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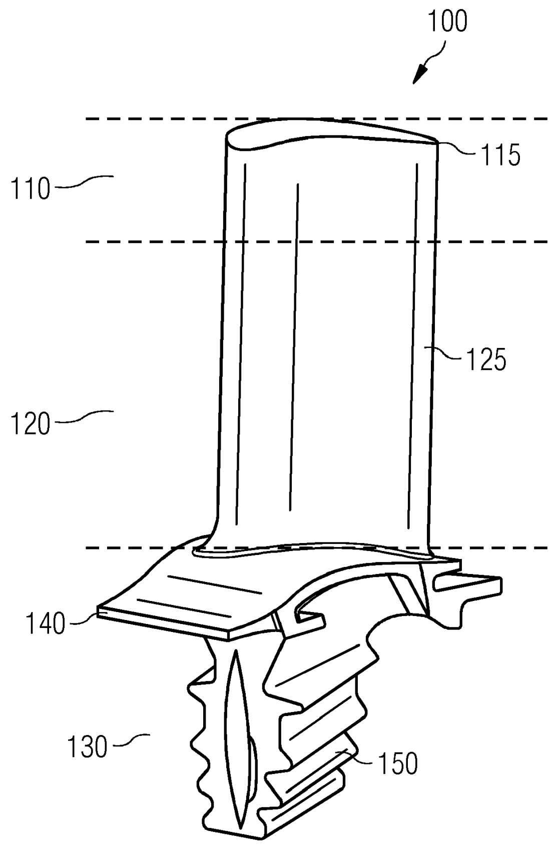
(71) Applicant: **Siemens Aktiengesellschaft**
80333 München (DE)

(72) Inventor: **Mathai, Manu**
Lincoln, LN5 7FD (GB)

(74) Representative: **Maier, Daniel Oliver**
Siemens AG
Postfach 22 16 34
80506 München (DE)

(54) IMPROVEMENTS RELATING TO SUPERALLOY COMPONENTS

(57) A component comprising 6.0 to 7.5 wt% aluminium; 8.0 to 10.0 wt% chromium; 5.0 to 7.0 wt% cobalt; 2.0 to 3.0 wt% tungsten; 0.5 to 1.0 wt% tantalum; 2.0 to 3.0 wt% niobium; 1.0 to 2.0 wt% molybdenum; 0.5 to 2.0 wt% titanium; and nickel. The metal alloy is a nickel super alloy. The metal alloy may be particularly suitable for forming a tip region of an aerofoil, suitably a turbine aerofoil, which may provide optimised mechanical and/or chemical properties in said regions of an aerofoil. A suitable metal alloy composition for an intermediate and root region of a turbine aerofoil is also provided. A component comprising said metal alloy compositions is also provided.



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Description

[0001] The present disclosure relates to components manufactured from metal alloys, the components comprising different metal alloy compositions in different regions of the component, which may provide improved mechanical and/or chemical properties and/or may allow a more cost manufacture compared to known metal alloy components. The present disclosure also relates to methods of providing said components and to apparatus for carrying out said methods.

[0002] In particular the disclosure is concerned with turbine aerofoils formed from nickel superalloy compositions which are tailored to meet specific requirements in specific regions of the component.

Background

[0003] A turbine aerofoil (or airfoil) can be considered to comprise a tip region, an intermediate region and a root region. The tip region comprises the tip of the aerofoil blade, the root region is where the aerofoil is attached to a turbine rotor disc and the intermediate region is between the tip region and the root region and comprises a main part of the aerofoil blade. The mechanical and/or chemical properties required at each of these regions vary due to the different operating conditions, for example stress, strain and temperature, which each region experiences in use.

[0004] Single crystal superalloys may provide improved mechanical properties, for example enhanced creep resistance, in turbine aerofoils when compared to conventionally cast components which may comprise a polycrystalline or grained structure. However, investment casting of complex components has numerous difficulties mainly due to the potential for developing a large number of spurious grains during casting, particularly in advanced blade designs comprising complex cooling passages. Also, casting yields (which is the weight of the casting divided by the amount of metal poured into the cast) for complex single crystal aerofoils are typically very low. Therefore the use of the single crystal superalloys in the manufacture of turbine aerofoils is very expensive which ultimately makes investment casting an entire turbine aerofoil of a single crystal material very cost prohibitive.

[0005] Hence, there is a need for functionally graded turbine aerofoils which can be manufactured in a cost effective manner.

[0006] US 6,331,217 relates to the fabrication of complex single crystal shapes by casting numerous relatively simple single crystal sub-components and joining the sub-components together with a transient liquid phase bonding process. The bond region generally provides a weakness in the finished component and so is located in an area of the component which experiences low stress in use.

Summary

[0007] It is one aim of the present invention, amongst others, to provide a metal alloy, a component and a method of forming a component that addresses at least one disadvantage of the prior art, whether identified here or elsewhere, or to provide an alternative to existing metal alloys, components and methods of forming said components.

[0008] For instance it may be an aim of the present invention to provide a turbine aerofoil having optimised mechanical and chemical properties in different regions of the turbine aerofoil.

[0009] The centrifugal pull at any location along an aerofoil is proportional to the mass, radial distance from the centre and the square of the angular velocity. Therefore the centrifugal pull in the tip region of the aerofoil is much greater than at the root region or the intermediate of the aerofoil. It therefore may be one aim of the present invention to provide a tip region which has a relatively low density, for example a lower density than the intermediate region and the root region. Such a relatively low density can reduce the weight of the tip region without changing its dimensions and therefore reduce the centrifugal pull experienced by the tip region.

[0010] The intermediate region of the aerofoil supports centrifugal loads with a small cross section. It therefore may be one aim of the present invention to provide an aerofoil with high creep strength. It may also be an aim of the present invention to provide the intermediate region with high oxidation resistance due to the exposure of the intermediate region to hot gas streams in use and to provide an enhanced thermal-mechanical fatigue (TMF) capability/life.

[0011] It may be a further aim of the present invention to provide a root region with a high notched low cycle fatigue (LCF) strength and good stress corrosion cracking resistance.

[0012] According to the present disclosure there is provided a metal alloy and a component as set forth in the appended claims. Other features of the invention will be apparent from the dependent claims, and the description which follows.

First aspect - tip region

[0013] According to a first aspect of the present invention, there is provided a metal alloy composition comprising:

6.0 to 7.5 wt% aluminium;

8.0 to 10.0 wt% chromium;
5.0 to 7.0 wt% cobalt;
2.0 to 3.0 wt% tungsten;
0.5 to 1.0 wt% tantalum;
2.0 to 3.0 wt% niobium;
1.0 to 2.0 wt% molybdenum;
0.5 to 2.0 wt% titanium; and
nickel.

[0014] The metal alloy of this first aspect is a nickel-based alloy, suitably a nickel superalloy. Suitably the metal alloy comprises at least 60 wt% nickel, suitably at least 65 wt% nickel. Suitably the metal alloy comprises up to 80 wt% nickel, suitably up to 75 wt%, for example up to 70 wt% nickel. It will be readily understood that the metal alloy of this first aspect may contain other elements, in addition those listed above, and that the nickel provides the remainder of the metal alloy mass balance once these other elements have been taken into account. These other elements may be present in a total amount of up to 2 wt%, suitably up to 1 wt% or up to 0.8 wt%.

[0015] The metal alloy composition of this first aspect may be used to form at least a part of an aerofoil, for example a turbine aerofoil. Suitably the metal alloy composition provides the tip region of a turbine aerofoil.

[0016] The inventor has found that the metal alloy of this first aspect may advantageously have a relatively low density due to the combination of elements along with titanium compared to known nickel superalloys. This relatively low density means that the mass of the tip region can be relatively low and therefore the centrifugal loads transferred from the tip region of an aerofoil to the intermediate and/or root regions of the aerofoil are reduced which in turn reduces strain and wear on the intermediate and/or root regions of the aerofoil.

[0017] The density of the superalloy is a function of various elements and can be calculated by the following equation (I):

$$\text{Density} = 8.29604 - 0.00435\,(\text{a.Co\%}) - 0.0164\,(\text{a.Cr\%}) + 0.01295\,(\text{a.Mo\%}) + 0.06274\,(\text{a. W\%}) - 0.06595\,(\text{a.Al\%}) - 0.0236\,(\text{a.Ti\%}) + 0.05441\,(\text{a.Ta\%})$$

[0018] The density of the metal alloy composition can be reduced to the maximum extent by additions in aluminium and titanium. However, high levels of titanium may adversely affect oxidation resistance even when the aluminium content is high. Therefore only a relatively moderate amount of titanium of from 0.5 to 2.0 wt% is provided in the metal alloy composition of this first aspect.

[0019] Relatively high amounts of aluminium and tantalum and low levels of titanium and niobium in the metal alloy composition may enable good oxidation resistance and good coating compatibility. The presence of niobium, instead of further tantalum for example, may reduce the density at the tip of the aerofoil even further.

[0020] Less aluminium may be needed for oxidation resistance for forming protective Al_2O_3 scale in the metal alloy composition, due to the relatively high amounts of chromium (of from 8.0 to 10.0 wt%) and tantalum (of from 0.5 to 1.0 wt%) and the relatively low amounts of titanium. The amounts of niobium and vanadium may also be low in the metal alloy composition for the same reason.

[0021] Cobalt is present in the metal alloy composition in an amount of from 5.0 to 7.0 wt% which may promote stability and hot corrosion resistance. If the cobalt content is below 3 wt%, the stability and hot corrosion resistance of the metal alloy composition may fall. If the cobalt content is above 10 wt% then the oxidation resistance may fall and the gamma prime solvus temperature may be reduced which would severely limit the elevated temperature rupture capability of a component formed of the metal alloy composition. The specified amount of cobalt may also be beneficial in providing some reduction in density.

[0022] Tungsten is present in the metal alloy composition in an amount of from 2.0 to 3.0 wt% which may contribute to the creep rupture strength of the metal alloy composition because tungsten it is a good solid solution strengthener. If the amount of tungsten is less than 2.0 wt%, the rupture strength of a component formed of the metal alloy composition may be insufficient. However, if the tungsten content is greater than 5.0 wt% there is potential for instability and also the hot corrosion and oxidation resistance may be low.

[0023] The density of the metal alloy composition may be determined to a certain extent by the amounts of refractory elements present. Therefore it may be advantageous to keep the content of refractory elements as low as possible to provide a relatively low density of the metal alloy composition. The contents of refractory elements influencing the density can be given by the equation (II) below:

$$\text{Refractory element content} = (0.5\text{ wt\% W}) + \text{wt\% Ta} + \text{wt\% Mo} + \text{wt\% Re} + \text{wt\% Ru}$$

[0024] Suitably the metal alloy composition comprises up to 8.0 wt% molybdenum, tungsten and tantalum (and ruthenium if present), suitably up to 7.5 wt%, suitably up to 7.0 wt%, for example up to 6.5 wt%.

[0025] The metal alloy composition of this first aspect comprises from 6.0 to 7.5 wt% aluminium, suitably from 6.5 wt% to 7.5 wt%, suitably from 6.0 to 7.0 wt%, suitably from 6.5 to 7.0 wt%.

[0026] The metal alloy composition of this first aspect comprises from 8.0 to 10.0 wt% chromium, suitably from 8.5 wt% to 10.0 wt%, suitably from 8.0 wt% to 9.5 wt%, suitably from 8.5 wt% to 9.5 wt%, suitably from 8.7 wt% to 9.3 wt%.

[0027] The metal alloy composition of this first aspect comprises from 5.0 to 7.0 wt% cobalt, suitably from 5.5 wt% to 7.0 wt%, suitably from 5.0 to 6.5 wt%, suitably from 5.5 to 6.5 wt%, suitably from 5.7 to 6.3 wt%.

[0028] The metal alloy composition of this first aspect comprises from 2.0 to 3.0 wt% tungsten, suitably from 2.3 wt% to 3.0 wt%, suitably from 2.0 to 2.7 wt%, suitably from 2.3 to 2.7 wt%.

[0029] The metal alloy composition of this first aspect comprises from 0.5 to 1.0 wt% tantalum, suitably from 0.6 wt% to 0.9 wt%, suitably from 0.5 to 0.8 wt%, suitably from 0.6 to 0.8 wt%.

[0030] The metal alloy composition of this first aspect comprises from 2.0 to 3.0 wt% niobium, suitably from 2.3 wt% to 3.0 wt%, suitably from 2.0 to 2.7 wt%, suitably from 2.3 to 2.7 wt%.

[0031] The metal alloy composition of this first aspect comprises from 1.0 to 2.0 wt% molybdenum, suitably from 1.3 wt% to 2.0 wt%, suitably from 1.0 to 1.7 wt%, suitably from 1.3 to 1.7 wt%.

[0032] The metal alloy composition of this first aspect comprises from 0.5 to 2.0 wt% titanium, suitably from 0.5 wt% to 1.5 wt%, suitably from 0.75 to 1.5 wt%, suitably from 0.8 to 1.2 wt%.

[0033] The metal alloy composition of this first aspect may comprise 0.05 to 0.15 wt% hafnium, suitably from 0.07 wt% to 0.15 wt%, suitably from 0.05 to 0.13 wt%, suitably from 0.07 to 0.13 wt%. Said content of hafnium may promote the stability of aluminium oxide scale which may in turn improve the oxidation resistance of the metal alloy composition. However, higher amounts of hafnium may reduce alloy stability due to sigma phase formation.

[0034] The metal alloy composition of this first aspect may comprise 0.05 to 0.10 wt% silicon, suitably from 0.07 wt% to 0.10 wt%, suitably from 0.05 to 0.07 wt%. Said content of silicon may improve the oxidation resistance of the metal alloy composition. However, higher amounts of silicon may reduce the strength of a component formed of the metal alloy composition due to formation of a weak beta phase.

[0035] The metal alloy composition of this first aspect may comprise up to 0.03 wt% yttrium. Said content of yttrium may promote aluminium scale stability and adherence. Higher amounts of yttrium may promote undesirable mould metal reaction at the casting surface and consequently increase the inclusion content in the material.

[0036] The metal alloy composition of this first aspect may comprise 0 to 0.1 wt% carbon.

[0037] The metal alloy composition of this first aspect may comprise 0 to 0.05 wt% cerium and/or lanthanum. Suitably the amount of cerium and lanthanum in the first metal alloy composition combined is from 0 to 0.05 wt%. Said content of cerium and/or lanthanum may promote oxidation resistance of the metal alloy composition.

[0038] The metal alloy composition of this first aspect may comprise any one or more of the following elements: 0.05 to 0.15 wt% hafnium, 0.05 to 0.10 wt% silicon, 0 to 0.1 wt% carbon, 0 to 0.05 wt% cerium and/or lanthanum.

[0039] The metal alloy composition of this first aspect may comprise 0.05 to 0.15 wt% hafnium, 0.05 to 0.10 wt% silicon, 0 to 0.1 wt% carbon, 0 to 0.05 wt% cerium and/or lanthanum.

[0040] It is desired to replace tantalum by niobium in the metal alloy composition, to a certain extent, specifically at a tip region of a turbine aerofoil. This has the advantage of further reducing the density of the first metal alloy composition in the first region of the component.

[0041] The metal alloy composition of this first aspect may comprise:

6.0 to 7.5 wt% aluminium;
8.0 to 10.0 wt% chromium;
5.0 to 7.0 wt% cobalt;
2.0 to 3.0 wt% tungsten;
0.5 to 1.0 wt% tantalum;
2.0 to 3.0 wt% niobium;
1.0 to 2.0 wt% molybdenum;
0.5 to 2.0 wt% titanium;
0.05 to 0.15 wt% hafnium;
0.05 to 0.10 wt% silicon;
0 to 0.03 wt% yttrium;
0 to 0.1 wt% carbon;
0 to 0.05 wt% cerium and/or lanthanum; and
nickel to balance.

[0042] The metal alloy composition of this first aspect may consist essentially or consist of the elements listed above.

[0043] The inventor has found that, taking into account the various factors discussed above and the trade-off between low density and optimal creep resistance properties required at the tip region of an aerofoil, the first metal alloy composition may provide an optimised and advantageous material for the formation of a tip region of an aerofoil, suitably a turbine aerofoil.

[0044] The metal alloy composition of this first aspect may be termed a first metal alloy composition.

Second aspect - intermediate region

[0045] According to a second aspect of the present invention, there is provided a metal alloy composition comprising:

6.0 to 7.5 wt% aluminium;
5.0 to 7.0 wt% chromium;
5.0 to 8.0 wt% cobalt;
3.0 to 5.0 wt% iron;
6.0 to 8.0 wt% tungsten;
6.0 to 8.0 wt% tantalum;
1.0 to 3.0 wt% molybdenum;
0.6 to 1.0 wt% titanium; and
nickel.

[0046] The metal alloy composition of this second aspect may be termed a second metal alloy composition.

[0047] This second metal alloy composition is a nickel-based alloy, suitably a nickel superalloy. Suitably the second metal alloy composition comprises at least 50 wt% nickel, suitably at least 55 wt% nickel, for example at least 60 wt% nickel. Suitably the second metal alloy composition comprises up to 75 wt% nickel, suitably up to 70 wt%, for example up to 65 wt% nickel. It will be readily understood that the second metal alloy composition may contain other elements, in addition those listed above, and that the nickel provides the remainder of the metal alloy mass balance once these other elements have been taken into account. These other elements may be present in a total amount of up to 2 wt%, suitably up to 1 wt% or up to 0.8 wt%.

[0048] The second metal alloy composition may be used to form at least a part of an aerofoil, for example a turbine aerofoil. Suitably the second metal alloy composition provides an intermediate region of a turbine aerofoil, as defined above.

[0049] The inventor has found that the second metal alloy composition may provide a region of a component, such as a turbine aerofoil, with a high creep strength and may have a high oxidation resistance. It is not as advantageous to have a relatively low density in said intermediate region of a turbine aerofoil as it is in the tip region, therefore the minimisation of the density may not be an important aim of the second metal alloy composition.

[0050] Suitably the second metal alloy composition comprises at least 16.0 wt% molybdenum, tungsten and tantalum (and ruthenium if present) suitably at least 17.0 wt%, suitably at least 18.0 wt%, for example at least 19 wt%. The inventor has found that such amounts of molybdenum, tungsten and tantalum (which may be known as refractory elements in such alloys) may provide the second metal alloy composition with a high creep strength which is particularly advantageous when the second metal alloy composition forms an intermediate region in an aerofoil, suitably a turbine aerofoil.

[0051] The contents of molybdenum, tungsten and tantalum may vary from greater than 18.0 wt% at highly creep resistant regions, for example at the intermediate region in an aerofoil, to less than 11.0 wt% in regions where less creep ductility is desired. The contents of molybdenum, tungsten and tantalum may be reduced to approximately 5 wt% at the root region of the aerofoil. In particular, a gradient of these elements is desired from root to tip.

[0052] The second metal alloy composition comprises a relatively low amount of chromium (for example compared to the first metal alloy composition) to account for the increased gamma prime phase content due to the relatively high amounts of molybdenum and tungsten, and to avoid excessive topologically close packed phases (TCP).

[0053] The creep strength is normally found to increase with a) gamma prime content b) concentration of strengtheners in the gamma matrix and c) the amount of added rhenium (Re).

[0054] Modelling of the alloy chemical composition has suggested a significantly increased aluminium activity when iron is added. An increase in aluminium activity due to the addition of iron enables an improved oxidation resistance and coating compatibility. An increase in the aluminium activity in the base alloy is expected to significantly reduce the loss of aluminium from the coating into the base alloy.

[0055] Vanadium is also added in small amounts in the range of 0.1 to 0.3 wt% to increase the ductility to account for the addition of iron.

[0056] The second metal alloy composition comprises from 6.0 to 7.5 wt% aluminium, suitably from 6.5 wt% to 7.5 wt%, suitably from 6.0 to 7.0 wt%, suitably from 6.5 to 7.0 wt%.

[0057] The second metal alloy composition comprises from 3.0 to 5.0 wt% iron, suitably from 3.5 wt% to 4.5 wt%, suitably from 3.0 to 4.0 wt%, suitably from 3.5 to 4.0 wt%.

[0058] The second metal alloy composition comprises from 5.0 to 7.0 wt% chromium, suitably from 5.5 wt% to 7.0 wt%, suitably from 5.0 wt% to 6.5 wt%, suitably from 5.5 wt% to 6.5 wt%, suitably from 5.7 wt% to 6.3 wt%.

[0059] The second metal alloy composition comprises from 5.0 to 8.0 wt% cobalt, suitably from 5.5 wt% to 8.0 wt%, suitably from 5.0 to 7.5 wt%, suitably from 5.5 to 7.5 wt%, suitably from 6.0 to 7.0 wt%.

[0060] The second metal alloy composition comprises from 6.0 to 8.0 wt% tungsten, suitably from 6.5 wt% to 8.0 wt%, suitably from 6.0 to 7.5 wt%, suitably from 6.5 to 7.5 wt%. The second metal alloy composition comprises from 6.0 to 8.0 wt% tantalum, suitably from 6.5 wt% to 8.0 wt%, suitably from 6.0 to 7.5 wt%, suitably from 6.5 to 7.5 wt%..

[0061] The second metal alloy composition comprises from 1.0 to 3.0 wt% molybdenum, suitably from 1.5 wt% to 3.0 wt%, suitably from 1.0 to 2.5 wt%, suitably from 1.5 to 2.5 wt%.

[0062] The second metal alloy composition comprises from 0.6 to 1.0 wt% titanium, suitably from 0.7 wt% to 1.0 wt%, suitably from 0.6 to 0.9 wt%, suitably from 0.7 to 0.8 wt%.

[0063] The second metal alloy composition may comprise 0.1-0.3 wt% vanadium, suitably from 0.1 to 0.5 wt%, suitably from 0.1 to 0.3 wt%.

[0064] The second metal alloy composition may comprise 0.05 to 1.5 wt% hafnium, suitably from 0.1 wt% to 1.5 wt%, suitably from 0.05 to 1.3 wt%, suitably from 0.1 to 1.3 wt%. Said content of hafnium may promote the stability of aluminium oxide scale which may in turn improve the oxidation resistance of the metal alloy composition. However, higher amounts of hafnium may promote formation of gamma prime phase which may reduce alloy stability due to sigma phase formation.

[0065] The second metal alloy composition may comprise 0.05 to 0.10 wt% silicon, suitably from 0.07 wt% to 0.10 wt%, suitably from 0.05 to 0.07 wt%. Said content of silicon may improve the oxidation resistance of the metal alloy composition. However, higher amounts of silicon may reduce the strength of a component formed of the metal alloy composition due to formation of a weak beta phase.

[0066] The metal alloy composition of this second aspect may comprise up to 0.03 wt% yttrium. Said content of yttrium may promote aluminium scale stability and adherence. Higher amounts of yttrium may promote undesirable mould metal reaction at the casting surface and subsequently increase the inclusion content in the material.

[0067] The second metal alloy composition may comprise 0 to 0.1 wt% carbon.

[0068] The second metal alloy composition may comprise 0 to 0.05 wt% cerium and/or lanthanum. Suitably the amount of cerium and lanthanum in the second metal alloy composition combined is from 0 to 0.05 wt%. Said content of cerium and/or lanthanum may promote oxidation resistance of the second metal alloy composition.

[0069] The second metal alloy composition may comprise any one or more of the following elements: 0.1-0.3 wt% vanadium, 0.05 to 0.15 wt% hafnium, 0.05 to 0.10 wt% silicon, 0 to 0.1 wt% carbon, 0 to 0.05 wt% cerium and/or lanthanum.

[0070] The second metal alloy composition may comprise 0.1-0.3 wt% vanadium, 0.05 to 0.15 wt% hafnium, 0.05 to 0.10 wt% silicon, 0 to 0.1 wt% carbon, 0 to 0.05 wt% cerium and/or lanthanum.

[0071] In addition, minor amounts of boron and zirconium may be added to increase the creep rupture ductility desired in this intermediate region of a turbine aerofoil. Boron and zirconium segregate to grain boundary regions due to the misfit with the nickel matrix (gamma phase). The addition of boron is also seen to modify the presence of deleterious grain boundary carbides which are detrimental to creep ductility. The second metal composition may therefore comprise approximately 0.01 wt% boron and approximately 0.01 wt% zirconium.

[0072] The second metal alloy composition may comprise:

6.0 to 7.5 wt% aluminium;
5.0 to 7.0 wt% chromium;
5.0 to 8.0 wt% cobalt;
3.0 to 5.0 wt% iron;
6.0 to 8.0 wt% tungsten;
6.0 to 8.0 wt% tantalum;
1.0 to 3.0 wt% molybdenum;
0.6 to 1.0 wt% titanium;
0.1 to 0.3 wt% vanadium;
0.05 to 1.5 wt% hafnium;
0.05 to 0.10 wt% silicon;
0 to 0.1 wt% carbon;
0.005 to 0.01 wt% boron;
0.005 to 0.01 wt% zirconium;
0 to 0.05 wt% cerium and/or lanthanum; and
nickel to balance.

[0073] The second metal alloy composition may consist essentially or consist of the elements listed above.

[0074] The inventor has found that, taking into account the desired properties of an intermediate region of an aerofoil, the second metal alloy composition may provide an optimised and advantageous material for the formation of an intermediate region of an aerofoil, suitably a turbine aerofoil.

Third aspect - root region

[0075] According to a third aspect of the present invention, there is provided a metal alloy composition comprising:

3.0 to 5.0 wt% aluminium;
10.0 to 13.0 wt% chromium;
5.0 to 7.0 wt% cobalt;
3.0 to 5.0 wt% tungsten;
6.0 to 9.0 wt% tantalum;
3.0 to 5.0 wt% niobium
0.0 to 0.25 wt% molybdenum;
0.7 to 1.0 wt% titanium; and
nickel.

[0076] The metal alloy composition of this third aspect may be termed a third metal alloy composition.

[0077] This third metal alloy composition is a nickel-based alloy, suitably a nickel superalloy. Suitably the third metal alloy composition comprises at least 50 wt% nickel, suitably at least 55 wt% nickel, for example at least 60 wt% nickel. Suitably the third metal alloy composition comprises up to 80 wt% nickel, suitably up to 75 wt%, for example up to 70 wt% nickel. It will be readily understood that the third metal alloy composition may contain other elements, in addition those listed above, and that the nickel provides the remainder of the metal alloy mass balance once these other elements have been taken into account. These other elements may be present in a total amount of up to 2 wt%, suitably up to 1 wt% or up to 0.8 wt%.

[0078] The third metal alloy composition may be used to form at least a part of an aerofoil, for example a turbine aerofoil. Suitably the third metal alloy composition provides a root region of a turbine aerofoil, as defined above.

[0079] The inventor has found that the third metal alloy composition may provide a region of a component, such as a turbine aerofoil, having a good low cycle fatigue (LCF) strength and good stress corrosion cracking (SCC) resistance, which is particularly advantageous in a root region of an aerofoil. The good stress corrosion cracking resistance is believed to be due to the chromium content of the third metal alloy composition being at least 10 wt% and more specifically from 10 to 13 wt%.

[0080] The inventor has also found that the third metal alloy composition may provide a moderately low density material which is advantageous for a root region of an aerofoil because this region provides a large fraction of the total mass of the aerofoil and reducing mass in this region is very helpful in minimising the total mass of aerofoil.

[0081] The tantalum content of at least 6 wt%, or more specifically from 6 to 9 wt%, is believed to provide solution strengthening to gamma prime particles contained in the third metal alloy composition.

[0082] In the third metal alloy composition, the amount of molybdenum is relatively low (for example compared to the first and second metal alloy compositions) and has been replaced by the specified amount of tantalum to improve resistance to the hot corrosion processes which are experienced by a root region of an aerofoil, suitably a turbine aerofoil, in use. A moderate amount of niobium is added in place of more tantalum in order to reduce the density at the root region of the aerofoil.

[0083] The third metal alloy composition comprises from 3.0 to 5.0 wt% aluminium, suitably from 3.5 wt% to 5.0 wt%, suitably from 3.0 to 4.5 wt%, suitably from 3.5 to 4.5 wt%.

[0084] The third metal alloy composition comprises from 10.0 to 13.0 wt% chromium, suitably from 10.5 wt% to 13.0 wt%, suitably from 10.0 wt% to 12.5 wt%, suitably from 10.5 wt% to 12.5 wt%, suitably from 11.0 wt% to 12.0 wt%.

[0085] The third metal alloy composition comprises from 5.0 to 7.0 wt% cobalt, suitably from 5.5 wt% to 7.0 wt%, suitably from 5.0 to 6.5 wt%, suitably from 5.5 to 6.5 wt%.

[0086] The third metal alloy composition comprises from 3.0 to 5.0 wt% tungsten, suitably from 3.5 wt% to 5.0 wt%, suitably from 3.0 to 4.5 wt%, suitably from 3.5 to 4.5 wt%.

[0087] The third metal alloy composition comprises from 6.0 to 9.0 wt% tantalum, suitably from 7.0 wt% to 9.0 wt%, suitably from 6.0 to 8.0 wt%, suitably from 7.0 to 8.0 wt%.

[0088] The third metal alloy composition comprises from 3.0 to 5.0 wt% niobium, suitably from 3.5 wt% to 4.5 wt%, suitably from 4.0 to 4.5 wt%.

[0089] The third metal alloy composition comprises from 0.0 to 0.25 wt% molybdenum, suitably from 0.0 wt% to 0.20 wt%, suitably from 0.05 to 0.25 wt%, suitably from 0.05 to 0.20 wt%.

[0090] The third metal alloy composition comprises from 0.7 to 1.0 wt% titanium, suitably from 0.8 wt% to 1.0 wt%, suitably from 0.7 to 0.9 wt%, suitably from 0.8 to 0.9 wt%.

[0091] The third metal alloy composition may comprise 0.05 to 0.15 wt% hafnium, suitably from 0.07 wt% to 0.15 wt%, suitably from 0.05 to 0.13 wt%, suitably from 0.07 to 0.13 wt%. Said content of hafnium may promote the stability of aluminium oxide scale which may in turn improves the oxidation resistance of the metal alloy composition. However, higher amounts of hafnium may promote formation of gamma prime phase which may reduces alloy stability due to sigma phase formation.

[0092] The third metal alloy composition may comprise 0 to 0.1 wt% carbon.

[0093] The third metal alloy composition may comprise 0.05 to 0.15 wt% hafnium and/or 0 to 0.1 wt% carbon.

[0094] The third metal alloy composition may comprise:

3.0 to 5.0 wt% aluminium;
10.0 to 13.0 wt% chromium;
5.0 to 7.0 wt% cobalt;
3.0 to 5.0 wt% tungsten;
6.0 to 9.0 wt% tantalum;
3.0 to 5.0 wt% niobium;
0.0 to 0.25 wt% molybdenum;
0.7 to 1.0 wt% titanium
0.05 to 0.15 wt% hafnium;
0 to 0.1 wt% carbon; and
nickel to balance.

[0095] The third metal alloy composition may consist essentially or consist of the elements listed above.

[0096] The inventor has found that, taking into account the desired properties of a root region of an aerofoil, the third metal alloy composition may provide an optimised and advantageous material for the formation of a root region of an aerofoil, suitably a turbine aerofoil.

Forth aspect - component

[0097] According to a fourth aspect of the present invention, there is provided a component comprising a metal alloy composition according to the first aspect in at least a first region of the component.

[0098] Therefore this fourth aspect may provide a component comprising a first metal alloy composition in at least a first region of the component. The first metal alloy composition may have any of the suitable features and advantages described in relation to the first metal alloy composition of the first aspect.

[0099] Suitably the component is a turbine aerofoil comprising a tip, a platform and a root; wherein the first region of the component is a tip region of the turbine aerofoil comprising the tip, as described in relation to the first aspect.

[0100] Suitably the component of this fourth aspect comprises a metal alloy composition according to the second aspect in at least a second region of the component.

[0101] Therefore this fourth aspect may provide a component comprising a first metal alloy composition in at least a first region of the component and a second metal alloy composition in at least a second region of the component. The second metal alloy composition may have any of the suitable features and advantages described in relation to the second metal alloy composition of the second aspect.

[0102] Suitably the component is a turbine aerofoil comprising a tip, a platform and a root; wherein the second region of the component is an intermediate region of the turbine aerofoil comprising the main part of the aerofoil blade between the tip and the root, as described in relation to the second aspect.

[0103] Suitably the component of this fourth aspect comprises a metal alloy composition according to the third aspect in at least a third region of the component.

[0104] Therefore this fourth aspect may provide a component comprising a first metal alloy composition in at least a first region of the component and a third metal alloy composition in at least a third region of the component. The third metal alloy composition may have any of the suitable features and advantages described in relation to the third metal alloy composition of the third aspect.

[0105] Suitably the component is a turbine aerofoil comprising a tip, a platform and a root; wherein the third region of the component is a root region of the turbine aerofoil comprising the root of the aerofoil, as described in relation to the third aspect.

[0106] Suitably, the component of this fourth aspect comprises a first metal alloy composition in at least a first region of the component, a second metal alloy composition in at least a second region of the component and a third metal alloy composition in at least a third region of the component, as described above.

[0107] Suitably the component is a turbine aerofoil comprising a tip, a platform and a root; wherein the first region of the component is a tip region of the turbine aerofoil comprising the tip, as described in relation to the first aspect; wherein the second region of the component is an intermediate region of the turbine aerofoil comprising the main part of the aerofoil blade between the tip and the root, as described in relation to the second aspect; and wherein the third region of the component is a root region of the turbine aerofoil comprising the root of the aerofoil, as described in relation to the third aspect.

[0108] The component of this fourth aspect may be formed by a known method of manufacturing such a component, for example a turbine aerofoil. After forming, the component is suitably subjected to a heat treatment in order to attain optimal properties.

[0109] According to a further aspect of the present invention, there is provided a component comprising a metal alloy composition according to the second aspect in at least a region of the component. The component may have any of the features of the component of the fourth aspect.

[0110] According to a further aspect of the present invention, there is provided a component comprising a metal alloy composition according to the third aspect in at least a region of the component. The component may have any of the features of the component of the fourth aspect.

[0111] According to a further aspect of the present invention, there is provided an aerofoil comprising a tip region formed of a first metal alloy composition, an intermediate region formed of a second metal alloy composition and a root region formed of a third metal alloy composition, wherein the intermediate region is between the tip region and the root region and wherein the density of the first metal alloy composition in the tip region is less than the density of the second metal alloy composition in the intermediate region and/or the third metal alloy composition in the root region.

[0112] Suitably the first, second and third metal alloy compositions are as described in relation to the first, second and third aspects, respectively.

[0113] According to a further aspect of the present invention, there is provided a component comprising an inner core and an outer layer, wherein the inner core comprises a polycrystalline metal alloy composition and wherein the outer layer comprises a single crystal metal alloy composition.

[0114] The component may have any of the suitable features and advantages of the component of the fourth aspect.

[0115] Suitably the component comprises the first and/or second and/or third metal alloy compositions in first and/or second and/or third regions of the outer layer of the component, respectively.

[0116] Suitably the component comprises the first and/or second and/or third metal alloy compositions in first and/or second and/or third regions of the inner core of the component, respectively.

[0117] Suitably the component comprises the first and/or second and/or third metal alloy compositions in first and/or second and/or third regions of the inner core and the outer layer of the component, respectively.

[0118] The component comprising an inner core of polycrystalline material and an outer layer of single crystal material may be formed by investment casting the outer layer around a preformed inner core.

[0119] The inventor has found that the casting of a single crystal outer layer of the component can provide the advantages of the single crystal material to the component without having to form the entire component from said single crystal material. This method can therefore provide a component with the advantageous mechanical properties of the single crystal material at a reduced manufacturing cost compared to known components. For example, the inventors have found this to be particularly advantageous in the manufacture of turbine aerofoils. The outer region of a turbine aerofoil is the region which is exposed to the highest temperature during engine operation. The outer region of the aerofoil is also the region where enhanced creep resistance is required and it is therefore the region where usage of single crystal material would provide the maximum benefit. The inner regions of the aerofoil are not exposed to as high a temperature as the outer surface of the aerofoil. Therefore this casting method can provide the advantages of the single crystal outer layer at a reduced cost due to the formation of a polycrystalline inner core.

[0120] Suitably the outer layer of the component comprises the first metal alloy composition as defined in the first aspect in at least a first region of the outer layer and a second metal alloy composition as defined in the second aspect in at least a second region of the outer layer.

[0121] Suitably the inner core of the component comprises the first metal alloy composition as defined in the first aspect in at least a first region of the inner core and a second metal alloy composition as defined in the second aspect in at least a second region of the inner core.

[0122] Suitably the component of this further aspect is a turbine aerofoil comprising a tip region, intermediate region and a root region, as described above, comprising the first, second and third metal alloy compositions respectively, in both the inner core and the outer layer.

Brief Description of the Drawings

[0123] Examples of the present disclosure will now be described with reference to the accompanying drawing, in which:
Figure 1 is a perspective view of a component according to the fourth aspect of the present invention.

Detailed Description

[0124] Figure 1 shows component (100) which is a turbine aerofoil formed of nickel-based alloys. The component (100) comprises a first region (110), a second region (120), a third region (130). The first region (110) of the component (100) comprises aerofoil tip (115) and extends approximately 10 mm from the tip along the aerofoil blade (125). The second region (120) of the component is an intermediate region comprising the main part of the aerofoil blade (125) which extends from the tip region (110) to the third region (130). The third region (130) of the component is a root region and comprises a platform (140) and a root (150), which are common parts of such turbine aerofoils with known functions.

[0125] The tip region (110) is formed of a nickel superalloy comprising:

6.0 to 7.5 wt% aluminium;
8.0 to 10.0 wt% chromium;
5.0 to 7.0 wt% cobalt;
2.0 to 3.0 wt% tungsten;
0.5 to 1.0 wt% tantalum;
2.0 to 3.0 wt% niobium;
1.0 to 2.0 wt% molybdenum;
0.5 to 2.0 wt% titanium;
0.05 to 0.15 wt% hafnium;
0.05 to 0.10 wt% silicon;
0 to 0.03 wt% yttrium;
0 to 0.1 wt% carbon;
0 to 0.05 wt% cerium and/or lanthanum; and
nickel to balance.

[0126] The intermediate region (120) is formed of a nickel superalloy comprising:

6.0 to 7.5 wt% aluminium;
5.0 to 7.0 wt% chromium;
5.0 to 8.0 wt% cobalt;
3.0 to 5.0 wt% iron;
6.0 to 8.0 wt% tungsten;
6.0 to 8.0 wt% tantalum;
1.0 to 3.0 wt% molybdenum;
0.6 to 1.0 wt% titanium;
0.1 to 0.3 wt% vanadium;
0.05 to 1.5 wt% hafnium;
0.05 to 0.10 wt% silicon;
0 to 0.1 wt% carbon;
0.005 to 0.01 wt% boron;
0.005 to 0.01 wt% zirconium;
0 to 0.05 wt% cerium and/or lanthanum; and
nickel to balance.

[0127] This root region (130) is formed of a nickel superalloy comprising:

3.0 to 5.0 wt% aluminium;
10.0 to 13.0 wt% chromium;
5.0 to 7.0 wt% cobalt;
3.0 to 5.0 wt% tungsten;
6.0 to 9.0 wt% tantalum;
3.0 to 5.0 wt% niobium;
0.0 to 0.25 wt% molybdenum;
0.7 to 1.0 wt% titanium
0.05 to 0.15 wt% hafnium;
0 to 0.1 wt% carbon; and
nickel to balance.

[0128] The turbine aerofoil (100) may be formed by a known method of manufacture, for example a casting process, a Hot Isostatic Pressing (HIP) process or a Spark Plasma Sintering (SIP) process.

[0129] After forming, the component is suitably subjected to a heat treatment in order to attain optimal properties. An example of a suitable heat treatment step is as follows:
A solutioning, homogenization and 'reduction in casting porosity' step by Hot Isostatic Pressing (HIP) consisting of:

a ramp up to 1,225 °C and 150 MPa (HIP) in 120 minutes,
a ramp up from 1,225 to 1,275 °C in 250 minutes,
a hold for 50 minutes at 1,275 °C,
a ramp down to 850 °C at 10 °C/minute while decreasing the pressure, and
a ramp down to ambient conditions at 70 °C/minute while further decreasing the pressure.

[0130] Further ageing heat treatment may then be carried at the end of HIP treatment. A suitable sequence of ageing treatments include:

a first ageing step of 4h at 1120 °C, and
a second ageing step of 24h at 845 °C.

[0131] In some embodiments, turbine aerofoil (100) comprises an inner core and an outer layer, wherein the inner core comprises a polycrystalline metal alloy composition and wherein the outer layer comprises a single crystal metal alloy composition. In said embodiments, both the inner core and the outer layer have the first, second and third metal alloy compositions described above in the tip, intermediate and root regions respectively. Suitably in said outer layer of the component which is a single crystal material, the boron, zirconium and/or hafnium is omitted from said metal alloy compositions.

[0132] The component (100) may have optimised properties in each of the tip, intermediate and root regions as described in relation to the first, second and third aspects of the present invention. In particular, the component (100) may have reduced centrifugal pull experienced by the tip region, improved creep strength and oxidation resistance in the intermediate region and improved low cycle fatigue strength in the root region, compared to known turbine aerofoils

[0133] In summary, the present invention provides a component, such as a turbine aerofoil, having different optimised metallic compositions in different regions of the component which may provide improved mechanical and chemical properties and may in particular have a reduced weight at the tip and root regions compared to known superalloy turbine aerofoils. The component comprises at least a first region formed of a nickel-based alloy comprising 6.0 to 7.5 wt% aluminium, 8.0 to 10.0 wt% chromium, 5.0 to 7.0 wt% cobalt, 2.0 to 3.0 wt% tungsten, 0.5 to 1.0 wt% tantalum, 2.0 to 3.0 wt% niobium, 1.0 to 2.0 wt% molybdenum, 0.5 to 2.0 wt% titanium; and nickel.

[0134] Throughout this specification, the term "comprising" or "comprises" means including the component(s) specified but not to the exclusion of the presence of other components. The term "consisting essentially of" or "consists essentially of" means including the components specified but excluding other components except for materials present as impurities, unavoidable materials present as a result of processes used to provide the components, and components added for a purpose other than achieving the technical effect of the invention. Typically, when referring to compositions, a composition consisting essentially of a set of components will comprise less than 5% by weight, typically less than 3% by weight, more typically less than 1% by weight of non-specified components.

[0135] The term "consisting of" or "consists of" means including the components specified but excluding addition of other components.

[0136] Whenever appropriate, depending upon the context, the use of the term "comprises" or "comprising" may also be taken to encompass or include the meaning "consists essentially of" or "consisting essentially of", and may also be taken to include the meaning "consists of" or "consisting of".

[0137] For the avoidance of doubt, wherein amounts of components in a composition are described in wt%, this means the weight percentage of the specified component in relation to the whole composition referred to. For example, "a metal alloy comprising 6.0 to 7.5 wt% aluminium" means that 6.0-7.5 wt% of the metal alloy is provided by aluminium.

[0138] Attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

[0139] All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive.

[0140] Each feature disclosed in this specification (including any accompanying claims, abstract and drawings) may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

[0141] The invention is not restricted to the details of the foregoing embodiment(s). The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

Claims

1. A metal alloy composition comprising:

6.0 to 7.5 wt% aluminium;
8.0 to 10.0 wt% chromium;
5.0 to 7.0 wt% cobalt;
2.0 to 3.0 wt% tungsten;
0.5 to 1.0 wt% tantalum;
2.0 to 3.0 wt% niobium;
1.0 to 2.0 wt% molybdenum;
0.5 to 2.0 wt% titanium; and
nickel.

2. The metal alloy composition according to claim 1, comprising up to 7.0 wt% molybdenum, tungsten and tantalum.

3. The metal alloy composition according to any one of the preceding claims, comprising any one or more of the following elements: 0.05 to 0.15 wt% hafnium, 0.05 to 0.10 wt% silicon, 0 to 0.1 wt% carbon, 0 to 0.05 wt% cerium and/or lanthanum.

4. The metal alloy composition according to claim 1 comprising:

6.0 to 7.5 wt% aluminium;
8.0 to 10.0 wt% chromium;
5.0 to 7.0 wt% cobalt;
2.0 to 3.0 wt% tungsten;
0.5 to 1.0 wt% tantalum;
2.0 to 3.0 wt% niobium;
1.0 to 2.0 wt% molybdenum;
0.5 to 2.0 wt% titanium;
0.05 to 0.15 wt% hafnium;
0.05 to 0.10 wt% silicon;
0 to 0.03 wt% yttrium;
0 to 0.1 wt% carbon;
0 to 0.05 wt% cerium and/or lanthanum; and
nickel to balance.

5. A component comprising a metal alloy composition according to any one of the preceding claims in at least a first region of the component.

6. The component according to claim 5, wherein the component is a turbine aerofoil and the first region is a tip region of the turbine aerofoil.

7. The component according to claim 5 or claim 6, comprising a second metal alloy composition in at least a second region of the component, the second metal alloy composition comprising:

6.0 to 7.5 wt% aluminium;
5.0 to 7.0 wt% chromium;
5.0 to 8.0 wt% cobalt;
3.0 to 5.0 wt% iron;
6.0 to 8.0 wt% tungsten;
6.0 to 8.0 wt% tantalum;

1.0 to 3.0 wt% molybdenum;
0.6 to 1.0 wt% titanium; and
nickel.

8. The component according to claim 7, wherein the second metal alloy composition comprises at least 18.0 wt% molybdenum, tungsten and tantalum.

9. The component according to claim 7 or claim 8, wherein the second metal alloy composition comprises:

6.0 to 7.5 wt% aluminium;
5.0 to 7.0 wt% chromium;
5.0 to 8.0 wt% cobalt;
3.0 to 5.0 wt% iron;
6.0 to 8.0 wt% tungsten;
6.0 to 8.0 wt% tantalum;
1.0 to 3.0 wt% molybdenum;
0.6 to 1.0 wt% titanium;
0.1 to 0.3 wt% vanadium;
0.05 to 1.5 wt% hafnium;
0.05 to 0.10 wt% silicon;
0 to 0.1 wt% carbon;
0.005 to 0.01 wt% boron;
0.005 to 0.01 wt% zirconium;
0 to 0.05 wt% cerium and/or lanthanum; and
nickel to balance.

10. The component according to any one of claims 5 to 9, comprising a third metal alloy composition in at least a third region of the component, the third metal alloy composition comprising:

3.0 to 5.0 wt% aluminium;
10.0 to 13.0 wt% chromium;
5.0 to 7.0 wt% cobalt;
3.0 to 5.0 wt% tungsten;
6.0 to 9.0 wt% tantalum;
3.0 to 5.0 wt% niobium
0.0 to 0.25 wt% molybdenum;
0.7 to 1.0 wt% titanium; and
nickel.

11. The component according to claim 10, wherein the third metal alloy composition comprises:

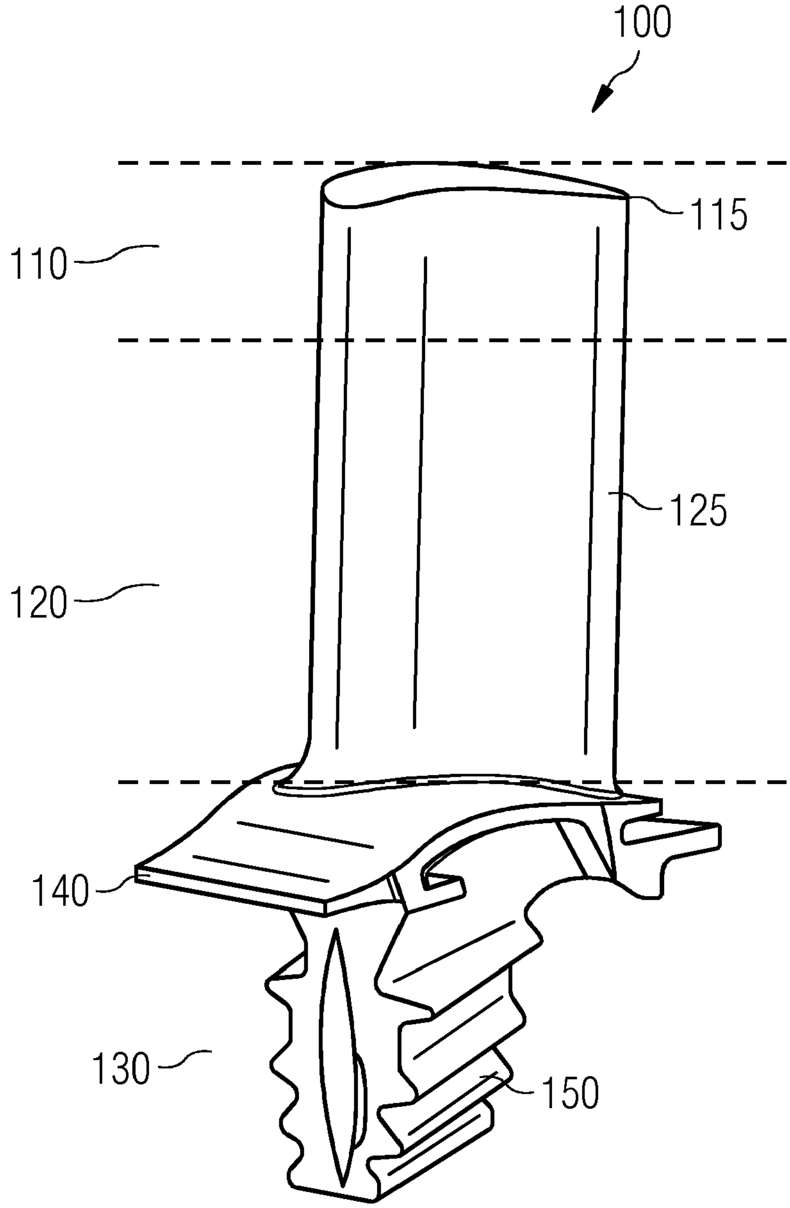
3.0 to 5.0 wt% aluminium;
10.0 to 13.0 wt% chromium;
5.0 to 7.0 wt% cobalt;
3.0 to 5.0 wt% tungsten;
6.0 to 9.0 wt% tantalum;
3.0 to 5.0 wt% niobium;
0.0 to 0.25 wt% molybdenum;
0.7 to 1.0 wt% titanium
0.05 to 0.15 wt% hafnium;
0 to 0.1 wt% carbon; and
nickel to balance.

12. An aerofoil comprising a tip region formed of a first metal alloy composition, an intermediate region formed of a second metal alloy composition and a root region formed of a third metal alloy composition, wherein the intermediate region is between the tip region and the root region and wherein the density of the first metal alloy composition in the tip region is less than the density of the second metal alloy composition in the intermediate region and/or the third metal alloy composition in the root region.

13. The component according to any of claims 5 to 12, comprising an inner core and an outer layer, wherein the inner core comprises a polycrystalline metal alloy composition and wherein the outer layer comprises a single crystal metal alloy composition.

14. The component according to claim 13, wherein the outer layer comprises the first metal alloy composition in at least a first region of the outer layer and a second metal alloy composition as defined in any one of claims 7, 8 and 9 in at least a second region of the outer layer.

15. The component according to claim 13 or claim 14, wherein the inner core comprises the first metal alloy composition in at least a first region of the inner core and a second metal alloy composition as defined in any one of claims 7, 8 and 9 in at least a second region of the inner core.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EUROPEAN SEARCH REPORT

Application Number
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C22C

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
Munich	30 November 2018	Rolle, Susett

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