which extend deeper into the CMC body 12 can be minimized yet still provide the desired reduced stress effect. By way of example, in certain embodiments, the number of second inserts 32 (that extend the furthest into the plies 22) is outnumbered by the number of first inserts 30 which extend into the CMC body to a lesser degree. In this way also, the in-plane strength reduction due to the presence of the grooves 24, 26 and inserts 30, 32 is reduced. In an embodiment, the number of second inserts 32 is minimized such that the first inserts 30 outnumber the second inserts 32 for the component 10. In an embodiment, a ratio of the first inserts 30 to the second inserts 32 is at least 10:1, and in certain embodiments is at least 5:1.

In addition, a length (depth into the CMC body 12) of the first and second inserts 30, 32 may comprise any suitable ratio of depths relative to one another. In an embodiment, the second inserts 32 may be at least 1.5-2x as long (e.g., extend into the through thickness 20 at least 1.5 to 2 times as much) as the first inserts 30. In addition, it is appreciated that the inserts 30, 32 may comprise any desired cross-sectional profile.

In accordance with another aspect, the inserts 27, 30, 32 facilitate the bonding of a TBC 36 to the CMC body 12. Accordingly, a TBC 36 may also be applied to any other embodiment of a component 10 having inserts 27, 30, 32 as described herein. By way of example only, FIG. 3 illustrates an embodiment wherein the component 10 further includes a thermal barrier coating (TBC) 36 over at least a portion of the top surface 16 of the CMC body 12 and over the glass inserts 30, 32 to provide an added degree of thermal protection to the body 12. The TBC 36 may comprise any suitable material which provides an increased temperature resistance to the body 12 when applied to a surface thereof. In an embodiment, the TBC 36 comprises a stabilized zirconia material. For example, the TBC 36 may comprise an yttria-stabilized zirconia (YSZ), which includes zirconium oxide ($ZrO_2$) with a predetermined concentration of yttrium oxide ($Y_2O_3$). In another embodiment, the TBC 36 may comprise a magnesia stabilized zirconia, ceria stabilized zirconia, aluminum silicate, or the like.

In another embodiment, the TBC 36 may comprise a pyrochlore structure. In an embodiment, the pyrochlore structure has the empirical formula $A_2B_2O_7$ or in general terms $A_vB_xO_z$ where v = 2, x = 2 and z = 7. Deviations from this stoichiometric composition for v, x and z may occur as a result of vacancies or minor, deliberate or undeliberate doping. In the formula $A_vB_xO_z$ where v = 2, x = 2 and z = 7, gadolinium (Gd) is typically used for A, and hafnium and/or zirconium (Hf, Zr) are typically used for B. In this case too, minor deviations from this stoichiometry may occur. When Hf and Zr are used as B (e.g., $Gd_v(Hf_xZr_y)O_z$), x + y = 2. In other embodiments, B = Zr or Hf individually, and the pyrochlore structure may comprise one of gadolinium zirconate ($Gd_2Zr_2O_7$) or gadolinium hafnate ($Gd_2Hf_2O_7$). In still other embodiments, the TBC 36 may comprise a bilayer 8YSZ/59 weight percent gadolinium stabilized zirconia (8YSZ/59GZO) coating, a bilayer 8YSZ/30-50 weight percent yttria stabilized zirconia ("30-50 YSZ") coating, or the like.

In yet another embodiment, the TBC 36 may comprise a dimensionally stable, abradable, ceramic insulating material comprising a plurality of hollow ceramic particles dispersed therein. The hollow particles may be of any suitable dimension, and in one embodiment may be from 1-100 micron in diameter. The TBC 36 may be applied by any suitable process, such as a thermal spray process, a slurry-based coating deposition process, or a vapor deposition process as is known in the art. In addition, the TBC 36 may further comprise a degree of porosity suitable for the desired application. Further, the TBC 36 may be of any suitable thickness for its intended use, such as from 0.1 to 2.0 mm.

In another aspect, a bond coat 38 as is known in the art may further be provided to any of the components described herein in order to improve adhesion of the TBC layer 36 to its underlying surface (body 12). FIG. 4 provides an example of a bond coat 38 between the body 12 and the TBC 36. The material for the bond coat 38 may comprise any suitable material. For example, an exemplary bond coat layer may comprise an MCrAlY material, where M denotes nickel, cobalt, iron, or mixtures thereof, Cr denotes chromium, Al denotes aluminum, and Y denotes yttrium. In other embodiments, the bond coat 38 may comprise alumina, yttrium aluminum garnet (YAG), or other suitable ceramic-based material, e.g., a rare earth oxide and/or rare earth garnet material. The bond coat 38 may also be applied by any known process, such as via a thermal spraying or a slurry-based deposition process.

In accordance with an aspect of the present invention, there is disclosed a process for manufacturing a component as described herein. In a first step, a base substrate 40 of the CMC material 14 as described herein is provided without grooves 24, 25, 26 in a desired shape and dimension. The CMC material 14 may be formed by any known process, such as by infiltrating a ceramic material into a plurality of plies 22, which is then sintered to form the CMC base substrate 40 as shown in FIG. 5. Thereafter, the grooves 24, 25, 26 are formed within the CMC substrate 40 in the desired dimensions and depths to define the CMC body 12 having grooves 24, 25, 26 therein (see e.g., grooves 24, 26) as shown in FIG. 6. When the body 12 comprises a plurality of plies 22 and grooves 24, 26 of differing depths, the grooves 24, 26 may extend into different plies 22 as described above. The formation of the grooves 24, 25, 26 may be accomplished by any suitable process, such as by mechanical, laser-based, or water jet cutting methods, or the like.

As mentioned previously, the crystallized glass material 28 may be prepared by any suitable glass formation process known in the art. For example, the glass material 28 may be prepared by mixing glass forming ingredients with one or more additives, such as one or more nucleating agents. Exemplary nucleating agents for use herein include titanium dioxide ($TiO_2$), zirconia, and mixtures thereof.

In an embodiment, the glass forming ingredients are subjected to a first heat treatment protocol at a temperature and duration effective to melt the materials and form a molten glass material 42. Subsequently, the molten glass material 42 is added to the grooves 24, 25, 26 by any suitable deposition process and allowed to cool within the grooves 24, 25, 26 such that the molten glass material 42 at least partially solidifies in the grooves 24, 25, 26. See, for example, material 42 in grooves 24, 26 of FIG. 7. Thereafter, the solidified glass material is crystallized within the grooves 24, 25, 26 by subjecting the solidified glass material to a second heat treatment protocol at a temperature and duration effective to crystallize the solidified glass material within the grooves 24, 25, 26 and form the inserts 27, 30, 32 of crystallized glass material 28 (see e.g., formed inserts 30, 32 in FIG. 3).

Once the inserts 27, 30, 32 of glass are formed, in certain embodiments, a TBC 36 (with or without bond coat 38) may be deposited over a top surface 16 of the CMC body 12 as described herein to provide the final product (component 10). See again FIGS. 3-4 adding a TBC 36 to the component 10. When the bond coat 38 is provided as shown in FIG. 4, the bond coat 38 is first deposited on the top surface 16 of the body 12, followed by deposition of the TBC 36. The TBC 36 and bond coat 38 (if provided) may be applied by any suitable process, e.g., a thermal spray process, a slurry-based coating deposition process, or a vapor deposition process, to provide the component 10. It is appreciated that the above process is merely exemplary and that the skilled artisan may make modifications thereto in order to produce a desired component 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.

CLAIMS

The invention claimed is:

1. A ceramic matrix composite component (10) comprising:

a body (12) comprising a ceramic matrix composite material (14);

a plurality of grooves (24, 25, 26) extending from a top surface (16) of the body (12) and into the body (12); and

an insert (27, 30, 32) of a crystallized glass material (28) disposed within respective ones of the plurality of grooves (24, 25, 26), wherein the inserts (27, 30, 32) of the crystallized glass material (28) are effective to at least increase an interlaminar strength of the ceramic matrix composite material (14).

2. The component (10) of claim 1, wherein the crystallized glass material (28) comprises a ceramic-glass material.

3. The component (10) of claim 2, wherein the ceramic-glass material is selected from the group consisting of $Li_2O \times Al_2O3 \times nSiO2$ system (LAS system); a $MgO \times Al_2O3 \times nSiO_2$ system (MAS system), and an $ZnO \times Al_2O_3 \times nSiO_2$ system (ZAS system),

4. The component (10) of claim 1, wherein the grooves (24, 25, 26) and inserts (27, 30, 32) are disposed in a random orientation on the body (12) of the ceramic matrix composite material (14).

5. The component (10) of claim 1, wherein the ceramic matrix composite material (14) comprises a plurality of plies (22) and a ceramic material infiltrated into the plies (22).

6. The component (10) of claim 5, wherein the inserts (27, 30, 32) of the crystallized glass material (28) extend to a depth greater than a depth of one ply (22) and less than a depth of ten plies (22).

7. The component (10) of claim 6, wherein the inserts (27, 30, 32) of the crystallized glass material (28) extends to a depth of 1.5 plies (22) to 3.5 plies (22).

8. The component (10) of claims 1 to 7, wherein the inserts (25) comprise first inserts (24) and second inserts (26) of the crystallized glass material (28), and wherein the second inserts (26) extend deeper in the ceramic matrix composite material (14) than the first inserts (24).

9. The component (10) of claim 8, wherein the first inserts (30) comprise two or more first inserts (30A, 30B) having different depths, and wherein a depth the two or more inserts (30A, 30B) is less than a depth of the second inserts (32).

10. The component (10) of claim 8, wherein a depth of the first inserts (30) and the second inserts (32) extend to different plies (22) in the body (12) of the ceramic matrix composite material (14).

11. The component (10) of claims 8 to 10, wherein the second inserts (32) are outnumbered by the first inserts (30) on the body (12).

12. The component of claim 11, wherein a ratio of the first inserts (30) to the second inserts (32) is at least 5:1.

13. The component (10) of claims 1 to 12, further comprising a thermal barrier coating (36) on the body (12) of the ceramic matrix composite material (14).

14. The component (10) of claim 13, further comprising a bond coat (38) between the body (12) and the thermal barrier coating (36).

15. A process for making a ceramic matrix composite component (10) comprising:

forming a plurality of grooves (24, 25, 26) within a body (12) of a ceramic matrix composite material (14), the grooves (24, 24, 26) extending from a top surface (16) of the body (12) and into the body (12); and

forming a plurality of inserts (27, 30, 32) of a crystallized glass material (28) within the plurality of grooves (24, 25, 26), wherein the inserts (27, 30, 32) of the crystallized glass material (28) are effective to at least increase an interlaminar strength of the ceramic matrix composite material (14).

16. The process of claim 15, wherein the crystallized glass material (28) comprises a ceramic-glass material.

17. The process of claim 15, wherein the ceramic matrix composite material (14) comprises a plurality of plies (22) and a ceramic material infiltrated into the plies (22).

18. The process of claim 15, wherein the inserts (27, 30, 32) of crystallized glass material (28) comprise first inserts (30) and second inserts (32) of the crystallized glass material (28), and wherein the second inserts (32) extend deeper in the ceramic matrix composite material (28) than the first inserts (30).

19. The process of claim 18, wherein the second inserts (32) are outnumbered by the first inserts (30) on the body (12).

20. The process of claims 15 to 19, further comprising depositing at least a thermal barrier coating (36) over the body (12) of the ceramic matrix composite material (14).

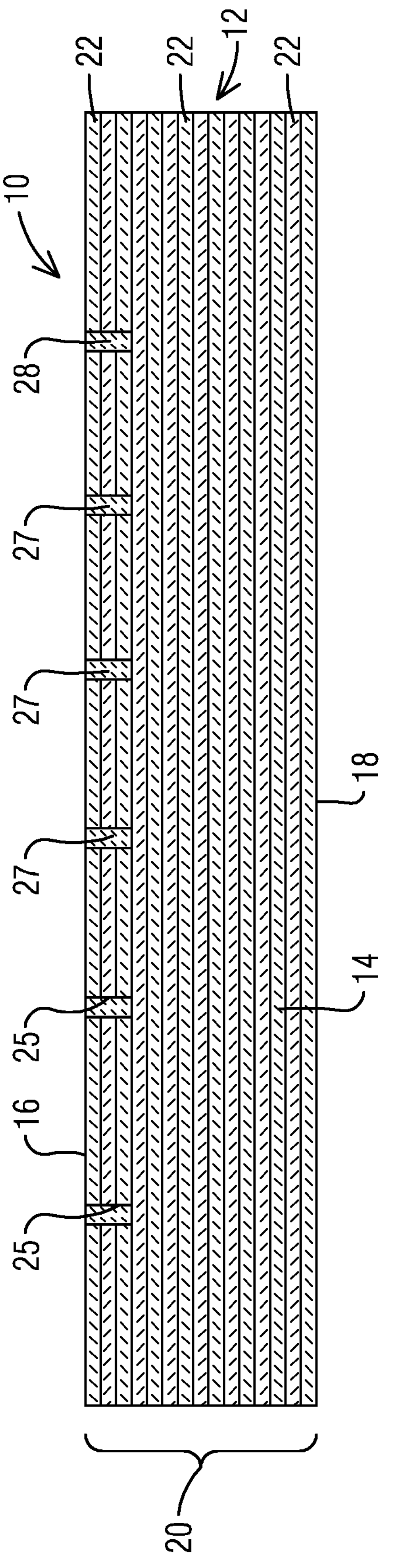
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FIG. 1

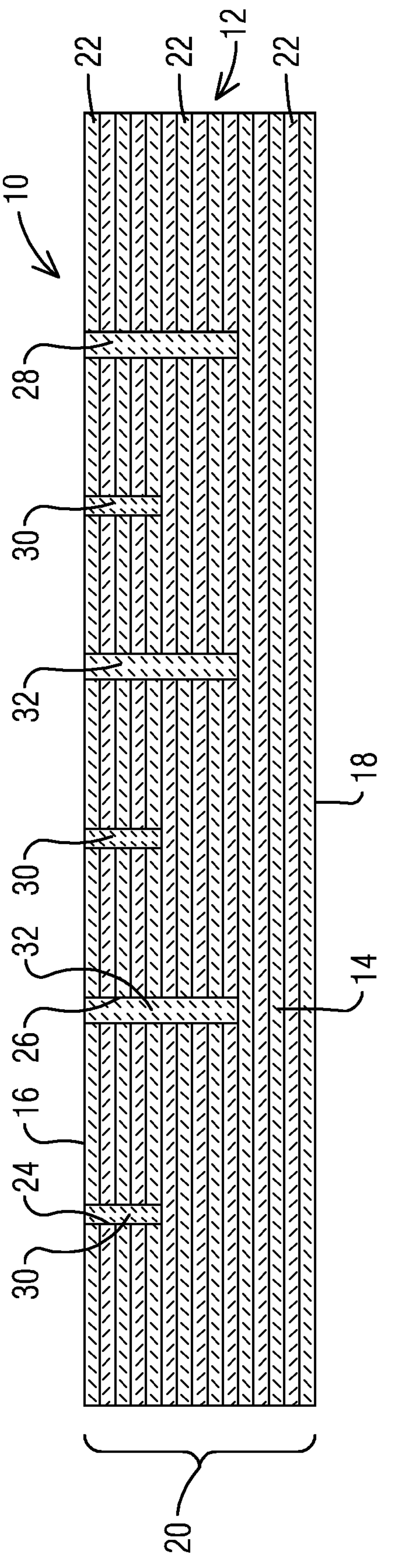
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FIG. 2

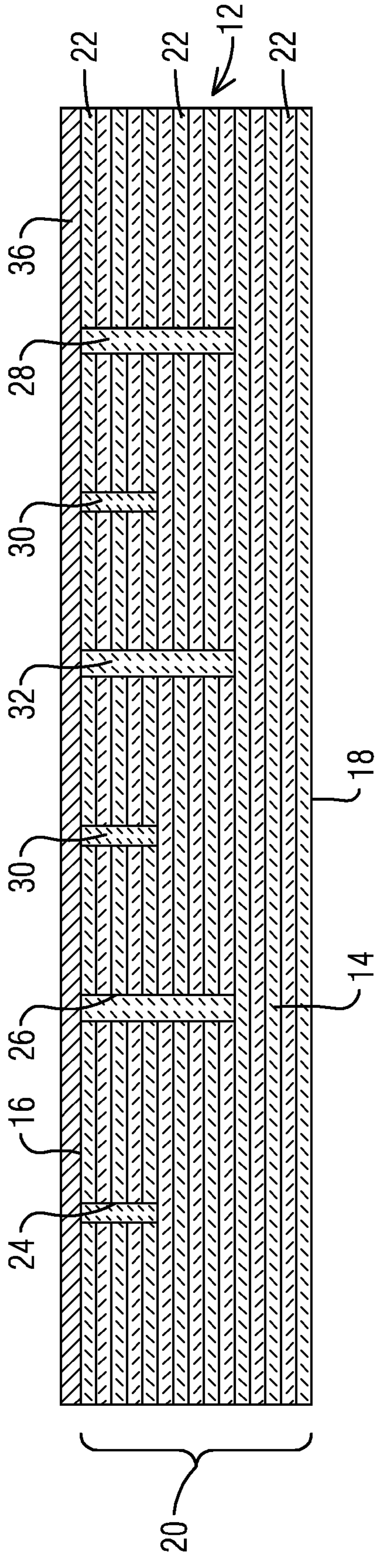
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FIG. 3

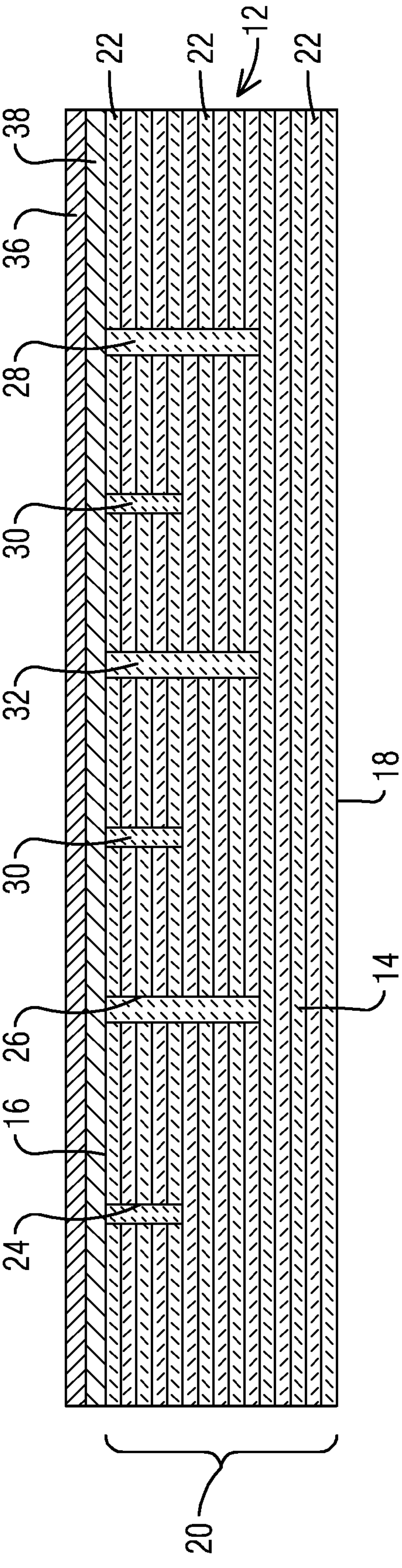
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FIG. 4

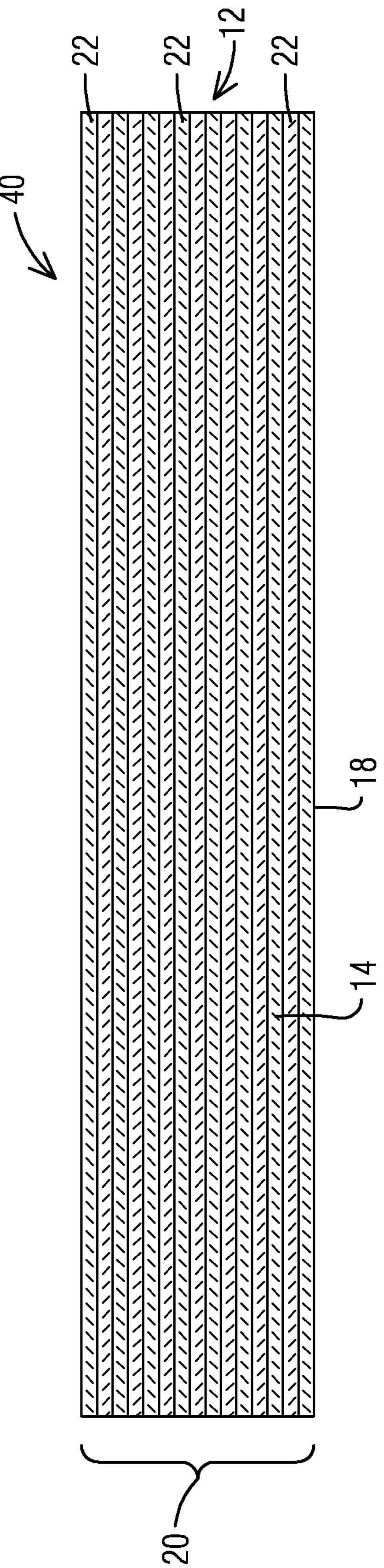


FIG. 5

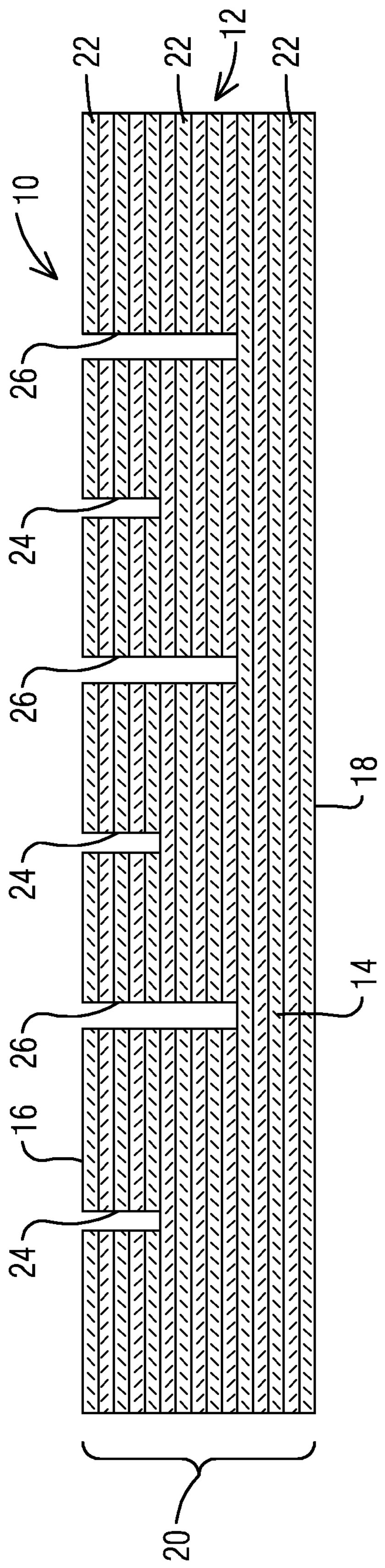


FIG. 6

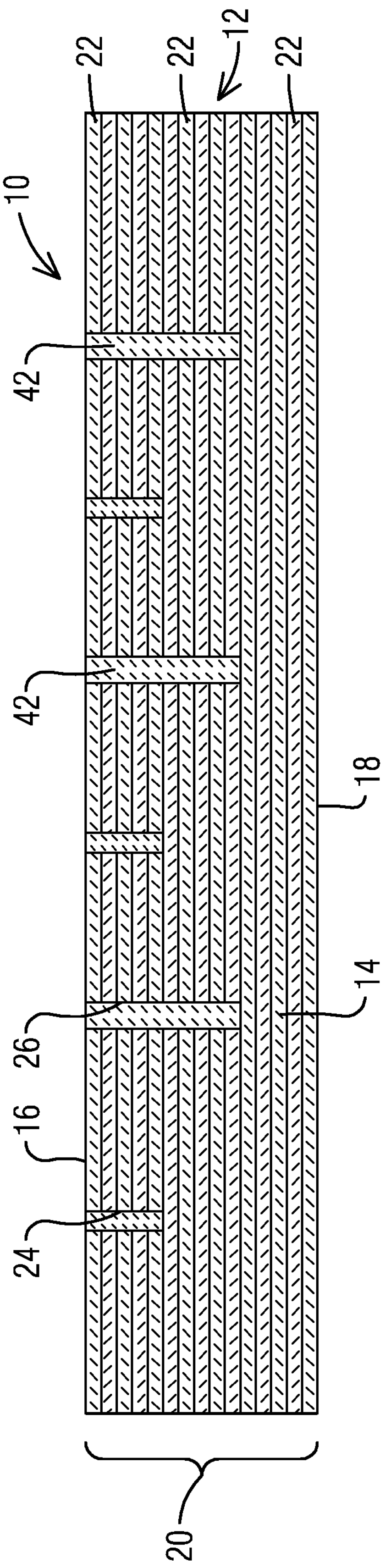


FIG. 7

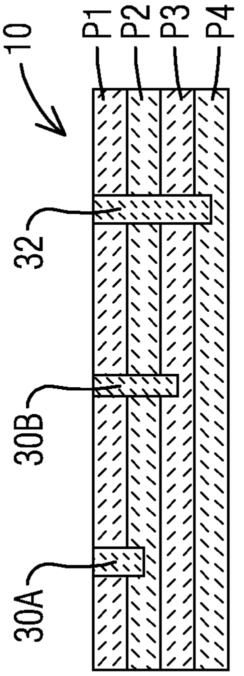


FIG. 8

# INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/064170

**A. CLASSIFICATION OF SUBJECT MATTER**
INV. F01D5/28 C04B35/653 B32B3/30 C04B35/82 F01D5/14
F23R3/00
ADD.

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)
F01D C04B B32B F23R

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

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X<br><br>Y | US 5 928 448 A (DAWS DAVID ERIC [US]) 27 July 1999 (1999-07-27)<br>column 3, lines 30-45; figures 1,2 | 1-5, 15-17<br>6-14, 18-20 |
| Y | WO 2017/146726 A1 (SIEMENS AG [DE]) 31 August 2017 (2017-08-31)<br>the whole document | 6-14, 18-20 |
| Y | US 2002/168505 A1 (MORRISON JAY A [US] ET AL) 14 November 2002 (2002-11-14)<br>paragraphs [0006] - [0008], [0015], [0019], [0020], [0022] - [0024]; figures 1,3 | 6-14, 18-20 |
| A | WO 2011/085376 A1 (ROLLS ROYCE CORP [US]; LEE KANG N [US]) 14 July 2011 (2011-07-14)<br>paragraphs [0052] - [0056], [0095], [0122], [0127]; figures 3,4 | 1-3, 13-16,20 |

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"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

"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

"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

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 29 October 2018 | 06/11/2018 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016 | Chatziapostolou, A |

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**Information on patent family members**

International application No
PCT/US2017/064170

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