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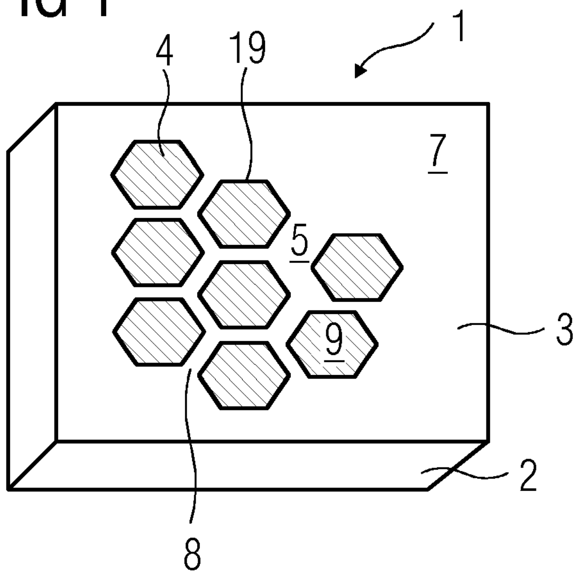
(54) Turbine airfoil and corresponding method of manufacturing

(57) A ridged turbine airfoil (1) for use in turbine engines exposed to high temperatures and a method of manufacturing the ridged turbine airfoil is disclosed. The turbine airfoil (1) comprises an outer wall (2) with an outer surface (3). The outer wall (2) comprises an arrangement (5) of raised ridges (8) having a predefined height (6) located on a region (7) of the outer surface (3) wherein each ridge (8) encloses an area (19) for receiving at least a portion (9) of a TBC layer (4). The TBC layer (4) is to be applied on the outer surface (3). The ridges (8) can be made from a similar material the airfoil (1) is made from to withstand the high temperatures. The area enclosed (19) by the raised ridges (8) enclosing the portion of TBC layer (4) preferably has a hexagonal (20), rectangular (21) or circular (22) shape.

FIG 1



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Description

[0001] The present invention relates to a ridged turbine airfoil and more particularly to a method of manufacturing a turbine airfoil with a ridged surface.

[0002] Turbo machines like gas turbines or steam turbines are required to operate at high temperatures to achieve high efficiency. However the parts of the turbo machines, for example airfoils, limit the operating temperatures of the turbo machine as the parts have to retain their structural integrity even during operation at high temperature levels. Turbine blades and vanes of the first stages receive high thermal loads due to high gas velocities as well as due to high temperature gases impinging on them and the high heat transfer coefficients caused by flow stagnation at the leading edge of the turbine blades. Such high performance extreme conditions can adversely affect the mechanical integrity of the parts.

[0003] To prevent this, the first stages of the turbine blades and vanes are coated with a ceramic thermal barrier coating (TBC) to reduce the heat flux from the hot gas to the blade or vane base material. This leads to lowering of the base metal temperatures of the turbine blades as compared to non-TBC-coated turbine blades. A TBC layer typically consist of four layers: the metal substrate, metallic bond coat, thermally grown oxide, and ceramic topcoat. The TBC layer is affixed to the base metal by a layer of bond coat. This bond coat not only holds the TBC layer to the base metal surface but also provides protection from oxidation of the base metal. The bond coat can be MCrAlY.

[0004] Furthermore to ensure that the integrity of the parts is maintained at such high operating temperatures, film cooling holes, fed by internal channels running inside the turbine blades, exit through the blade at thermally high loaded areas and create a separation of cold air between the hot gas flow and the blade surface.

[0005] However, with the need for increasing gas turbine efficiency, not only the turbine inlet temperatures increase but also the allowed cooling air mass flows decrease. This necessitates thicker TBC coating and less film cooling to ensure that the base metal temperatures are at levels that can still maintain structural integrity of the turbine blades. Yet, a strong and prime reliance on TBC could lead to fatal failure of the turbine blades if, from certain portions of the turbine blade, the TBC is lost and the underlying bond coat or metal surface is exposed. Due to no or little film cooling, temperatures even higher than the base metal melting point can be reached. These temperatures would compromise the mechanical integrity of the part and can lead to fatal part failure within a very short time span.

[0006] US patent number 7404700 discloses an airfoil used in a gas turbine engine exposed to high temperatures. The airfoil has a TBC layer that includes fibres of reinforcing material to add strength to the layer of TBC. The fibres are made from a similar material the airfoil is made from to withstand the high temperatures.

[0007] But the need to ensure that even a damaged part, from where the TBC has eroded, survives until the next inspection interval and does not cause any harm to either the engine or the environment still persists.

[0008] It is an object of the present invention to provide for a turbine airfoil with a surface which will protect the airfoil in case of damage from complete failure so that even a damaged part will survive until the next inspection interval and not cause any harm to the engine or the environment.

[0009] The object is achieved by modifying the base metal surface, especially in regions prone to foreign object damages (FOD), by forming raised ridges on the outer base metal surface in such a way so as to limit a TBC loss due to spallation to predefined limited areas.

[0010] The proposed solution overcomes the issue of complete failure of the part due to TBC loss and ensures that some TBC is retained on the surface so that the partly damaged part can still perform normally at least until the time of the next inspection cycle when the TBC layer can be restored.

[0011] A ridged turbine airfoil for use in turbine engines exposed to high temperatures and a method of manufacturing the ridged turbine airfoil is disclosed. The turbine airfoil comprises an outer wall with an outer surface. The outer wall comprises an arrangement of raised ridges having a predefined height located on a region of the outer surface wherein each raised ridge encloses an area for receiving at least a portion of a TBC layer. The TBC layer is to be applied on the outer surface. A layer of bond coat on the outer surface ensures that the TBC is affixed on the outer surface and held on to the outer surface firmly. In other words, the bond coat acts as a glue and ensures that the TBC layer sticks to the outer surface of the airfoil. The raised ridges can be made from a similar material the airfoil is made from to withstand the high temperatures. The area enclosed by the raised ridges enclosing the portion of TBC layer preferably has a hexagonal, rectangular or circular shape.

[0012] A turbine airfoil as disclosed comprises an outer wall with an outer surface. On the outer surface the outer wall comprises an arrangement of raised ridges having a predefined height. Each raised ridge encloses an area for receiving at least a portion of a TBC layer of a given thickness to be applied on the outer surface. The outer surface of the airfoil is the surface on which hot gas or steam impinges during operation of the turbine. So the outer surface of the airfoil comes in direct contact with the high temperature fluids. For better performance, in an embodiment of this invention the height of the raised ridge is greater than a minimum thickness of the TBC layer needed for operation of the turbine airfoil. This minimum thickness of the TBC layer is sufficient to operate the airfoil of the turbo machine at least up till the time for the next inspection cycle. Each enclosed portion of TBC layer would appear as a depression with the raised ridge forming its circumference. The raised ridges will encircle the portion of TBC layer and prevent it from spalling off and will act as rip-stoppers in the TBC layer holding the TBC layer together. However, the raised ridges would eventually have a coating of TBC layer so that no ridges are left exposed to the impact of hot gases. This would ensure that no heat transfer takes place through the raised ridges to the base metal.

[0013] In another embodiment of the turbine airfoil, the raised ridges are located on a region of the outer surface, the region being located at a suction side portion of a leading edge of the turbine airfoil, i.e. the region extends from a leading edge zone into a suction side zone of the airfoil. The suction side portion of the leading edge of the turbine airfoil faces high thermal loads during operation of the turbo machine, moreover, the suction side portion of the leading edge is more prone to TBC loss related to foreign object damage, hence the ridged airfoil surface on this region will provide for a longer protection and ensure that the damaged parts can operate until the next inspection cycle without leading to any further damage.

[0014] In a further embodiment, the outer wall comprises a base metal. The base metal is a part of a body of the airfoil and the outer wall is integrated with the airfoil body forming one continuous mass. This will provide a robust outer surface to the airfoil.

[0015] In yet another embodiment, the arrangement of raised ridges is formed out of the base metal. So the raised ridges extend out of the outer wall as protruding base metal structures. As the base metal has a high capacity to withstand high temperatures, the raised ridges made from base metal will also be able to withstand high temperatures.

[0016] Eventually the TBC layer will always completely cover any base metal raised ridges. One way of applying the TBC is the Air Plasma Spray (APS) process. In this process the TBC is applied in layers of a few μm at a time.

[0017] In ordinary airfoil surfaces, the TBC layer is generally in the form of a continuous coating having lesser resistance to FOD and thus is more prone to spallation. In the event of damage due to FOD, large chunks of TBC may fall off from an ordinary airfoil surface leaving the base metal directly exposed to the hot fluids. However, in a ridged airfoil surface, as disclosed in this invention, the structure of raised ridges will encircle an area containing a portion of the TBC layer. This structure will be holding the encircled portion of TBC in its place. According to the present invention, the TBC layer is divided into smaller portions and is held together by the arrangement of the raised ridges, instead of being a single continuous damage-prone layer, as in ordinary airfoil surfaces. The raised ridges provide the necessary support to the TBC layer to remain in its place and prevent foreign objects from chipping off large chunks of TBC. Thus, this arrangement of raised ridges helps in protecting the TBC from spalling off due to FOD. These raised ridges will retain at least some portions of the TBC layer thereby giving the minimum necessary protection to the airfoils until the next inspection interval.

[0018] In a further embodiment the TBC layer is a multi-layer TBC comprising at least an inner TBC layer applied on the outer surface and an outer TBC layer applied on the inner TBC layer. The layering of the multi-layer TBC is such that the inner TBC layer is located between the outer surface and the outer TBC layer. The outermost TBC layer can coat the entire outer surface, even covering the raised ridges. The composition of each TBC layer in a multi-layer TBC differs from the other layer. This is achieved during the APS process by changing the composition of the TBC being sprayed after spraying for a few μm, as per requirement. Multi-layer coatings increase performance as the combination exhibits the best qualities of each coating. Therefore, multi-layer TBC offers superior protection to the turbine airfoil as each layer of the TBC will have its own properties which will help in providing a better and more effective protection to the turbine airfoil against the harmful effects of hot gases or steam.

[0019] In another embodiment the height of the raised ridge is greater than a thickness of the inner TBC layer. This will ensure that the raised ridge will contain at least the inner TBC layer and prevent fatal part failure due to loss of outer TBC layer.

[0020] In another embodiment where the TBC layer is a multi-layer TBC, the height of the raised ridges is lower than the given thickness of the multi-layer TBC layer. In other words, the thickness of all the TBC layers together is greater than the height of the raised ridges.

[0021] In yet another embodiment the portion of the TBC layer enclosed by the raised ridge has a maximum diameter of 10 mm. The smaller diameter of the enclosed TBC layer portion reduces the occurrence of spallation or damage to the TBC layer as the raised ridges can more effectively contain and protect a smaller portion of the TBC layer as compared to a larger portion.

[0022] In an embodiment of the invention, the arrangement of the raised ridges is such that the region enclosed by at least one of the raised ridges has a hexagonal, rectangular or circular shape. These shapes will provide a better grip containing the TBC layer within its circumference in comparison to other irregular shapes.

[0023] In yet another embodiment the turbine airfoil further comprises the TBC layer of the given thickness applied on the outer surface of the outer wall, wherein the portion of the TBC layer is located in at least one of the areas enclosed by the raised ridges.

[0024] The ridged surface of the airfoil may look like a golf ball with an arrangement of depressions and protrusions.

[0025] In an embodiment of the method of manufacturing a turbine airfoil, the method comprises a step of forming an outer wall of the turbine airfoil, wherein the outer wall has an outer surface, a step of forming an arrangement of raised ridges on a region of the outer surface such that each raised ridge encloses a an area for receiving at least a portion of a TBC layer, and finally a step of applying the TBC layer of a given thickness on the outer surface.

[0026] In another embodiment the outer wall comprises a base metal and the arrangement of raised ridges is formed out of the base metal.

[0027] In a further embodiment of the method the outer wall and the arrangement of raised ridges are made of one piece of material, wherein the step of forming the outer wall and the step of forming the arrangement of raised ridges are executed at the same time.

[0028] In a further embodiment of the method the TBC layer is affixed to the outer surface by a layer of bond coat.

[0029] The TBCs used in turbines are selected based on the TBC properties, the applications of the turbine, the type of the turbine, the operating conditions etc. Therefore, depending on this, a skilled person would know the properties of a suitable TBC based on the requirement for a particular turbine, including the thickness of the TBC to be applied and the structure of the TBC, for example a single layer TBC or a multi-layer TBC, and the corresponding thickness of each of the layers. Hence, it should be noted that as soon as the turbine's type and/or purpose are known, the given thickness of the TBC becomes well known to the skilled person. It must also be considered as well known in the art that bond coats are generally used to affix TBC layers on to base metal surfaces. The bond coat holds the TBC layer onto the base metal and ensures a better grip of the TBC layer on to the surface of the base metal.

[0030] A turbine airfoil according to the invention and protected against hot gases in the environment of the airfoil during operation of the turbo machine comprises an outer wall with an outer surface and a TBC layer applied on the outer surface, wherein the outer wall comprises an arrangement of raised ridges having a predefined height and being located on a region of the outer surface, wherein each raised ridge encloses an area for receiving at least a portion of the TBC layer of a given thickness on the outer surface.

[0031] Additionally, that turbine airfoil with the TBC layer can comprise some or all the features which have been mentioned above for the different embodiments of the turbine airfoil according to the invention.

[0032] The above-mentioned and other features of the invention will now be addressed with reference to the accompanying drawings of the present invention. The illustrated embodiments are intended to illustrate, but not limit the invention. The drawings contain the following figures, in which like numbers refer to like parts, throughout the description and drawings.

FIG. 1 is a schematic diagram of a part of an exemplary ridged turbine airfoil.

FIG. 2 is a schematic diagram of a cross-section of the part of the ridged turbine airfoil.

FIG. 3 is a schematic diagram of a cross-section of a part of the ridged turbine airfoil having multi-layer TBC.

FIG. 4 is a schematic diagram of the same cross-section of the part of the ridged turbine airfoil having multi-layer TBC which has been damaged due to FOD.

FIG. 5, FIG.6 and FIG.7 are schematic diagrams depicting the various possible shapes of the area enclosed by the raised ridges.

FIG. 8 is a schematic diagram of the cross section of a turbine airfoil highlighting the area prone to TBC loss caused by foreign object damage.

FIG. 9 is a flowchart depicting the method of manufacturing a ridged turbine airfoil.

[0033] Various embodiments are described with reference to the drawings, wherein like reference numerals are used to refer to like elements throughout. In the following description, for purpose of explanation, numerous specific details are set forth in order to provide a thorough understanding of one or more embodiments. It may be evident that such embodiments may be practiced without these specific details.

[0034] Embodiments of the present invention described below relate to an airfoil of a turbo machine. The turbo machine may include a gas turbine, a steam turbine, a turbofan and the like.

[0035] FIG. 1 is a schematic diagram of a part of an exemplary ridged turbine airfoil. The turbine airfoil 1 broadly comprises an outer wall 2 with an outer surface 3. The outer wall 2 comprises an arrangement 5 of raised ridges 8 located on a region 7 of the outer surface 3 wherein each raised ridge 8 encloses an area 19 such that a plurality of areas 19 is formed. In FIG. 1, only one of the areas 19 has been marked with a reference sign. As will be shown in FIGs.5, 6 and 7, the areas 19 preferably have a hexagonal 20, rectangular 21, or circular 22 shape. However, other shapes and arrangements of the raised ridges 8 leading to different shapes of the areas 19 would also be possible.

[0036] Moreover, the turbine airfoil 1 comprises a TBC layer 4 applied on the outer surface 3 of the outer wall 2. The TBC layer 4 comprises a plurality of portions 9, wherein each raised ridge 8 encloses a portion 9 of the TBC layer 4 on the outer surface 3. Thus, the portions 9 of the TBC layer 4 are located in the areas 19. Again, only one of the regions 9 has been marked with a reference sign.

[0037] Referring now to FIG. 2, a schematic diagram of a cross-section of the part of the ridged turbine airfoil 1 is disclosed. In accordance with the aspects of the present invention, each raised ridge 8 has a predefined height 6 which is less than a given thickness 10 of the TBC layer 4, i.e. the thickness of the portion 9 of the TBC layer 4 enclosed by the raised ridge 8. Fig. 2 also shows a cross section of the arrangement 5 of raised ridges 8 having the TBC layer 4 in between adjacent raised ridges

8. The arrangement 5 of raised ridges 8 is on the outer surface 3 of the outer wall 2 of the airfoil 1. For example, the diameter of the areas 19 and, correspondingly, the width of each portion 9 of TBC layer 4 enclosed by the raised ridges 8 is having a maximum diameter 18 of 10 mm. The thickness 10 of the TBC layer 4, for example, is 0.4 mm and the height 6 of the raised ridge 8, for example, is 0.3 mm. The figure also shows a layer of bond coat 26 present between the outer surface 3 of the base metal 14 and the TBC layer 4. This bond coat 26 helps to attach the TBC layer 4 on to the outer surface 3 of the base metal 14, as is well known to the skilled person in this field.

[0038] As seen in FIG. 2, the raised ridges 8 are integrated with the outer wall 2 at the outer surface 3 forming a single unit. In other words, the outer wall 2 with the raised ridges 8 is not formed by attaching the raised ridges 8 to the wall 2 or by assembling an outer wall component and a separate raised ridge component, but the whole component is formed out of one piece or, for example, molded together. Preferably, both the outer wall 2 and the raised ridges 8 comprise a base metal 14. In one embodiment, both the outer wall 2 and the raised ridges 8 consist of that base metal 14.

[0039] FIG. 3 shows a schematic diagram of a cross-section of the part of the ridged turbine airfoil 1 having the arrangement 5 of raised ridges 8. In this preferred embodiment, the TBC layer 4 is a multi-layer TBC 4 comprising an inner TBC layer 15 and an outer TBC layer 16. The inner TBC layer 15 is arranged between the outer TBC layer 16 and the outer surface 3 of the outer wall 2. Optionally, the multi-layer TBC 4 may comprise one or more further TBC layers between the inner and the outer TBC layers 15, 16 (not shown). The multi-layer TBC 4 is in direct contact with the outer surface 3 via the inner TBC layer 15. The outer TBC layer 16 is then coated over the inner TBC layer 15. As can be understood from FIG. 1 in combination with FIG. 4, the inner TBC layer 15 consists of a plurality of segments which are not directly connected with each other, but separated by the raised ridges 8. The ridge height 6 is greater than a thickness 17 of the inner TBC layer 15. The thickness of the outer TBC layer 16 may be lesser than, equal to or greater than the ridge height above the inner 15 TBC layer. It might be mentioned, that the thickness of the whole multi-layer TBC 4 is preferably greater than the ridge height 6. The inner TBC layer 15 is affixed onto the outer surface 3 by a layer of bond coat 26.

[0040] FIG. 4 shows the same cross-section of the part of the ridged turbine airfoil 1, wherein a portion of the outer TBC layer 16 is lost due to damage like FOD. However, the raised ridges 8 have prevented the inner TBC layer 15 from spalling off by acting as a stopper holding the inner TBC layer 15 in its place thereby guarding the inner TBC layer 15 and retaining it in the area 19. Therefore, the inner TBC layer 15 is held in place due to the presence of the raised ridges 8 around the portion 9 of the TBC layer holding the inner TBC layer in the area 19 by acting as rip-stoppers.

[0041] FIG. 5, FIG. 6 and FIG. 7 show schematic diagrams depicting various possible shapes of the area 19 enclosed by the raised ridges 8. The arrangement 5 of raised ridges 8 can enclose an area 19 having any one of the shapes like hexagonal 20, rectangular 21 or circular 22. Any irregular but enclosed shape can also be possible but the most effective performance can be achieved by hexagonal, rectangular or circular shape. Thus, the portion 9 of the TBC layer 4 as shown in FIG. 1 and the inner TBC layer 15 as shown in FIG. 4, respectively, which is arranged in the area 19, would have the same hexagonal 20, rectangular 21 or circular 22 shape as the area 19.

[0042] FIG. 8 shows a schematic diagram of the cross section of a turbine airfoil 1 highlighting the area 27 prone to TBC loss caused by foreign object damage (FOD). FIG. 8 depicts a leading edge 13 of the airfoil 1, a trailing edge 24, a pressure side 25 and a suction side 12. The region 7 of the outer surface 3 comprising the arrangement 5 of raised ridges 8 is preferably located on the area 27 prone to FOD which is the suction side 12 portion of a leading edge 13 of the turbine airfoil 1. The ridged airfoil surface can even extend to the whole of the suction side 12 of the turbine airfoil 1.

[0043] Referring now to FIG. 9, a flowchart depicting a method 100 of manufacturing a ridged turbine airfoil 1 is shown. The method 100 of manufacturing the turbine airfoil 1 comprises a step 101 of forming an outer wall 2 of the turbine airfoil 1, wherein the outer wall 2 has an outer surface 3, a step 102 of forming an arrangement 5 of raised ridges 8 on a region 7 of the outer surface 3 such that each raised ridge 8 encloses a portion 9 of the TBC layer 4 on the outer surface 3, and finally a step 103 of applying a TBC layer 4 of a given thickness 10 on the outer surface 3, wherein the TBC layer 4 is affixed to the outer surface 3 by a layer of bond coat 26.

[0044] Although the invention has been described with reference to specific embodiments, this description is not meant to be construed in a limiting sense. Various modifications of the disclosed embodiments, as well as alternate embodiments of the invention, will become apparent to persons skilled in the art upon reference to the description of the invention. It is therefore contemplated that such modifications can be made without departing from the embodiments of the present invention as defined.

Claims

1. A turbine airfoil (1) comprising an outer wall (2) with an outer surface (3), wherein the outer wall (2) comprises on the outer surface (3) an arrangement (5) of raised ridges (8) having a predefined height (6), wherein each raised ridge (8) encloses an area (19) for receiving at least a portion (9) of a TBC layer (4) of a given thickness (10) to be applied on the outer surface (3).

2. The turbine airfoil (1) according to claim 1, wherein the height (6) of the raised ridges (8) is greater than a minimum thickness (10) of the TBC layer (4) needed for operation of the turbine airfoil (1).

3. The turbine airfoil (1) according to any one of the preceding claims, wherein the raised ridges (8) are located on a region (7) of the outer surface (3), the region (7) being located at a suction side (12) portion of a leading edge (13) of the turbine airfoil (1).

4. The turbine airfoil (1) according to any one of the preceding claims, wherein the outer wall (2) comprises a base metal (14).

5. The turbine airfoil (1) according to any one of the preceding claims, wherein the arrangement (5) of raised ridges (8) is formed out of the base metal (14).

6. The turbine airfoil (1) according to any one of the preceding claims, wherein the TBC layer (4) is a multi-layer TBC comprising at least an inner TBC layer (15) to be applied on the outer surface (3) and an outer TBC layer (16) to be applied on the inner TBC layer (15).

7. The turbine airfoil (1) according to claim 7, wherein the height (6) of the raised ridges (8) is greater than a thickness (17) of the inner TBC layer (15).

8. The turbine airfoil (1) according to claim 7 or 8, wherein the height (6) of the raised ridges (8) is less than the given thickness (10) of the TBC layer (4).

9. The turbine airfoil (1) according to any one of the preceding claims, wherein the area (19) enclosed by the raised ridges (8) has a maximum diameter (18) of 10 mm.

10. The turbine airfoil (1) according to any one of the preceding claims, wherein the arrangement (8) of the raised ridges (5) is such that the area (19) enclosed by at least one of the raised ridges (8) has a hexagonal (20), rectangular (21) or circular (22) shape.

11. A turbine airfoil (1) according to any one of the preceding claims, further comprising the TBC layer (4) of the given thickness (10) applied on the outer surface (3) of the outer wall (2), wherein the portion (9) of the TBC layer (4) is located in at least one of the areas (19) enclosed by the raised ridges (8).

12. A method (100) of manufacturing a turbine airfoil (1), the method (100) comprising:

- a step (101) of forming an outer wall (2) of the turbine airfoil (1), wherein the outer wall (2) has an outer surface (3),
- a step (102) of forming an arrangement (5) of raised ridges (8) on a region (7) of the outer surface (3) such that each raised ridge (8) encloses an area (19) for receiving at least a portion (9) of a TBC layer (4),
- a step (103) of applying the TBC layer (4) of a given thickness (10) on the outer surface (3).

13. The method (100) according to claim 13, wherein the outer wall (2) comprises a base metal (14) and the arrangement (5) of raised ridges (8) is formed out of the base metal (14).

14. The method (100) according to claim 13 or 14, wherein the outer wall (2) and the arrangement (5) of raised ridges (8) are made of one piece of material, wherein the step (101) of forming the outer wall (2) and the step (102) of forming the arrangement (5) of raised ridges (8) are executed simultaneously.

15. The method (100) according to claim 13, wherein the TBC layer (4) is affixed to the outer surface (3) by a layer of bond coat (26).

FIG 1

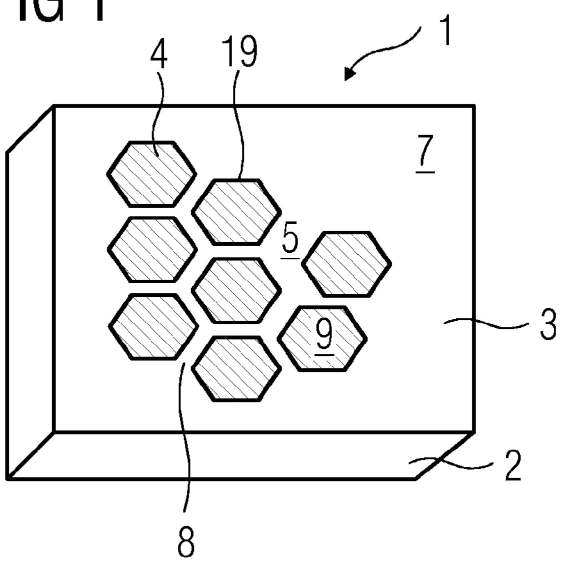


FIG 2

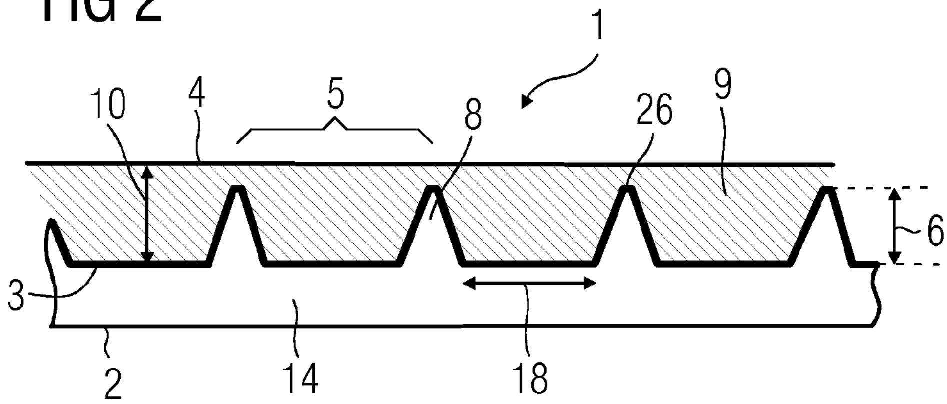


FIG 3

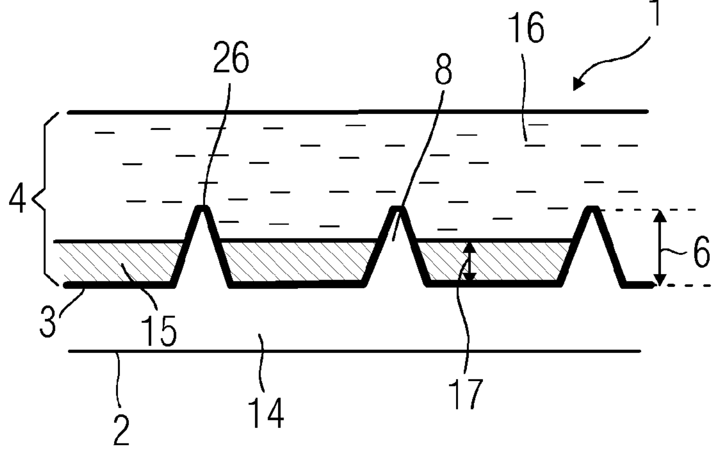


FIG 4

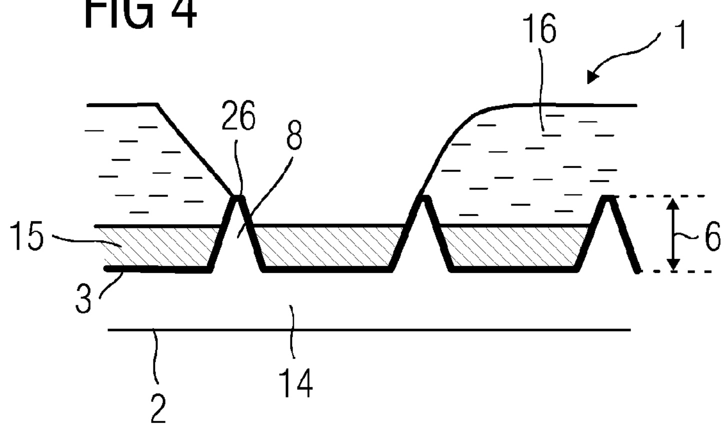


FIG 5

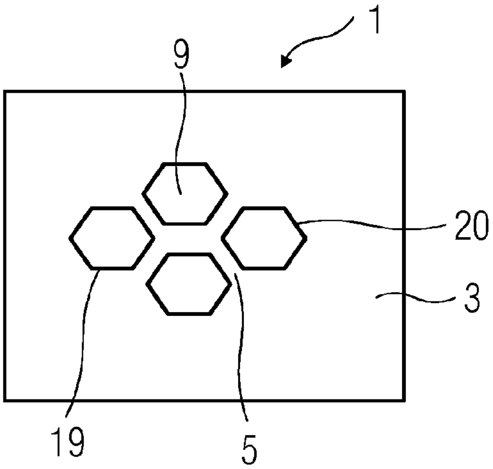


FIG 6

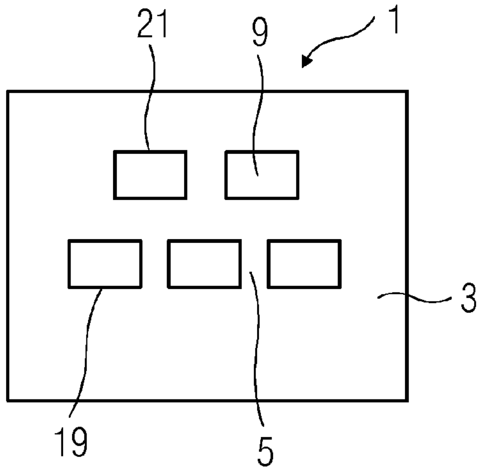


FIG 7

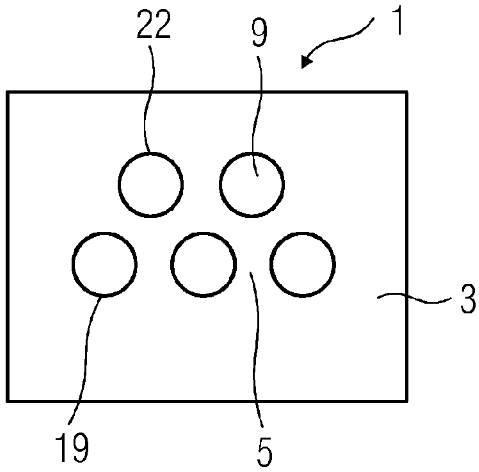


FIG 8

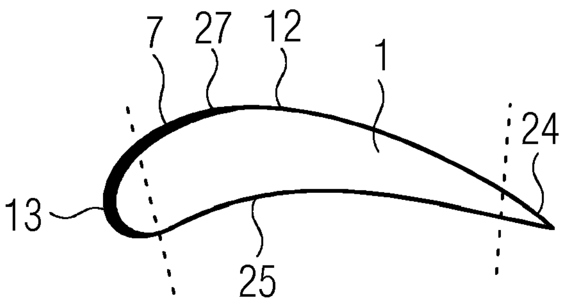
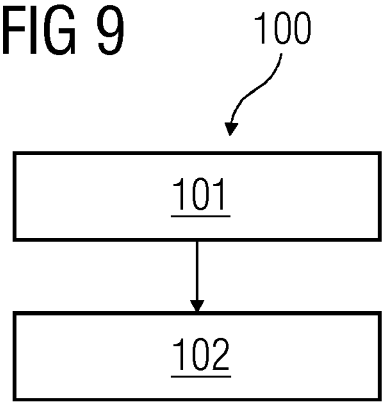


FIG 9



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EUROPEAN SEARCH REPORT

Application Number
EP 13 18 6885

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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Place of search	Date of completion of the search	Examiner
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EUROPEAN SEARCH REPORT

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