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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 THE METAL ALLOY COMPONENTS AND THEIR MANUFACTURE**

(57) A component comprising at least two different iron-based compositions in different regions of the component, including a first iron-based composition comprising 11.0-15.0 wt% chromium; 1.0-4.0 wt% nickel; 5.0-8.0 wt% cobalt; and iron. The first iron-based composition may also comprise 2.0-6.0 wt% copper, 4.0-7.0 wt% molybdenum and one or more of niobium, manganese, silicon, and phosphorous. The component may be a compressor aerofoil for a gas turbine. A metal injection moulding method for forming a component and an apparatus for carrying out said method are also provided. The composition of the component and/or the method and apparatus may provide a reduction in delta ferrite formation in the component and an improvement in mechanical properties of the component, particularly in relation to compressor aerofoils.

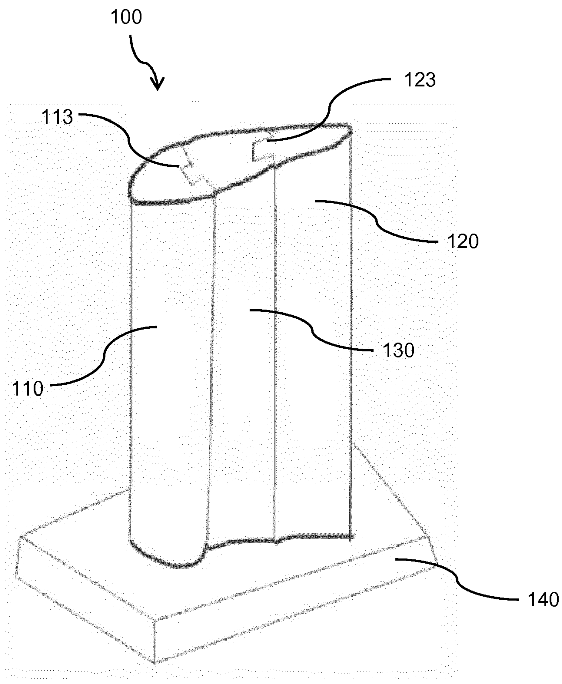

Fig. 2

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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 pitting corrosion resistance and mechanical properties. 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 compressor aerofoils formed from different iron-based compositions which are tailored to meet specific requirements in specific regions of the component and to reduce delta ferrite formation.

Background

[0003] Generally, pitting corrosion (also known as pitting) is a type of localized corrosion of a metal that results in the formation of pits (small holes) in the metal. A cause of pitting corrosion is depassivation of a typically small surface area of the metal, which becomes anodic while the remainder of the surface becomes cathodic, thereby resulting localised galvanic corrosion. This corrosion penetrates the surface of metal. Pitting corrosion typically occurs in alloys, for example stainless steels, nickel alloys and aluminium alloys, that are normally protected by passivation surface layers, for example oxide layers, in environments that contain aggressive species, for example chloride ions, are at elevated temperatures, have increased concentrations of oxidants and/or are acidic.

[0004] Generally, gas turbine components, for example rotating and stationary compressor blades (also known as aerofoils or airfoils), require at least a combination of high strength, toughness and fatigue resistance to withstand static and/or dynamic stresses, for example centripetal stresses and/or stress cycling, at operational temperatures. Stainless steels, for example ASTM P91, ASTM P92, GTD 450, SAE 400 series, SAE 600 series such as SAE type 630 (also known as 17-4 or 17-4PH; also known as UNS 17400), may meet these requirements. However, such components may also be susceptible to pitting corrosion, which may initiate fatigue cracking during high cycle fatigue, for example. Growth of such fatigue cracks may result in catastrophic failure of the components. In addition, such components may be susceptible to water droplet erosion (WDE) which may be caused by impingement of liquid water droplets sprayed on the components to provide cooling. WDE may also contribute towards fatigue of the components and ultimately failure. Leading edges of compressor blades may be particularly susceptible to pitting corrosion and/or WDE.

[0005] Conventional approaches to improving pitting corrosion resistance and/or WDE include providing ceramic coatings, modifying component design to reduce stresses and developing new alloys. However, such ceramic coatings may be susceptible to delamination. Modifying the component design to reduce stresses does not affect susceptibility to pitting corrosion and/or WDE. New alloy development may be costly, typically requiring new manufacturing processes and/or new qualification of components formed therefrom.

[0006] One steel material currently used to manufacture compressor aerofoils is 17-4PH which is a precipitation hardened martensitic stainless steel. The composition of 17-4PH is as follows:

15.0-17.5 wt% chromium;
3.0-5.0 wt% nickel;
3.0-5.0 wt% copper,
up to 0.5 wt% molybdenum;
up to 0.45 wt% niobium;
up to 1.0 wt% manganese;
up to 1.0 wt% silicon;
up to 0.03 wt% phosphorous; and
iron to balance.

[0007] 17-4PH is prone to delta ferrite formation predominantly in the longitudinal direction of the aerofoil which results in anisotropy in mechanical properties and a significant drop in the mechanical properties in the longitudinal direction. This drop in mechanical properties is believed to have caused numerous tip failures in compressor aerofoils manufactured from 17-4PH. The issues with delta ferrite formation and various corrosion issues due to pitting corrosion are observed in such compressor aerofoils.

[0008] Figure 1 shows the microstructure of a section taken in the longitudinal direction in a compressor aerofoil manufactured from 17-4PH. This image was produced after etching the section with 20% NaOH and processing the image to highlight the delta ferrite streaks (1). Figure 1 shows that the delta ferrite streaks are clearly visible in the sections taken in the longitudinal direction i.e. in the direction of deformation expected in use. The delta ferrite is typically seen to be aligned in the direction of working during manufacture of the compressor aerofoils from a rolled bar. It is evident based on the microstructure shown in Figure 1, that the delta-ferrite is elongated in the martensite matrix of the aerofoil. Based on analysis of the image of Figure 1, the percentage of delta ferrite at various locations was between 5.5 and 6 % which is above a desired level of free ferrite for maintaining acceptable mechanical performance. Although a small amount of delta ferrite can be beneficial for increasing tensile properties and resistance to stress-corrosion cracking, the levels of delta ferrite observed in Figure 1 are believed to significantly reduce toughness during use of the aerofoil and therefore risk failures of the aerofoil.

[0009] Hence, there is a need to improve pitting corrosion and/or reduce delta ferrite formation in said components.

Summary

[0010] It is one aim of the present invention, amongst others, to provide 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 components and methods of forming said components.

[0011] For instance it may be an aim of the present invention to provide a component, such as a compressor aerofoil, having a leading edge with improved resistance to pitting corrosion compared to prior art components.

[0012] It may be an alternative or additional aim of the present invention to provide a component, such as a compressor aerofoil, having a leading edge with improved resistance to damage from foreign objects compared to prior art components.

[0013] It may be an alternative or additional aim of the present invention to provide a component, such as a compressor aerofoil, having a reduced amount of delta ferrite compared to prior art components.

[0014] It may be an alternative or additional aim of the present invention to provide a method of forming a component, such as a compressor aerofoil, with a reduced amount of material wastage compared to prior art methods.

[0015] It may be an alternative or additional aim of the present invention to provide a method of forming a component, such as a compressor aerofoil, without requiring a joining process for forming a bond between regions of the component having different metal alloy compositions.

[0016] According to the present disclosure there is provided a component, a method of forming a component and an apparatus as set forth in the appended claims. Other features of the invention will be apparent from the dependent claims, and the description which follows.

[0017] According to a first aspect of the present invention, there is provided a component comprising a first iron-based composition in at least a first region of the component, the first iron-based composition comprising:

11.0-15.0 wt% chromium;
1.0-4.0 wt% nickel;
5.0-8.0 wt% cobalt; and
iron.

[0018] The iron-based composition is suitably a metal alloy comprising mainly iron with the specified alloying elements and optionally other alloying elements. The iron-based composition is suitably a steel.

[0019] The inventor has found that the addition of the specified alloying elements to the first iron-based composition may reduce delta ferrite formation in the component compared to a similar component formed of an iron-based composition of the prior art, such as 17-4PH, and therefore may improve the mechanical properties of the component.

[0020] The inventor has also found that the addition of the specified alloying elements to the first iron-based composition may also improve the pitting corrosion resistance of the first region of the component compared to a similar region of a component formed of an iron-based composition of the prior art, such as 17-4PH. As nickel and cobalt are austenite formers, the amount of nickel is lower in the first iron-based composition compared to 17-4PH to accommodate the cobalt in the first iron-based composition without increasing the austenite forming potential of the first iron-based composition whilst increasing pitting corrosion resistance.

[0021] The inventor has also found that the addition of the specified alloying elements to the first iron-based composition may also improve the resistance of the first region of the component to impacts of foreign objects compared to a similar region of a component formed of an iron-based composition of the prior art, such as 17-4PH. This may be particularly useful when the first region is a region of the component exposed to the outside environment in use, such as a leading edge region of a compressor aerofoil. This improvement may be at least partially due to the cobalt content of the first iron-based composition.

[0022] Suitably the first iron-based composition comprises 2.0-6.0 wt% copper, suitably 3.0-5.0 wt% copper.

[0023] Suitably the first iron-based composition comprises 4.0-7.0 wt% molybdenum. Suitably the first iron-based composition comprises 5.0-6.0 wt% molybdenum, suitably 5.5-6.0 wt%.

[0024] Suitably the first iron-based composition comprises:

11.0-15.0 wt% chromium;
1.0-4.0 wt% nickel;
5.0-8.0 wt% cobalt;
2.0-6.0 wt% copper;
4.0-7.0 wt% molybdenum; and
iron.

[0025] Suitably the first iron-based composition comprises:

12.0-14.0 wt% chromium;
2.0-3.0 wt% nickel;
6.0-7.0 wt% cobalt;
3.0-5.0 wt% copper;
5.0-6.0 wt% molybdenum; and
iron.

[0026] The inventor has found that the addition of molybdenum to the first iron-based composition may further improve the pitting corrosion resistance compared to a similar component formed of an iron-based composition of the prior art, such as 17-4PH. As chromium and molybdenum are ferrite and martensite formers, the amount of chromium is lower in the first iron-based composition compared to 17-4PH, to accommodate the molybdenum in the first iron-based composition without increasing the ferrite and martensite forming potential of the first iron-based composition whilst increasing pitting corrosion resistance. Molybdenum is considered to have a more significant effect on the pitting corrosion resistance of the first iron-based composition than chromium.

[0027] Suitably the first iron-based composition comprises one or more of niobium, manganese, silicon, and phosphorous, suitably in an amount of up to 1.0 wt%.

[0028] Suitably the first iron-based composition comprises niobium, suitably in an amount of up to 0.3 wt%, suitably approximately 0.3 wt%, suitably 0.3 wt%.

[0029] The addition of small amounts of niobium may have the advantage of providing an increase in strength of the component, for example an increase in the resistance to foreign object impacts.

[0030] Suitably the phosphorous, when present, is present in the first iron-based composition in an amount of up to 0.03 wt%.

[0031] Suitably the first iron-based composition comprises:

12.0-14.0 wt% chromium;
2.0-3.0 wt% nickel;
6.0-7.0 wt% cobalt;
3.0-5.0 wt% copper,
5.0-6.0 wt% molybdenum;
up to 0.5 wt% niobium;
up to 1.0 wt% manganese;
up to 1.0 wt% silicon;
up to 0.03 wt% phosphorous; and
iron to balance.

[0032] Suitably the first iron-based composition comprises niobium in an amount of at least 0.2 wt%. Suitably the first iron-based composition comprises manganese in an amount of at least 0.2 wt%. Suitably the first iron-based composition comprises silicon in amount of at least 0.8 wt%. Suitably the first iron-based composition comprises phosphorous in an amount of at least 0.02 wt%.

[0033] Suitably the first iron-based composition comprises:

12.0-14.0 wt% chromium;
2.0-3.0 wt% nickel;
6.0-7.0 wt% cobalt;
3.0-5.0 wt% copper,
5.0-6.0 wt% molybdenum;
0.2-0.5 wt% niobium;
0.4-1.0 wt% manganese;
0.8-1.0 wt% silicon;
0.02-0.03 wt% phosphorous; and
iron to balance.

[0034] Suitably the first region of the component comprises an edge of the component. Suitably the edge of the component is exposed to the environment during use of the component and is therefore susceptible to pitting corrosion and to impacts from foreign objects. As discussed above, the first iron-based composition of the component of this first aspect provides the first region with particular properties which would be advantageous at such an edge region.

[0035] Suitably the component is an iron-based component. Suitably the component is entirely formed from iron-based compositions, the compositions being different in the first region of the component compared to other regions of the component. Suitably the component is formed of a steel.

[0036] Suitably the component is a compressor aerofoil and the first region is a leading edge region of the compressor aerofoil. Suitably the component is a compressor aerofoil, suitably intended to operate at a temperature of 350 °C.

[0037] Suitably the component of this first aspect comprises a second iron-based composition in a second region of the component, the second iron-based composition comprising:

14.0-18.0 wt% chromium;
4.0-6.0 wt% nickel;
0.5-2.0 wt% cobalt;
optionally one or more of manganese, silicon, and phosphorous; and
iron.

[0038] Suitably the second iron-based composition comprises 2.0-6.0 wt% copper, suitably 3.0-5.0 wt% copper.

[0039] Suitably the second iron-based composition does not comprise molybdenum. Suitably the second iron-based composition does not comprise niobium. Suitably the second iron-based composition does not comprise molybdenum or niobium.

[0040] Suitably the second iron-based composition comprises a lower amount of cobalt compared to the first iron-based composition. Suitably the second iron-based composition comprises a higher amount of nickel compared to the first iron-based composition. Therefore the second iron-based composition is different to the first iron-based composition.

[0041] In embodiments wherein the component is a compressor aerofoil and the first region is a leading edge of the compressor aerofoil, the second region is suitably a trailing edge of the compressor aerofoil. The trailing edge of such a compressor aerofoil does not require the same level of pitting corrosion resistance and strength to resist foreign object impacts as required of the leading edge of the compressor aerofoil. Therefore, the second iron-based composition may advantageously comprise less of the expensive cobalt alloying element to save on the overall cost of manufacturing the component.

[0042] Suitably the second iron-based composition comprises:

14.0-18.0 wt% chromium;
2.0-6.0 wt% nickel;

0.5-2.0 wt% cobalt;
2.0-6.0 wt% copper;
optionally one or more of manganese, silicon, and phosphorous; and
iron.

[0043] Suitably the second iron-based composition comprises:

14.0-18.0 wt% chromium;
2.0-6.0 wt% nickel;
0.5-2.0 wt% cobalt;
2.0-6.0 wt% copper;
up to 1.0 wt% manganese;
up to 1.0 wt% silicon;
up to 0.03 wt% phosphorous; and
iron to balance.

[0044] Suitably the second iron-based composition comprises:

14.0-18.0 wt% chromium;
2.0-6.0 wt% nickel;
0.5-2.0 wt% cobalt;
2.0-6.0 wt% copper;
0.4-1.0 wt% manganese;
0.8-1.0 wt% silicon;
0.02-0.03 wt% phosphorous; and
iron to balance.

[0045] Suitably the second iron-based composition comprises:

15.0-17.0 wt% chromium;
3.0-5.0 wt% nickel;
1.0-1.5 wt% cobalt;
3.0-5.0 wt% copper;
up to 1.0 wt% manganese;
up to 1.0 wt% silicon;
up to 0.03 wt% phosphorous; and
iron to balance.

[0046] Suitably the second iron-based composition comprises:

15.0-17.0 wt% chromium;
3.0-5.0 wt% nickel;
1.0-1.5 wt% cobalt;
3.0-5.0 wt% copper;
0.4-1.0 wt% manganese;
0.8-1.0 wt% silicon;
0.02-0.03 wt% phosphorous; and
iron to balance.

[0047] Suitably the first and second regions of the component are shaped to interlock with adjacent regions of the component. The first and second regions being shaped in this way may improve the mechanical properties of the join between the first and second regions and the adjacent regions and therefore improve the mechanical properties of the component.

[0048] Suitably the component of this first aspect comprises a third iron-based composition in a third region of the component, the third iron-based composition comprising:

14.0-18.0 wt% chromium;
2.0-4.0 wt% nickel;
1.0-4.0 wt% cobalt;
optionally one or more of niobium, manganese, silicon, and phosphorous; and
iron.

[0049] Suitably the third iron-based composition comprises 2.0-6.0 wt% copper, suitably 3.0-5.0 wt% copper.

[0050] Suitably the third iron-based composition does not comprise molybdenum.

[0051] Suitably the third iron-based composition comprises a lower amount of cobalt compared to the first iron-based composition and a higher amount of cobalt than the second iron-based composition. Suitably the third iron-based composition comprises a higher amount of nickel compared to the first iron-based composition and a lower amount of nickel compared to the second iron-based composition. Therefore the third iron-based composition is different to the first iron-based composition and the second iron-based composition. The variation in these alloying elements described above provides a gradual transition in chemical composition which may advantageously provide a gradual transition in mechanical properties from the first iron-based composition through the third iron-based composition to the second iron-based composition. Such a gradual transition may provide an improved bond between the different regions of the component which avoids a mechanical weakness seen in prior art components formed from more significantly different iron-based compositions, for example by joining different regions of a component having different compositions together by brazing.

[0052] Suitably the third region of the component is arranged between and in contact with the first region and the second region of the component.

[0053] In embodiments wherein the component is a compressor aerofoil and the first region is a leading edge of the compressor aerofoil and the second region is a trailing edge of the compressor aerofoil, the third region is suitably an intermediate region arranged between and in contact with the leading edge and the trailing edge regions. The intermediate region of such a compressor aerofoil does not require the same level of pitting corrosion resistance and strength to resist foreign object impacts as required of the leading edge of the compressor aerofoil. Therefore, the third iron-based composition may advantageously comprise less of the expensive cobalt alloying element to save on the overall cost of manufacturing the component.

[0054] Suitably the third iron-based composition comprises:

14.0-18.0 wt% chromium;
2.0-4.0 wt% nickel;
1.0-4.0 wt% cobalt;
2.0-6.0 wt% copper;
optionally one or more of niobium, manganese, silicon, and phosphorous; and
iron.

[0055] Suitably the third iron-based composition comprises:

14.0-18.0 wt% chromium;
2.0-4.0 wt% nickel;
1.0-4.0 wt% cobalt;
2.0-6.0 wt% copper;
up to 0.2 wt% niobium;
up to 1.0 wt% manganese;
up to 1.0 wt% silicon;
up to 0.03 wt% phosphorous; and
iron to balance.

[0056] Suitably the third iron-based composition comprises:

14.0-18.0 wt% chromium;
2.0-4.0 wt% nickel;
1.0-4.0 wt% cobalt;
2.0-6.0 wt% copper;
0.1-0.2 wt% niobium;
0.4-1.0 wt% manganese;
0.8-1.0 wt% silicon;
0.02-0.03 wt% phosphorous; and
iron to balance.

[0057] Suitably the third iron-based composition comprises:

15.0-17.0 wt% chromium;
2.5-3.5 wt% nickel;
2.0-3.0 wt% cobalt;
3.0-5.0 wt% copper;
up to 0.2 wt% niobium;
up to 1.0 wt% manganese;
up to 1.0 wt% silicon;
up to 0.03 wt% phosphorous; and
iron to balance.

[0058] Suitably the third iron-based composition comprises:

15.0-17.0 wt% chromium;
2.5-3.5 wt% nickel;
2.0-3.0 wt% cobalt;
3.0-5.0 wt% copper;
0.1-0.2 wt% niobium;
0.4-1.0 wt% manganese;
0.8-1.0 wt% silicon;
0.02-0.03 wt% phosphorous; and
iron to balance.

[0059] Suitably the first, second and third regions of the component are shaped so that the third region interlocks with the first and second regions of the component.

[0060] According to a second aspect of the present invention, there is provided a component comprising:

a first iron-based composition in at least a first region of the component, the first iron-based composition comprising chromium, nickel, cobalt and iron;

a second iron-based composition in at least a second region of the component, the second iron-based composition comprising chromium, nickel, cobalt and iron;

wherein the second iron-based composition comprises a lower amount of cobalt than the first iron-based composition and wherein the second iron-based composition comprises a higher amount of nickel than the first iron-based composition.

[0061] The component, first iron-based composition and second iron-based composition of this second aspect may have any of the suitable features and advantages described in relation to the first aspect.

A method of forming a component by metal injection moulding

[0062] According to the third aspect of the present invention, there is provided a method of forming a component, the 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 method comprising the steps of:

a) depositing the first metal alloy composition into a first section of a mould;

b) depositing the second metal alloy composition into a second section of the mould;

c) allowing the first metal alloy composition and the second metal alloy composition to solidify in the mould to provide a preform of the component;

d) removing the preform of the component from the mould;

e) processing the preform of the component to provide the component.

[0063] Suitably the method of this third aspect is a metal injection moulding (MIM) process.

[0064] Steps a) and b) may be carried out in any order or simultaneously. Suitably steps a) and b) are carried out simultaneously. Suitably the remaining steps c)-e) are carried out after steps a) and b) in the order of step c) followed by step d) followed by step e).

[0065] Using the method of this third aspect to form the component may advantageously allow the manufacture of such a component with a reduced amount of material wastage compared to prior art methods. The method may also advantageously provide a component, such as a compressor aerofoil, formed from different metal alloy compositions in different regions of the component without requiring a joining process for forming a bond between said regions. Such a component may therefore have improved mechanical properties compared to a similar component formed using a joining process.

[0066] Suitably, step a) is carried out by extruding the first metal alloy composition into the first section of the mould. Suitably, step b) is carried out by extruding the second metal alloy composition into the second section of the mould.

[0067] Suitably steps a) and b) are carried out by extruding the first and second metal alloy compositions into the first and second sections of the mould through a die.

[0068] In embodiments wherein the first and second regions of the component are shaped to interlock with adjacent regions of the component, suitably steps a) and b) are carried out by extruding the first and second metal alloy compositions into the first and second sections of the mould through a die, wherein the die shapes the first and second metal alloy compositions to interlock with adjacent regions of the component. For example, the die may impart a profile on the first and second metal alloy compositions which defines interlocking male and female parts which resist the first and second regions being pulled away from their adjacent regions.

[0069] Additionally or alternatively, sliding cores, ejectors and other moving components can be used to divide the mould into said sections to facilitate formation of the component in this method of the third aspect. For example, a removable core can be used to form a female interlocking profile in the first section of the mould. In this variant of the injection moulding process, the first metal alloy composition is injected into the first section of the mould and allowed to solidify. The removable core is then removed. The second metal alloy composition is then injected into the second section of the mould to form the male interlocking profile cavity against the female interlocking profile of the first metal alloy composition. This sequence may be repeated for any number of different metal alloy compositions, for example a third metal alloy composition as described above. Depending on the complexity of the inner cavities of the aerofoil, the injection unit along with the individual mould sections and/or removable cores can all be rotated or moved in a desired sequence to inject and solidify the various material compositions.

[0070] Therefore step a) may be preceded by a step of placing a first removable core into the mould to define and provide the first section of the mould. Step a) may be followed by a step of removing the removable core from the mould before step b) is carried out, suitably after the first metal alloy composition has solidified. Therefore step c) may involve allowing the second metal alloy composition to solidify, the first metal alloy composition having already solidified.

[0071] These steps may be repeated and adapted appropriately to provide further metal alloy compositions in further regions of the component. For example, to provide a component having a third region comprising a third metal alloy composition wherein the third region is located between the first and second regions of the component, a second removable core may be placed into the mould to define the second section of the mould and a third section of the mould. The second removable core may then be removed after depositing and solidifying of the third metal alloy composition in the third section of the mould before the second metal alloy composition is deposited and solidified in the second section of the mould.

[0072] Suitably the first metal alloy composition and the second metal alloy composition are admixed with a binder before steps a) and b) are carried out.

[0073] The binder is suitably a material that is chemically compatible with the metallic powder and allows the required processing, i.e. mixing, injection, solidification and finally leaching to be carried out. The binder may be a thermoplastic resin. The binder may be selected from a polyacrylate, a polyethylene or a polypropylene. In some embodiments the binder may be water, oil or wax.

[0074] The admixtures of metal alloy composition and binder may comprise up to 70 wt% binder, suitably from 30 to 50 wt% binder.

[0075] Suitably step e) involves removing the binder from the preform of the component. Suitably step e) involves removing the binder from the preform of the component with a solvent.

[0076] Suitably step e) involves sintering the preform of the component, suitably after the solvent has been removed from the preform of the component. Sintering may be carried out at a temperature of from 950 °C and 1,800 °C.

[0077] After step e), the component may then be removed from the apparatus used to carry out the injection moulding and allowed to cool.

[0078] The method of this third aspect may involve, after step e), a step f) of heat treating the component. Suitably step f) involves heating the component at a temperature greater than 1,000 °C for at least 2 hours. Suitably step f) involves heating the component in a solution at a temperature of at least 800 °C, suitably followed by quenching, suitably in a salt bath. Suitably step f) involves ageing the component at a temperature of between 400 and 600 °C for at least 1 hour. Suitably step f) involves each of the heating and ageing steps discussed above.

[0079] In one embodiment, the component comprises a third metal alloy composition in a third region of the component and the method comprises a step of depositing the third metal alloy composition into a third section of the mould. Suitably the third region of the component is arranged between and in contact with the first region and the second region of the component.

[0080] In embodiments wherein the first, second and third regions of the component are shaped so that the third region interlocks with the first and second regions of the component, suitably steps a) and b) are carried out by extruding the first, second and third metal alloy compositions into the first, second and third sections of the mould through a die, wherein the die shapes the first, second and third metal alloy compositions so that the third region interlocks with the first and second regions of the component. For example, the die may impart a profile on the first, second and third metal alloy compositions which defines interlocking male and female parts which resist the first, second and third regions being pulled apart.

[0081] The component and the first, second and third metal alloy compositions of this third aspect may have any of the suitable features and advantages described in relation to the component and the first, second and third iron-based compositions of the first aspect.

[0082] Suitably the method of this third aspect provides a method of forming a component according to the first or second aspects, wherein the first metal alloy composition is the first iron-based composition and the second metal alloy composition is the second iron-based composition.

[0083] According to a fourth aspect of the present invention, there is provided an apparatus for forming a metal alloy component, the apparatus comprising:

a mould comprising a cavity shaped to correspond to the shape of said component or a component preform, and an opening for receiving metal alloy compositions into the cavity; and

at least two depositing mechanisms with separate feeds for said metal alloy compositions, the depositing mechanisms arranged adjacent to the opening of the mould and adjacent to each other.

[0084] Suitably the mould is formed from separable mould parts to enable the mould to be opened to remove said component.

[0085] Suitably the depositing mechanisms with separate feeds are extruders, suitably rotating screw extruders. Suitably the extruders comprise hoppers for receiving said metal alloy compositions. Suitably the hoppers are heated.

[0086] Suitably the apparatus comprises a die arranged between the depositing mechanisms and the opening, for shaping said metal alloy compositions. Suitably the die has a profile adapted to impart an interlocking shape on said metal alloy compositions passing through the die from the adjacent at least two depositing mechanisms.

[0087] Suitably the apparatus of this fourth aspect is a metal injection moulding apparatus.

Brief Description of the Drawings

[0088] Examples of the present disclosure will now be described with reference to the accompanying drawings, in which:

Figure 1 is a processed microscopic image of a longitudinal section of a prior art compressor aerofoil;

Figure 2 is a perspective view of a component according to the first aspect of the present invention; and

Figure 3 is a schematic of a metal injection moulding apparatus according to the fourth aspect of the present invention being used to carry out a method according to the third aspect of the present invention.

Detailed Description

[0089] Figure 2 shows component (100) which is a compressor aerofoil formed of a steel with a different composition in different regions of the aerofoil (100). The component (100) comprises a first region (110) which is a leading edge region of the aerofoil, a second region (120) which is a trailing edge region of the aerofoil, a third region (130) which is an intermediate region of the aerofoil between the leading and trailing edge regions and a platform (140), which are common parts of such compressor aerofoils with known functions.

[0090] The leading edge region (110) of the aerofoil (100) has the following iron-based composition:

12.0-14.0 wt% chromium;
2.0-3.0 wt% nickel;
6.0-7.0 wt% cobalt;
3.0-5.0 wt% copper,
5.0-6.0 wt% molybdenum;
0.2-0.5 wt% niobium;
0.4-1.0 wt% manganese;
0.8-1.0 wt% silicon;
0.02-0.03 wt% phosphorous; and
iron to balance.

[0091] The trailing edge region (120) of the aerofoil (100) has the following iron-based composition:

15.0-17.0 wt% chromium;
3.0-5.0 wt% nickel;
1.0-1.5 wt% cobalt;
3.0-5.0 wt% copper;
0.4-1.0 wt% manganese;

0.8-1.0 wt% silicon;
0.02-0.03 wt% phosphorous; and
iron to balance.

[0092] The intermediate region (130) of the aerofoil (100) has the following iron-based composition:

15.0-17.0 wt% chromium;
2.5-3.5 wt% nickel;
2.0-3.0 wt% cobalt;
3.0-5.0 wt% copper;
0.1-0.2 wt% niobium;
0.4-1.0 wt% manganese;
0.8-1.0 wt% silicon;
0.02-0.03 wt% phosphorous; and
iron to balance.

[0093] The leading edge region (110) is adjacent to and in contact with the intermediate region (130) at a first interface (113) which runs through aerofoil (100) in a longitudinal direction. The trailing edge region (120) is adjacent to and in contact with the intermediate region (130) at a second interface (123) which runs through aerofoil (100) in a longitudinal direction. The first and second interfaces (113 and 123) are shaped to provide an interlocking of the respective regions. The first interface (113) defines a female profile in the leading edge region (110) and a complementary male profile in the intermediate region (130). The second interface (123) defines a female profile in the intermediate region (130) and a complementary male profile in the trailing edge region (120). Said male and female profiles interlock in the aerofoil (100) to provide resistance to the adjacent regions separating in a transverse direction (i.e. in a direction between the leading and trailing edges) to improve the mechanical integrity of the aerofoil (100) comprising the different regions having different compositions.

[0094] The different compositions of the leading edge region (110), the intermediate region (130) and the trailing edge region (120) may provide the aerofoil (100) with improved mechanical properties compared to a similar aerofoil formed from a single known iron-based composition such as 17-4PH. The leading edge region (110) may provide the leading edge of the aerofoil (100) with improved pitting corrosion resistance and improved resistance to impacts from foreign objects which may strike the aerofoil (100) in use, due to the optimised amounts of alloying elements. The composition of the trailing edge region (120) may provide a cost saving due to the lower amount of expensive alloying elements such as cobalt compared to the leading edge region (110). The composition of the intermediate region (130) may provide a more gradual change in composition between the leading edge region (110) and the trailing edge region (120) than may otherwise be possible if only two different iron-based compositions were used to form the aerofoil (100). This gradual change in composition may avoid the negative effects on mechanical properties observed with prior art components which have used significantly different compositions in adjacent regions of such components. The compositions of each of the leading edge region (110), the intermediate region (130) and the trailing edge region (120) may provide a reduced tendency to form delta ferrite structures in the aerofoil (100) compared with prior art aerofoils, due to the optimised amounts of alloying elements in each iron-based composition, in particular the amounts of nickel, cobalt and copper. Suitably the aerofoil (100) is essentially free of delta ferrite.

Formation of the component by metal injection moulding

[0095] Figure 3 shows an apparatus (200) for forming a component such as a compressor aerofoil (100) by metal injection moulding. The apparatus (200) comprises a first, second and third extruder (210, 220 and 230), each comprising a hopper (211, 221 and 231) for receiving metal alloy compositions and feeding said metal alloy compositions into the extruders (210, 220 and 230). Each extruder may be a rotating screw extruder. Each extruder (210, 220 and 230) is provided with a die (212, 222 and 232) for shaping the metal alloy composition from the extruders into the interlocking shape discussed in relation to Figure 2. The extruders (210, 220 and 230) are arranged above and adjacent to the mould (240). The mould (240) has a shape which corresponds to a component, such as an aerofoil (100), and is formed of two mould parts (242 and 243). Although the mould (240) as shown in Figure 3 is divided into the two mould parts (242 and 243) horizontally, the mould may alternatively be divided vertically which may improve the ease of removal of the component from the mould.

[0096] The mould (240) comprises a cavity (250) into which the extruders (210, 220 and 230) deposit metal alloy compositions, in use. The cavity can be nominally divided into a first, second and third cavity section (251, 251 and 253) divided by the dotted lines shown in Figure 3.

[0097] In order to form a component such as an aerofoil (100) by metal injection moulding, the following procedure is carried out using the apparatus (200).

[0098] Fine metallic powders of first, second and third metal alloy compositions which correspond to the compositions of the leading edge region (110), the trailing edge region (120) and the intermediate region (130) of aerofoil (100) are each thoroughly mixed with a binder to provide first, second and third metal alloy and binder mixtures which are then separately charged into the first, second and third hoppers (211, 221 and 231) respectively. Although several industrial processes are available for the production of alloys in the initial powder form, inert gas atomisation is a preferred method for the production of spherical powder particles. The powder particle sizes produced by this method are normally in the range from around 5 to 45 μm. The initial average powder particle size, particle size distribution and the shape of the metal powder particles may influence the injection viscosity and subsequently the integrity of the final product. The powders of first, second and third metal alloy compositions suitably have a range of both small and large particle sizes in order to obtain a high initial packing density.

[0099] The first, second and third metal alloy and binder mixtures are then heated to melt the binder components to provide first, second and third liquid metal alloy and binder mixtures which comprise metallic powders coated with binder. The first, second and third liquid metal alloy and binder mixtures are then extruded through the first, second and third extruders respectively (210, 220 and 230), through the dies (212, 222 and 232) and into the cavity (250) of the mould (240). The first liquid metal alloy and binder mixture is deposited into the first cavity section (251), the second liquid metal alloy and binder mixture into the second cavity section (252) and the third liquid metal alloy and binder mixture into the third cavity section (253). The dies (212, 222 and 232) provide liquid metal alloy and binder mixtures with the interlocking profile discussed above and as shown in Figure 2. Each liquid metal alloy and binder mixture is in contact with the adjacent liquid metal alloy and binder mixture and in contact with walls of the mould which define the cavity (250). The liquid metal alloy and binder mixtures retain the shape imparted on them by the dies (212, 222 and 232) after depositing into the cavity (250).

[0100] Although in this specific example three different metal alloy compositions, hoppers, extruders and cavity sections are used, any number of said different metal alloy compositions, hoppers, extruders and cavity sections can be used as required to form specific components with different metal alloy compositions.

[0101] The first, second and third liquid metal alloy and binder mixtures are then solidified in the mould (240) to produce a component preform. The mould (240) may be heated to avoid excessively rapid cooling and solidification of the binder which can subsequently result in a brittle component preform. Said heating of the mould (240) could be targeted at specific regions of the component likely to become brittle during solidification.

[0102] Once the first, second and third liquid metal alloy and binder mixtures have solidified, the two mould parts (242 and 243) are separated and the component preform is removed. The term "green state" may alternatively be used to describe the component preform. Both of these terms are used in the art to denote a solidified mixture of metal alloy composition and binder having an approximate shape of a finished component after injection moulding. The component preform is brittle at this stage of the process.

[0103] The component preform is then washed with a suitable solvent known in the art to remove the binder from the metal alloy composition. Then the component preform is sintered by heating to a temperature in the range of 950 °C to 1,800°C and holding at that temperature for 2-6 hours. The sintering increases the density of the component preform by the formation of bonding between metallic particles of the metal alloy compositions. The sintering temperature is suitably selected to be a temperature below the solidus temperature of the powders of first, second and third metal alloy compositions. However, the sintering temperature needs to be high enough for the powders of first, second and third metal alloy compositions to fuse together and consolidate. The use of the gradual variation in metal alloy compositions as described above enables the sintering process to achieve near perfect inter-particle bonding which may not have been possible with prior art components having significantly different metal alloy compositions. This sintering process may provide an improved bond between the different regions of the component compared to a joining process of the prior art, such as a brazing process.

[0104] The component then undergoes a heat treatment step to improve the ultimate tensile strength of the component. An example of a suitable heat treatment step is as follows:

a) homogenization heat treatment for approximately 10 hours at 1,200 °C;
b) solution treatment at 1,050° C for 1 hour followed by quenching in a salt bath maintained at 150 °C;
c) ageing at approximately 480 °C for around 90 minutes.

[0105] The component produced by this method, for example a compressor aerofoil, may have the desired strength in the appropriate regions of the component and may be free from delta ferrite. The elimination of delta ferrite would result in uniform mechanical properties in both longitudinal and transverse directions and prevent tip failures observed in compressor aerofoils of the prior art.

[0106] This method may also provide the advantage that the amount of material wastage in the production of such components using prior art methods can be significantly reduced, improving the cost-effectiveness of the process.

[0107] A similar metal injection moulding process may be used to form other components, for example an aerofoil root. Alternatively, a mould could be used which provides for the formation of an aerofoil root in combination with the aerofoil moulding described above, to avoid the need to bond these two parts together.

[0108] In summary, the present invention provides a component, such as a compressor aerofoil, having different optimised metallic compositions in different regions of the component which may provide improved mechanical properties and improved pitting corrosion resistance and may in particular eliminate the formation of delta ferrite in the component. The component comprises at least two different iron-based compositions in different region of the component, including a first iron-based composition comprising 11.0-15.0 wt% chromium; 1.0-4.0 wt% nickel; 5.0-8.0wt% cobalt; and iron. The first iron-based composition may also comprise comprises 2.0-6.0 wt% copper, 4.0-7.0 wt% molybdenum and one or more of niobium, manganese, silicon, and phosphorous. A metal injection moulding method for forming a component and an apparatus for carrying out said method are also provided.

[0109] 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.

[0110] The term "consisting of" or "consists of" means including the components specified but excluding addition of other components.

[0111] 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".

[0112] 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, "the first iron-based composition comprises 11.0-15.0 wt% chromium" means that 11.0-15.0 wt% of the first iron-based composition is provided by chromium.

[0113] 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.

[0114] 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.

[0115] 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.

[0116] 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 component comprising a first iron-based composition in at least a first region of the component, the first iron-based composition comprising:

   11.0-15.0 wt% chromium;
   1.0-4.0 wt% nickel;
   5.0-8.0 wt% cobalt; and
   iron.

2. The component according to claim 1, wherein the first iron-based composition comprises 2.0-6.0 wt% copper.

3. The component according to claim 1 or claim 2, wherein the first iron-based composition comprises 4.0-7.0 wt% molybdenum.

4. The component according to any one of the preceding claims, wherein the first iron-based composition comprises one or more of niobium, manganese, silicon, and phosphorous.

5. The component according to any one of the preceding claims, wherein the first iron-based composition comprises:

   12.0-14.0 wt% chromium;
   2.0-3.0 wt% nickel;
   6.0-7.0 wt% cobalt;
   3.0-5.0 wt% copper,
   5.0-6.0 wt% molybdenum;
   0.2-0.5 wt% niobium;
   0.4-1.0 wt% manganese;
   0.8-1.0 wt% silicon;
   0.02-0.03 wt% phosphorous; and
   iron to balance.

6. The component according to any one of the preceding claims, wherein the component is a compressor aerofoil and the first region is a leading edge region of the compressor aerofoil.

7. The component according to any one of the preceding claims, comprising a second iron-based composition in a second region of the component, the second iron-based composition comprising:

   14.0-18.0 wt% chromium;
   2.0-6.0 wt% nickel;

0.5-2.0 wt% cobalt;
optionally one or more of manganese, silicon, and phosphorous; and
iron.

8. The component according to any one of the preceding claims, comprising a third iron-based composition in a third region of the component, the third iron-based composition comprising:

14.0-18.0 wt% chromium;
2.0-4.0 wt% nickel;
1.0-4.0 wt% cobalt;
optionally one or more of niobium, manganese, silicon, and phosphorous; and
iron.

9. A method of forming a component, the 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 method comprising the steps of:

a) depositing the first metal alloy composition into a first section of a mould;
b) depositing the second metal alloy composition into a second section of the mould;
c) allowing the first metal alloy composition and the second metal alloy composition to solidify in the mould to provide a preform of the component;
d) removing the preform of the component from the mould;
e) processing the preform of the component to provide the component.

10. The method according to claim 9, wherein the first metal alloy composition and the second metal alloy composition are admixed with a binder before steps a) and b) are carried out.

11. The method according to claim 10, wherein step e) involves removing the binder from the preform of the component.

12. The method according to any one of claims 9 to 11, wherein step e) involves sintering the preform of the component.

13. The method according to any one of claims 9 to 12, wherein the component is a component according to any one of claims 1 to 8 and wherein the first metal alloy composition is the first iron-based composition and the second metal alloy composition is the second iron-based composition.

14. An apparatus for forming a metal alloy component, the apparatus comprising:

a mould comprising a cavity shaped to correspond to the shape of said component or a component preform, and an opening for receiving metal alloy compositions into the cavity; and
at least two adjacent depositing mechanisms with separate feeds for said metal alloy compositions, the depositing mechanisms arranged adjacent to the opening of the mould.

15. The apparatus according to claim 14 comprising a die arranged between the depositing mechanisms and the opening, for shaping said metal alloy compositions, wherein the die has a profile adapted to impart an interlocking shape on said metal alloy compositions passing through the die from the adjacent at least two depositing mechanisms.

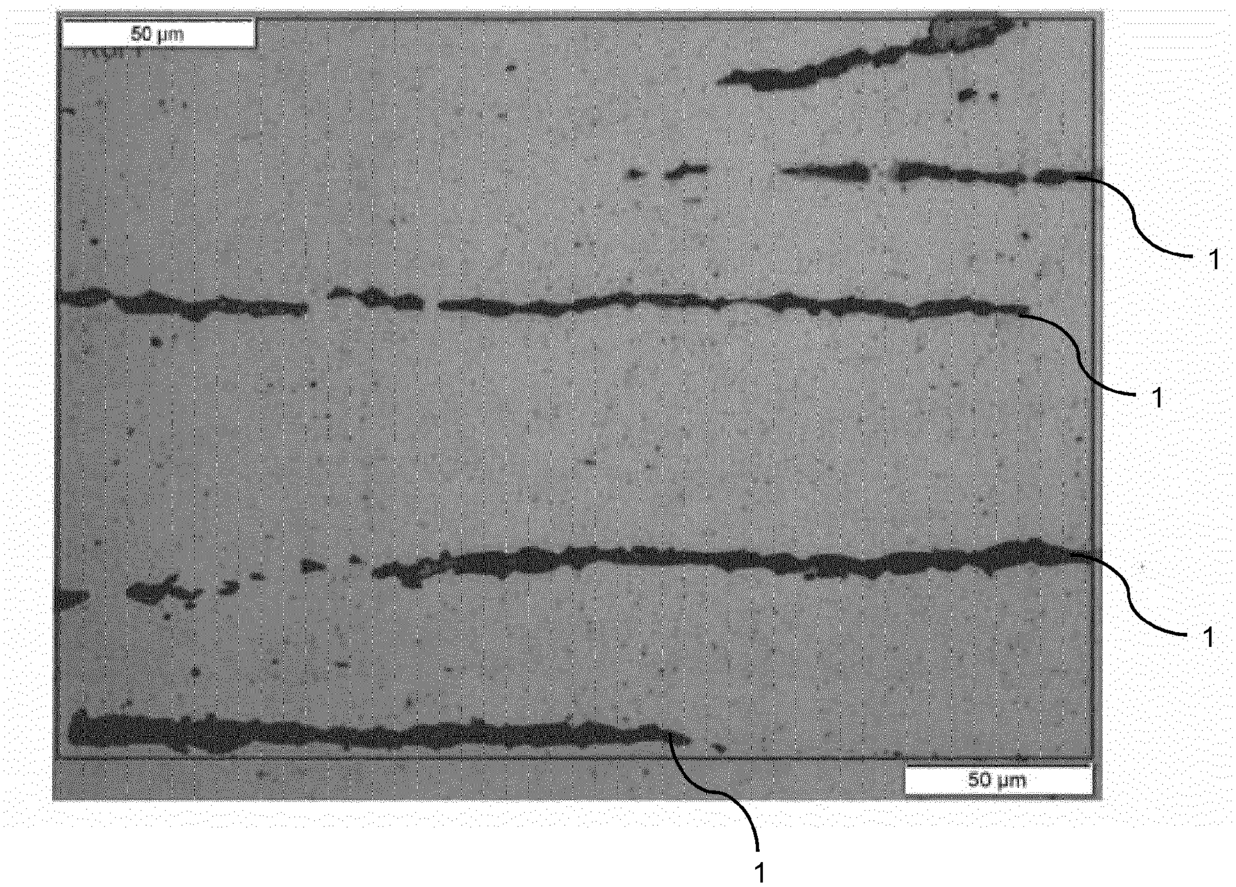

Fig. 1

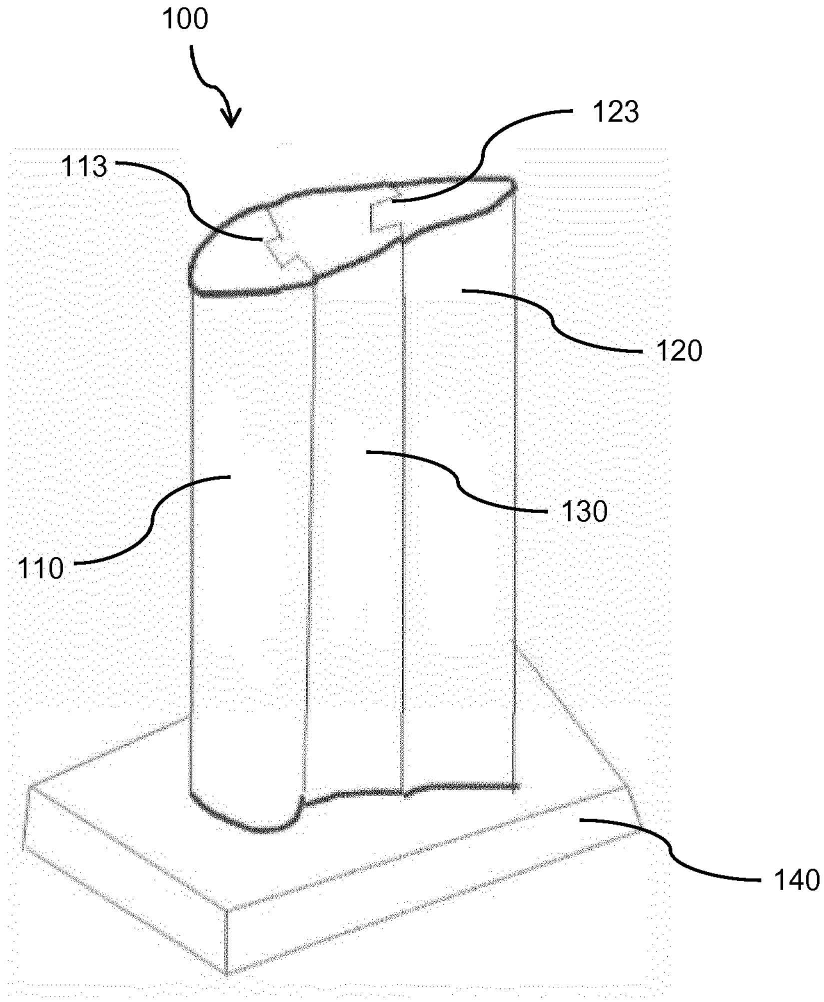

Fig. 2

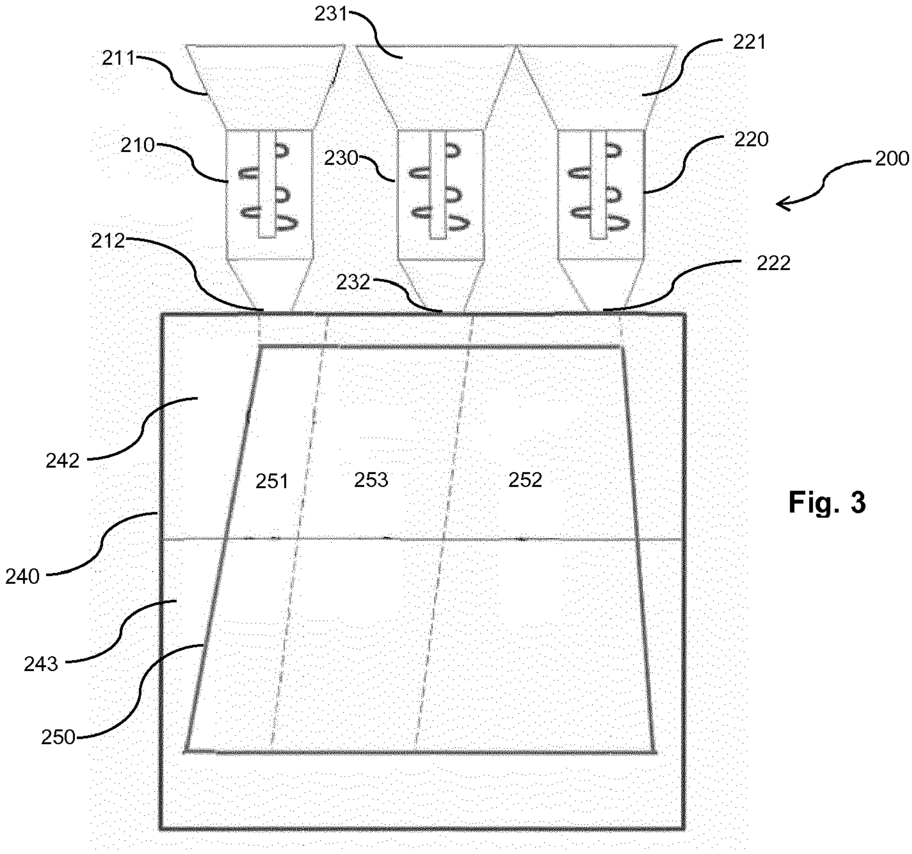
231
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Fig. 3

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EUROPEAN SEARCH REPORT

Application Number
EP 18 15 9319

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X A	JP 2000 192196 A (SUMITOMO METAL IND) 11 July 2000 (2000-07-11) * abstract; claims 1,2 * * paragraph [0001]; table 1 *	1-6 7,8	INV. C22C38/02 C22C38/04 C22C38/42 C22C38/44 C22C38/48 C22C38/52 B22F3/22 B22F5/04 B23P15/04 F01D5/00 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
The Hague	19 June 2018	Rausch, Elisabeth

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

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Application Number
EP 18 15 9319

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

☐ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

☒ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

1-8

☐ The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).

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LACK OF UNITY OF INVENTION SHEET B

Application Number
EP 18 15 9319

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1-8

   Component comprising a first iron-based composition in at least a first region of the component, the first iron-based composition comprising: 11-15% Cr, 1-4% Ni and 5-8 % Co and Fe.

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2. claims: 9-13

   Method of forming a component, the 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.

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3. claims: 14, 15

   Apparatus for forming a metal alloy component

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 18 15 9319

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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19-06-2018

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82