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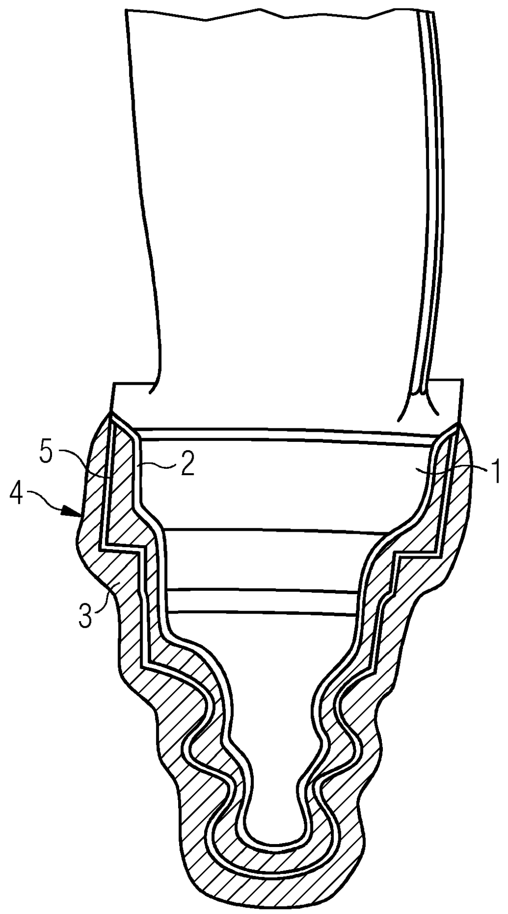
(54) DUAL ALLOY TURBINE BLADE MANUFACTURED BY METAL SPRAY ADDITIVE MANUFACTURING

(57) There is provided a method of manufacturing a turbine blade comprising an aerofoil portion and a root portion, the method comprising the steps of:
(a) providing a cast component of a first alloy composition comprising a cast aerofoil portion and a cast root portion;
(b) applying a second alloy composition to the surface of the cast root portion to provide an oversized root portion; and
(c) shaping the oversized root portion.



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Description

FIELD OF INVENTION

[0001] The present invention relates to turbine blades and methods of manufacturing the same.

BACKGROUND OF INVENTION

[0002] In particular the present invention relates to dual alloy turbine blades and processes for making these. The present invention relates especially to the production of turbine blades having a high creep strength aerofoil section and a corrosion-resistant root section.

[0003] Turbines are useful for the extraction of electric power from the combustion of fuel, including gas and liquid fuels. Gas turbines are also useful for providing mechanical drive in the pumping of gas and oils. However, the operation of gas turbines exposes the turbine blades in the hot section of the gas turbine to mechanical stress and corrosive conditions.

[0004] Currently an investment casting process is used for manufacturing hot section turbine blades. However this process is limited to the production of components in single alloys. Typically low chromium alloys based on nickel are chosen for their high creep strength. However, problems can occur with these alloys under conditions of use such as type II hot corrosion, corrosion fatigue and stress corrosion cracking.

[0005] The present invention may be used with land based gas turbines as well as with aero engines.

[0006] Until now, potential problems associated with the use of low chromium alloys have been addressed by the application of protective coatings. However, the coatings are unreliable in many cases. They are also expensive and difficult to apply consistently. Coatings are typically applied by thermal spray processes. However they cannot be applied to the root fixings of the turbine blades due to the need for close dimensional tolerance control and material property requirements. This means that the root forms remain exposed to the corrosive atmosphere and there is thus the potential for cracking.

[0007] It is an aim of the present invention to provide an improved method of manufacturing turbine blades which offers one or more advantages over the prior art.

SUMMARY OF INVENTION

[0008] According to a first aspect of the present invention there is provided a method of manufacturing a turbine blade comprising an aerofoil portion and a root portion, the method comprising the steps of:

(a) providing a cast component of a first alloy composition comprising a cast aerofoil portion and a cast root portion;
(b) applying a second alloy composition to the surface of the cast root portion to provide an oversized root portion; and
(c) shaping the oversized root portion.

[0009] According to a second aspect of the present invention there is provided a turbine blade comprising a cast component of a first alloy composition comprising an aerofoil portion and a root portion, wherein the surface of the root portion is covered with a second alloy composition.

[0010] According to a third aspect of the present invention there is provided a gas turbine comprising at least one turbine blade according to the second aspect of the present invention.

[0011] Preferred features of the first, second, and third aspects will now be described.

[0012] In the method of the first aspect of the present invention, step (a) involves providing a cast component of a first alloy composition. The cast component may be produced using any suitable casting process. Such processes will be known to the person skilled in the art. Preferably the cast component is produced using normal investment casting techniques.

[0013] The dimensions of the casting used in step (a) may be selected to ensure the root portion can accommodate a coating.

[0014] Step (a) may optionally involve shaping the cast root portion to generate a cast root portion of suitable dimensions. Suitably the shaping comprises machining the cast root portion.

[0015] The first alloy composition may comprise any suitable turbine blade alloy. By "turbine blade alloy" we mean to refer to an alloy having chemical and physical properties rendering it suitable for use as a turbine blade. Turbine blade alloys will be known to the person skilled in the art.

[0016] In some embodiments the first alloy composition may be provided as an equiaxed, directionally solidified, or single crystal alloy.

[0017] The first alloy composition is preferably a nickel based low chromium alloy. Suitable low chromium alloys comprise a majority of nickel and have a chromium content of less than 12 wt%.

[0018] Typically the nickel based low chromium alloy has a chromium content of up to 10 wt%, preferably up to 9.5 wt%, more preferably up to 9 wt%.

[0019] Suitably the nickel based low chromium alloy has a chromium content of at least 1 wt%, suitably at least 2 wt%, preferably at least 3 wt%, more preferably at least 4 wt%, for example at least 5 wt%.

[0020] The nickel based low chromium alloy may optionally comprise one or more additional strengthening elements. Suitable additional strengthening elements include aluminium, titanium, tantalum, tungsten, rhenium, molybdenum and cobalt.

[0021] Aluminium, when present, is suitably included in the nickel based low chromium alloy in an amount of from 3 to 7 wt%, preferably 5 to 6 wt%.

[0022] Titanium, when present, is suitably included in the nickel based low chromium alloy in an amount of from 0 to 4 wt%, preferably 0.5 to 1.5 wt%.

[0023] Tantalum, when present, is suitably included in the nickel based low chromium alloy in an amount of from 1.5 to 12 wt%, preferably 1.5 to 7 wt%.

[0024] Tungsten, when present, is suitably included in the nickel based low chromium alloy in an amount of from 4 to 12.5 wt%, preferably 4 to 9 wt%.

[0025] Rhenium, when present, is suitably included in the nickel based low chromium alloy in an amount of from 3 to 7 wt%, preferably 3 to 6 wt%.

[0026] In some preferred embodiments rhenium is absent.

[0027] Molybdenum, when present, is suitably included in the nickel based low chromium alloy in an amount of from 0.05 to 6 wt%, preferably 0.2 to 2 wt%.

[0028] Cobalt, when present, is suitably included in the nickel based low chromium alloy in an amount of from 5 to 12 wt%, preferably 6 to 11 wt%.

[0029] In some preferred embodiments the low chromium alloy is a nickel based alloy having a chromium content of 5 to 10 wt%, an aluminium content of 3 to 7 wt%, a titanium content of 0 to 4 wt%, a tantalum content of 3 to 7 wt%, a tungsten content of 4 to 10 wt%, a rhenium content of 0 to 4 wt%, a molybdenum content of up to 6 wt%, and a cobalt content of 6 to 12 wt%.

[0030] Equiaxed and directionally solidified low chromium alloys may suitably comprise up to 0.2 wt% carbon and up to 0.03 wt% boron to facilitate carbide and/or boride strengthening phases in said alloys. However, for single crystal low chromium alloys, the tight control of these two elements (i.e., 0.01 wt% maximum may be) necessary to prevent such phases forming.

[0031] Non-limiting examples of a low chromium equiaxed grain alloy include those sold under trade names MarM247 and CM247. A non-limiting example of a low chromium directionally solidified alloy is CM247DS. Non-limiting examples of a low chromium single crystal alloy include those sold under trade names CMSX4 and CMSX8. These materials are available from Cannon Muskegon Corp.

[0032] Step (b) of the method of the present invention involves applying a second alloy composition to the surface of the cast root portion provided in step (a) to provide an oversized root portion. Suitably the second alloy composition is applied to at least a portion of the surface of the cast root portion. Preferably the second alloy composition is applied to the majority of the surface of the cast root portion. More preferably the second alloy composition is applied to substantially all of the surface of the cast root portion such that entire surface of the cast root portion is covered by the second alloy composition.

[0033] The second alloy composition may be applied to the cast root portion using any suitable means. Such means will be known to the person skilled in the art. Preferably the second alloy composition is applied to the cast root portion using a metal spray process. Suitable metal spray processes include High Velocity Oxy-Fuel (HVOF), Low Pressure Plasma Spraying (LPPS), and Cold Spray. Other such processions will be known to the skilled person.

[0034] The second alloy composition may comprise any alloy having chemical or physical properties rendering it suitable for use as the surface of the root portion of a turbine blade. These chemical and physical properties include having relatively high fatigue strength and being resistant to the corrosive atmosphere of a gas turbine during operation.

[0035] The second alloy composition is preferably a nickel based high chromium alloy. Suitable high chromium alloys comprise a majority of nickel and have a chromium content of more than 12 wt%.

[0036] Typically the nickel based high chromium alloy has a chromium content of at least 13 wt%, for example at least 14 wt%. In some embodiments the nickel based high chromium alloy may have a chromium content of more than 16 wt%, for example more than 18 wt% or more than 20 wt%.

[0037] Suitably the nickel based high chromium alloy has a chromium content of up to 30 wt%, suitably up to 26 wt%, preferably up to 24 wt%.

[0038] The nickel based high chromium alloy may optionally comprise one or more additional elements. Suitable additional elements include cobalt, aluminium, titanium, tantalum, tungsten, molybdenum and niobium.

[0039] Cobalt, when present, is suitably included in the nickel based high chromium alloy in an amount of from 5 to

20 wt%. In such embodiments cobalt is present in an amount of from 7 to 10 wt%. In some embodiments cobalt is present in an amount of from 18 to 20 wt%.

[0040] Aluminium, when present, is suitably included in the nickel based high chromium alloy in an amount of from 1 to 6 wt%, preferably 1 to 4 wt%.

[0041] Titanium, when present, is suitably included in the nickel based high chromium alloy in an amount of from 0.1 to 5 wt%, preferably 3 to 4 wt%.

[0042] Tantalum, when present, is suitably included in the nickel based high chromium alloy in an amount of from 0.5 to 4 wt%, preferably 1 to 2.5 wt%.

[0043] Tungsten, when present, is suitably included in the nickel based high chromium alloy in an amount of from 1 to 7 wt%, preferably 1 to 4 wt%.

[0044] Molybdenum, when present, is suitably included in the nickel based high chromium alloy in an amount of from 1 to 4 wt%, preferably 1 to 2.5 wt%.

[0045] Niobium, when present, is suitably included in the nickel based high chromium alloy in an amount of from 0.1 to 5 wt%, preferably 0.5 to 2 wt%.

[0046] In some preferred embodiments the high chromium alloy is a nickel based alloy having a chromium content of 12 to 23 wt%, a cobalt content of 8 to 20 wt%, an aluminium content of 1 to 6 wt%, a titanium content of 0 to 5 wt%, a tantalum content of 1 to 3 wt%, a tungsten content of 1 to 4 wt%, a molybdenum content of 1 to 4 wt%, and a niobium content of 0 to 2 wt%.

[0047] In addition, the nickel based high chromium alloy may suitably comprise up to 0.25 wt% carbon and up to 0.025 wt% boron to facilitate carbide and/or boride strengthening phases in the alloy. The tight control of these carbon and boron together with control of zirconium content (typically 0-0.03 wt%) may help to ensure the best stability of the alloy.

[0048] Non-limiting examples of a nickel based high chromium alloy include those materials sold under the trade names IN939, IN6203DS, IN738LC, STAL15, STAL125, and IN792. IN939, IN6203DS, IN738LC and IN792 are available from Special Metals Ltd. STAL15 and STAL125 are available from Siemens pic.

[0049] Suitably the nickel based high chromium alloy is selected from IN939 and IN738LC. Preferably the nickel based high chromium alloy is IN939.

[0050] Step (c) of the method of the present invention involves shaping the oversized root portion into the final desired root shape. This is suitably achieved by machining the oversized root portion. The thickness of the second alloy composition on the surface of the cast root portion may allow some areas to be machined and other areas to be left as sprayed. Suitable machining techniques will be known to the skilled person in the art and include, for example, grinding, electrical discharge machining (EDM) and electrochemical machining (ECM).

[0051] In preferred embodiments the method of the first aspect of the invention further involves a step (d) of heat treating the shaped component provided in step (c).

[0052] Suitable heat treatments will depend on the specific alloy used. The selection of a suitable heat treatment step or steps will be within the competence of the person skilled in the art.

[0053] Step (d) is preferably carried out at a temperature high enough to cause diffusion bonding of first alloy composition and the second alloy composition and increase the strength of the interface. In some embodiments one or more heat treatment steps may be carried out to increase the bulk strength of the cast and sprayed parts of the turbine blade.

[0054] Typically heat treatment steps include a diffusion bonding cycle followed by a solution heat treatment and then precipitation or ageing cycles. Heat treatments are suitably carried out in a vacuum or in a protective atmosphere. Typically temperatures for heat treatment may be 1100 to 1200°C, although in some cases temperatures of up to 1300°C may be used. Heat treatments are typically carried out for at least 2 to 4 hours.

[0055] In some embodiments the second alloy composition may be optionally subjected to hot isostatic pressing to increase density and thereby increase material properties such as fatigue strength.

[0056] The aerofoil portion of the turbine blade may suitably be provided with a protective coating. Suitable protective coatings will be known to the person skilled in the art. The protective coating is suitably applied to at least a portion of the surface of the cast aerofoil portion, preferably to the majority of the surface of the cast aerofoil portion, and more preferably to substantially all of the surface of the cast aerofoil portion.

[0057] The protective coating may be applied by any suitable means. Such means will be known to the person skilled in the art and include, for example, chemical vapour deposition (CVD), slurry spray processes and thermal spray processes. In some embodiments thermal spray processes are preferred.

[0058] Suitably, the cast component of the turbine blade is covered by the second alloy composition around the root portion and the protective coating around the aerofoil portion such that the first alloy composition is not exposed in use to the operating atmosphere.

[0059] The turbine blades produced in accordance with the method of the present invention suitably have a high creep strength aerofoil portion and a high fatigue strength, corrosion resistant root portion.

[0060] The combination of traditional casting techniques and advanced metal spraying processes according to the present invention allow a turbine blade component to be manufactured with a high chromium alloy root surface (where fatigue and corrosion fatigue properties are important but creep less so) and a low chromium single crystal or directionally solidified alloy aerofoil (where creep strength is more important than fatigue). A high chromium blade root resists corrosion related cracking in the high stressed area of the blade root on turbines operated in poor environments or with poor quality fuel.

[0061] The spraying process produces extremely fine grained microstructures that can give excellent tensile and fatigue properties and this is of great benefit in the root section of the blade where fatigue is often the life limiting factor. Use of a spray process rather than a process such as welding or laser metal deposition avoids melting of the first alloy composition and potential dilution effects between the first alloy composition and second alloy composition. This can avoid shrinkage and cracking defects associated with welding processes. High strength turbine blade alloys are difficult to weld without solidification cracking during welding or strain age cracking on post weld heat treatment. Application of the second alloy composition by a metal spray process can avoid these defects.

[0062] A further advantage of using a spray process is that it can be carried out more quickly and at a lower cost than some alternative processes.

[0063] The invention will now be further defined with reference to the following non-limiting examples and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0064] Figure 1 shows a cross-sectional view of a turbine blade at various stages of the manufacturing process according to the present invention.

DETAILED DESCRIPTION OF INVENTION

[0065] Initially a blade casting (1) is produced from a first alloy composition, for example by investment casting. The initial surface shape of the cast root portion (2) can be provided directly by investment casting or machining of the investment casting. A second alloy composition (3) is sprayed onto the cast root portion (2) to produce an oversized root portion having an outer surface (4). The oversized root portion is machined to obtain a root portion having a finished shape (5).

[0066] In one embodiment the first alloy composition, a nickel based for chromium alloy is CM247DS. This has the following composition:

	Min	Max		Max
Chromium	8.0	8.50	Silicon	0.03
Cobalt	9.0	9.50	Copper	0.005
Titanium	0.6	0.9	Bismuth	0.0001
Aluminum	5.45	5.75	Selenium	0.0005
Tungsten	9.3	9.7	Silver	0.0005
Tantalum	3.1	3.3	Lead	0.0005
Carbon	0.07	0.08	Vanadium	0.10
Hafnium	1.2	1.6	Sulfur	0.0005
Zirconium	0.005	0.02	Oxygen	0.0025
Boron	0.01	0.02	Iron	0.5
Molybdenum	0.4	0.6	Phosphorus	0.005
Nitrogen		0.005	Gallium	0.0015
Nickel	Balance			

[0067] In one embodiment the first alloy composition, a nickel based low chromium alloy is CMSX4. This has the following composition:

Element	Weight %
Carbon	0.01 max
Chromium	6.2 - 6.6
Cobalt	9.3 - 10.0
Tungsten	6.2 - 6.6
Niobium	0.1 max
Tantalum	6.3 - 6.7
Hafnium	0.07 - 0.12
Titanium	0.9 - 1.1
Aluminum	5.45 - 5.75
Aluminum + Titanium	6.35 - 6.85
Rhenium	2.8 - 3.1
Zirconium	0.0075 max (75 ppm max)
Boron	0.0025 max (25 ppm max)
Nitrogen	0.001 max (10 ppm max)
Sulphur	0.0005 max (5 ppm max)
Phosphorus	0.003 max (30 ppm max)
Iron	0.15 max
Molybdenum	0.5 - 0.7
Silicon	0.04 max
Manganese	0.01 max
Copper	0.005 max (50 ppm max)
Lead	0.0002 max (2 ppm max)
Bismuth	0.00002 max (0.2 ppm max)
Tellurium	0.00002 max (0.2 ppm max)
Silver	0.0002 max (2 ppm max)
Arsenic	0.0002 max (2 ppm max)
Magnesium	0.008 max (80 ppm max)
Selenium	0.00005 max (0.5 ppm max)
Oxygen	0.001 max (10 ppm max)
Thallium	0.00003 max (0.3 ppm max)
Cadmium	0.0002 max (2 ppm max)
Gallium	0.0015 max (15 ppm max)
Indium	0.0002 max (2 ppm max)
Antimony	0.0002 max (2 ppm max)
Zinc	0.0005 max (5 ppm max)
Nickel	Balance

[0068] In one embodiment, the second alloy composition, a nickel based high chromium alloy is IN939. This has the following composition:

Element	Percentage
Carbon	0.13 - 0.17
Chromium	22.0 - 22.8
Cobalt	18.5 - 19.5
Tungsten	1.8 - 2.2
Niobium	0.9 - 1.1
Tantalum	1.3 - 1.5
Titanium	3.6 - 3.8
Aluminum	1.8 - 2.0
Zirconium	0.02 - 0.03

(continued)

Element	Percentage
Iron	0.5 max
Silicon	0.2 max
Manganese	0.2 max
Boron	0.004 - 0.006 (40 - 60 ppm)
Sulphur	0.005 max (50 ppm max)
Nitrogen	0.005 max (50 ppm max)
Oxygen	0.002 max (20 ppm max)
Silver	0.0005 max (5 ppm max)
Selenium	0.0005 max (5 ppm max)
Bismuth	0.00005 max (0.5 ppm max)
Lead	0.00005 max (0.5 ppm max)
Nickel	BALANCE

[0069] In one embodiment, the second alloy composition, a nickel based high chromium alloy is IN738LC. This has the following composition:

	Minimum%	Maximum%
Carbon	0.09	0.13
Silicon	-	0.30
Manganese	-	0.20
Sulphur	-	0.015
Phosphorous	-	0.015
Cobalt	8.00	9.00
Copper	-	0.10
Iron	-	0.5
Chromium	15.70	16.30
Aluminum	3.20	3.70
Titanium	3.20	3.70
Molybdenum	1.50	2.00
Boron	0.007	0.012
Zirconium	0.03	0.08
Niobium	0.60	1.10
Tantalum	1.50	2.00
Tungsten	2.40	2.80
Aluminium + Titanium	6.50	7.20
Nickel	Balance	

Claims

1. A method of manufacturing a turbine blade having an aerofoil portion and a root portion, the method comprising the steps of:

   (a) providing a cast component of a first alloy composition comprising a cast aerofoil portion and a cast root portion;
   (b) applying a second alloy composition to the surface of the cast root portion to provide an oversized root portion;
   (c) shaping the oversized root portion.

2. A turbine blade comprising a cast component of a first alloy composition comprising an aerofoil portion and a root portion, wherein the surface of the root portion is covered with a second alloy composition.

3. A method or turbine blade according to any preceding claim wherein the first alloy composition comprises a nickel based low chromium alloy having a chromium content of less than 12 wt%.

4. A method or turbine blade according to any preceding claim wherein the second alloy composition comprises a nickel based high chromium alloy having a chromium content of more than 12 wt%.

5. A method or turbine blade according to any preceding claim wherein the first alloy composition has an aluminium content of 3 to 7 wt%, a titanium content of 0 to 4 wt%, a tantalum content of 1.5 to 7 wt%, a tungsten content of 4 to 12.5 wt%, a rhenium content of 3 to 7 wt%, a molybdenum content of up to 6 wt%, and a cobalt content of 6 to 12 wt%.

6. A method or turbine blade according to any preceding claim wherein the first alloy is selected from the group consisting of MarM247, CM247, CM247DS, CMSX4, and CMSX8.

7. A method or turbine blade according to any of preceding claim wherein the second alloy has a cobalt content of 5 to 20 wt%, an aluminium content of 1 to 6 wt%, a titanium content of 0.1 to 5 wt%, a tantalum content of 0.5 to 4 wt%, a tungsten content of 1 to 7 wt%, a molybdenum content of 1 to 4 wt%, and a niobium content of 0.1 to 5 wt%.

8. A method or turbine blade according to any preceding claim wherein the second alloy is selected from the group consisting of IN939, IN6203DS, IN738LC, STAL15, STAL125, and IN792, preferably wherein the second alloy is IN939 or IN738LC, more preferably wherein the second alloy is IN939.

9. A method or turbine blade according to any preceding claim wherein the first alloy composition is provided as an equiaxed, directionally solidified, or single crystal alloy.

10. A method according to any of claims 1 or 3 to 9 wherein the cast component is provided in step (a) by investment casting.

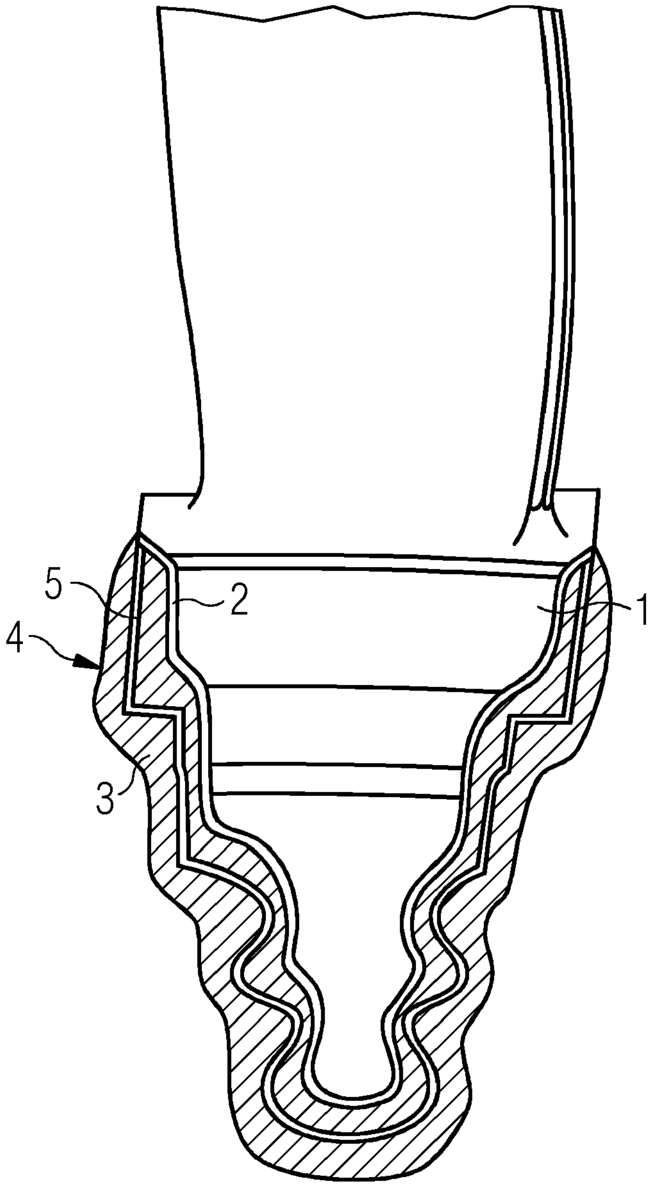
11. A method according to any of claims 1 or 10 wherein step (a) further involves shaping the cast root portion.

12. A method according to any of claims 1 or 3 to 11 wherein step (b) comprises a metal spray process selected from the group consisting of High Velocity Oxy-Fuel (HVOF), Low Pressure Plasma Spraying (LPPS), and Cold Spray.

13. A method according to any of claims 1 or 3 to 12 wherein the component provided by step (c) is subjected to one or more heat treatments.

14. A method according to any of claims 1 or 3 to 13 wherein the root portion is subjected to hot isostatic pressing.

15. A gas turbine comprising a turbine blade according to or prepared by the method of any preceding claim.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EUROPEAN SEARCH REPORT

Application Number
EP 18 17 4258

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X Y	EP 3 075 880 A1 (SIEMENS AG [DE]) 5 October 2016 (2016-10-05) * paragraph [0032] - paragraph [0047]; figures * -----	1,2,4,7, 8,10,11, 13-15 3,5,6,9, 12	INV. F01D5/30 C23C24/08 C23C28/02 F01D5/28
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1 The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	12 October 2018	Teissier, Damien

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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E : earlier patent document, but published on, or after the filing date
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& : member of the same patent family, corresponding document

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 18 17 4258

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82