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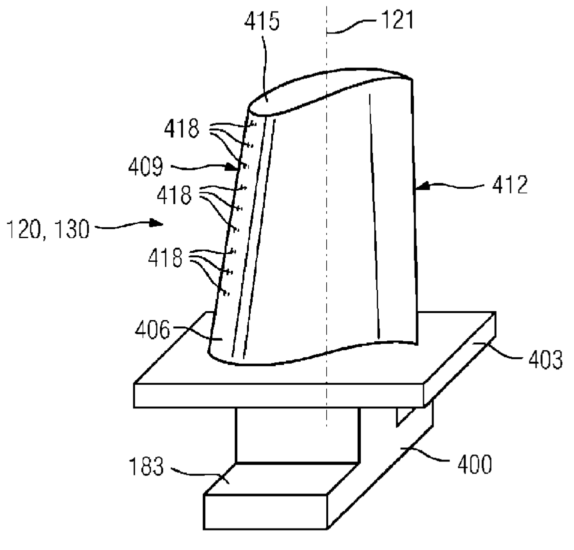

FIG. 1

(57) **Abstract:** The present disclosure relates to novel nickel-base alloy compositions including 7.25-7.75 wt% Cr, 0.6-1.0 wt% Mo, 8.5-9.1 wt% W, 6.0-6.4 wt% Al, 0.6-1.0 wt% Ti, 0.06-0.10 wt% C, 0.01-0.02 wt% B, 0.4-0.6 wt% Hf, and at least one of: 8.6-9.6 wt% Co and 4.0-4.8 wt% Ta; or 8.6-9.4 wt% Co, 3.8-4.4 wt% Ta, and 0.4-0.6 wt% Re, with the balance being nickel and trace impurities. Gas turbine blades or guide vanes are also provided, where the blades or vanes are formed using an alloy having such compositions.

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HIGH-TEMPERATURE NICKEL-BASED ALLOYS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to and the benefit of the filing date of U.S. Provisional Application No. 62/479,573, filed March 31, 2017, the entirety of which is hereby incorporated by reference.

TECHNICAL FIELD

[0002] This disclosure relates in general to the field of nickel-based alloys. More particularly, it relates to such alloys that may possess improved high-temperature oxidation resistance, corrosion resistance, castability, and mechanical properties such as creep strength and thermomechanical fatigue resistance.

BACKGROUND

[0003] Many industries, including gas turbine, power generation, and the like require high-temperature materials for components that are exposed to demanding environments, including corrosive or chemically reactive environments, where the stability of mechanical, environmental, and thermophysical properties such materials is critical at the high temperatures encountered.

[0004] For example, alloys designed to withstand degradation and failure in the gas turbine industry may operate at service temperatures in excess of 1100 °C. Such high temperatures can accelerate oxidation and corrosion processes and microstructural evolution/instability (e.g. solutionizing of precipitates, grain growth and phase coarsening, dislocation motion, and the like), which can lead to degradation of properties and, ultimately, to component failure.

[0005] Some nickel-based alloys can exhibit and retain desirable physical, mechanical, and chemical properties at high temperatures. Such alloys, sometimes referred to as ‘superalloys,’ are alloys composed primarily of nickel, with the addition of several other elements. High-temperature nickel-based alloys are often used to form components of gas turbines such as, e.g., blades, vanes, and ring segments, which are typically exposed to high temperatures, mechanical forces, oxidation, and corrosive environments during service.

[0006] There are many high-temperature alloys with various compositions being produced and used in industry. Different alloying elements can provide certain benefits, e.g., by forming and/or stabilizing precipitates (which may be continuous or discontinuous), stabilizing grain boundaries, forming protective coatings when exposed to high temperatures and/or certain environments, etc. The types and amounts of these additive elements can be selected for their ability to improve overall high temperature performance and may focus on one or more beneficial effects, e.g., resistance to creep, oxidation, corrosion, fatigue, and other thermo-mechanical or chemical failure modes at elevated temperatures.

[0007] The types and amounts of particular additive elements used in an alloy cannot be optimized in isolation to produce certain properties. For example, the effects of a single element (e.g. chromium or cobalt) may vary with its concentration in the alloy. Such properties as precipitate formation and compositions, transition from continuous to discontinuous precipitates, etc. may be related to composition in simple systems. However, with multiple alloying components present the effects become far more complex. Different elements may substitute for others in precipitate phases, preferentially migrate to boundaries, stabilize lattices, alter chemical reactivity, etc.

[0008] For example, U.S. Patent No. 5,399,313 to Ross et al. describes a nickel-based superalloy that has good tolerance for low-angle grain boundaries when formed as a single crystal, as well as a balance between oxidation and corrosion resistance at high temperatures. Another nickel-based alloy, described in U.S. Patent Publication No. US 2014/0241936 of Deschandol et al., modifies a known alloy, René 125, by reducing the concentrations of certain components to reduce the appearance of cracks when casting the alloy while maintaining certain desirable properties of René 125. Many other examples of nickel-based alloys can be found in the literature, with various combinations of elements and concentrations thereof that may provide certain desirable properties or compromises between such properties. Another nickel-based alloy, described in International Patent Publication No. WO 2015/183955 of Gong et al., has relatively low levels of rhenium to provide improved single-crystal processing while maintaining other desirable high-temperature properties.

[0009] Thus, there is often a trade-off (and possibly some effects difficult to predict) when trying to improve alloy properties such as creep resistance, thermo-mechanical fatigue resistance, oxidation, and corrosion resistance by varying the presence and amounts of alloying elements present. For example, alloys with greater creep resistance often sacrifice good hot corrosion resistance and thermo-mechanical fatigue resistance. Similarly, alloys exhibiting greater hot corrosion resistance tend to exhibit lower levels of creep resistance and/or thermo-mechanical fatigue resistance. Certain alloy compositions may focus on optimizing one or more of such properties at the expense of others.

[00010] Accordingly, it is desirable to provide high-temperature nickel-based alloys (e.g., superalloys) that can exhibit desirable levels of various properties, such as creep resistance, oxidation resistance, corrosion resistance, and fatigue resistance, when exposed to temperatures and conditions that may exist in such environments as turbine engines.

SUMMARY OF EXEMPLARY EMBODIMENTS

[00011] The herein described exemplary embodiments pertain to new nickel-based alloy compositions that can provide a balance of desirable properties for use in severe environments, including high-temperature environments such as those that may be present gas turbines.

[00012] In one embodiment of the disclosure, a nickel-based alloy is provided that comprises the following elements, with the associated composition ranges provided as a range of approximate weight percents (wt%) in the alloy: Cr: 7.25-7.75; Co: 8.6-9.6; Mo: 0.6-1.0; W: 8.5-9.1; Al: 6.0-6.4; Ti: 0.6-1.0; Ta: 4.0-4.8; C: 0.06-0.10; B: 0.01-0.02; and Hf: 0.4-0.6; with the balance of the alloy consisting of Ni and unavoidable or trace impurities.

[00013] In a further embodiment, a nickel-based alloy can be provided that has a nominal composition of: 7.5 wt% Cr; 9.1 wt% Co; 0.8 wt% Mo; 8.8 wt% W; 6.2 wt% Al; 0.8 wt% Ti; 4.4 wt% Ta; 0.08 wt% C; 0.015 wt% B; 0.5 wt% Hf; and the balance of the alloy consisting of Ni and unavoidable or trace impurities.

[00014] In a still further embodiment of the disclosure, a nickel-based alloy is provided that comprises the following elements, with the associated composition ranges provided as a range of approximate weight percents (wt%) in the alloy: Cr: 7.25-7.75; Co: 8.6-9.4; Mo: 0.6-1.0; W: 8.5-9.1; Al: 6.0-6.4; Ti: 0.6-1.0; Ta: 3.8-4.4; C: 0.06-0.10; B: 0.01-0.02; Hf: 0.4-0.6; and Re: 0.4-0.6, with the balance of the alloy consisting of Ni and unavoidable or trace impurities.

[00015] In yet another embodiment, a nickel-based alloy can be provided that has the following nominal composition: 7.7 wt% Cr; 9.0 wt% Co; 0.8 wt% Mo; 8.8 wt% W; 6.2

wt% Al; 0.8 wt% Ti; 4.1 wt% Ta; 0.08 wt% C; 0.015 wt% B; 0.5 wt% Hf; 0.5 wt% Re; and the balance of the alloy consisting of Ni and unavoidable or trace impurities.

[00016] Additional embodiments of the enclosure can provide components of a gas turbine system, such as blades or vanes, where such components comprise at least one of the alloy compositions described herein. In still further embodiments, a gas turbine system can be provided in which at least one blade or vane comprises or is made of at least one of the alloy compositions described herein.

[00017] These and other objects, features and advantages of the present disclosure will become apparent upon reading the following detailed description of embodiments of the disclosure, when taken in conjunction with the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[00018] Further objects, features and advantages of the present disclosure will become apparent from the following detailed description taken in conjunction with the accompanying figure showing illustrative embodiments, results and/or features of the exemplary embodiments of the present disclosure, in which:

[00019] FIG. 1 is a perspective view of a gas turbine component in accordance with an exemplary embodiment of the present disclosure.

[00020] While the present disclosure will now be described in detail with reference to the figure, it is done so in connection with the illustrative embodiments and is not limited by the particular embodiments illustrated in the figure. It is intended that changes and modifications can be made to the described embodiments without departing from the true scope and spirit of the present disclosure as defined by the appended claims.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[00021] Embodiments of the present can provide nickel-based alloys having certain compositions, where such alloys may possess desirable properties such as, e.g., high creep resistance and improved oxidation resistance. Such alloys may also exhibit other desirable properties such as, e.g., good castability, and good corrosion resistance when used in high-temperature environments. For example, embodiments of the disclosure can provide alloys (and components made therefrom) that exhibit desirable properties when solidified as single crystals, directionally solidified, and when cast in a conventional equiaxed solidification process.

[00022] In one embodiment of the disclosure, a nickel-based alloy is provided that comprises the following elements, with the associated composition ranges provided as a range of approximate weight percents (wt%) in the alloy: Cr: 7.25-7.75; Co: 8.6-9.6; Mo: 0.6-1.0; W: 8.5-9.1; Al: 6.0-6.4; Ti: 0.6-1.0; Ta: 4.0-4.8; C: 0.06-0.10; B: 0.01-0.02; and Hf: 0.4-0.6; with the balance of the alloy comprising Ni and unavoidable impurities.

[00023] In a further embodiment, a nickel-based alloy can be provided that has the following nominal composition: 7.5 wt% Cr; 9.1 wt% Co; 0.8 wt% Mo; 8.8 wt% W; 6.2 wt% Al; 0.8 wt% Ti; 4.4 wt% Ta; 0.08 wt% C; 0.015 wt% B; 0.5 wt% Hf; and the balance of the alloy consisting of Ni and unavoidable impurities. These embodiments of the disclosure are summarized in Table 1 below.

[00024] The total wt% of Cr+Mo+W in these embodiments is 17 wt%, which is higher than the sum of these component weight percentages in many other nickel-based alloys. Such compositions can provide increased solid solution strengthening when the alloy is exposed to higher temperatures.

Element	Nominal wt%	Range of wt%
Cr	7.5	7.25-7.75
Co	9.1	8.6-9.6
Mo	0.8	0.6-1.0
W	8.8	8.5-9.1
Al	6.2	6.0-6.4
Ti	0.8	0.6-1.0
Ta	4.4	4.0-4.8
C	0.08	0.06-0.10
B	0.015	0.01-0.02
Hf	0.5	0.4-0.6
Ni	Balance	---

Table 1: Nominal composition and composition ranges for a nickel-based alloy in accordance with certain embodiments of the disclosure.

[00025] The aluminum composition of 6.20 wt% (e.g., between 6.0 and 6.4 wt%) is greater than that in many other nickel-based alloys. This higher level of Al can provide a superior oxidation resistance with lower levels of chromium and titanium present. Such reduction of chromium levels can also allow introduction of higher concentrations of capable refractory metals such as tungsten and molybdenum for further high-temperature strengthening with fewer adverse effects. Further, the total amount of Al+Cr in the alloy compositions disclosed herein, e.g., between 13.25-14.15 wt%, or 13.7 wt%, can provide good resistance to oxidation and hot corrosion, e.g., in a temperature range of 600 to 1100° C, which are typical service temperatures for large gas turbine blades and vanes. Such improved properties at elevated temperatures may extend service life of turbine components formed of the alloys disclosed herein to 100,000 hours or more.

[00026] The disclosed aluminium levels can also enhance gamma prime (γ') precipitation, thereby also improving creep stability and strength at high temperatures. Gamma prime is the principal high-temperature strengthening phase that occurs in the nickel-rich gamma (γ) phase of such alloys. The enhanced high-temperature strengthening can be achieved with relatively low levels of titanium and tantalum, which also promote gamma prime precipitate formation to improve strength.

[00027] For example, the total weight percent of the gamma prime formers in a nickel-based alloy in accordance with embodiments of the present disclosure, Al+Ta+Ti, is between 10.6 and 12.2 wt%. Such total composition percentage of these elements can provide suitable amounts of gamma prime phases for creep resistance while balancing the effects of these elements on other material properties of the alloy as described herein.

[00028] Further, the higher levels of Al in embodiments of the present disclosure allow a reduction in the amount of Ti while maintaining desirable high-temperature strengthening properties. Reduced levels of Ti can also promote a more adherent oxide scale formation in harsh environments, thereby improving environmental protection of the alloy.

[00029] Certain alloying elements such as tantalum, chromium, molybdenum, and tungsten can form carbides, which segregate to grain boundaries to retard grain boundary sliding. This inhibition of grain boundary displacement (e.g., grain-boundary sliding) at high temperatures can improve creep strength. However, excessive amounts of carbide particles at grain boundaries can promote nucleation of microcracks at the grain boundaries, e.g., at the matrix- carbide interface, and result in increased material failure by intergranular fracture.

[00030] Accordingly, embodiments of the present disclosure provide alloys having balanced compositions of refractory elements such as, e.g., Ta, W, Mo, and Cr, to maximize certain high-temperature properties such as creep strength while reducing or avoiding adverse effects such as, e.g., formation of harmful topologically close-packed (TCP) phases and excessive carbides. TCP phases typically form as plates within the matrix, e.g., when sufficiently high levels of such refractory elements are present, and can adversely affect mechanical properties such as ductility and creep resistance. For example, TCP phases can retain elements that strengthen gamma and gamma prime phases in a non-useful form, thereby reducing creep strength, and they can also serve as crack initiators because of their brittle nature.

[00031] In further embodiments of the disclosure, a nickel-based alloy is provided that also includes rhenium. Rhenium can improve creep strength, e.g., based on its low diffusion rates in nickel-based superalloys, which can help to stabilize precipitate phases and structures at elevated temperatures. However, rhenium can also promote formation of topologically close-packed (TCP) phases in nickel-based alloys when present in sufficiently high concentrations, and such intermetallic TCP phases can degrade certain alloy properties.

[00032] Accordingly, in another embodiment of the disclosure, a nickel-based alloy is provided that includes the following elements, with the associated composition ranges provided as a range of approximate weight percents (wt%) in the alloy: Cr: 7.25-7.75; Co: 8.6-9.4; Mo: 0.6-1.0; W: 8.5-9.1; Al: 6.0-6.4; Ti: 0.6-1.0; Ta: 3.8-4.4; C: 0.06-0.10; B: 0.01-0.02; Hf: 0.4-0.6; and Re: 0.4-0.6, with the balance of the alloy consisting of Ni and unavoidable impurities.

[00033] In yet another embodiment, a nickel-based alloy can be provided that has the following nominal composition: 7.7 wt% Cr; 9.0 wt% Co; 0.8 wt% Mo; 8.8 wt% W; 6.2 wt% Al; 0.8 wt% Ti; 4.1 wt% Ta; 0.08 wt% C; 0.015 wt% B; 0.5 wt% Hf; 0.5 wt% Re; and the balance of the alloy consisting of Ni and unavoidable impurities.

[00034] These embodiments of the disclosure, in which the nickel-based alloy also contains rhenium, are summarized in Table 2 below.

[00035] As can be seen by comparing the alloy compositions of the alloys in Table 2 with those shown in Table 1, the amount of tantalum present can be reduced slightly when introducing rhenium. This trade-off can improve creep resistance due to the slow diffusion of rhenium, while avoiding harmful formation of excessive amounts of carbides as described herein above.

[00036] In nickel-based alloys such as those described herein, certain atoms can substitute for nickel atoms in a unit cell to improve solid solution strengthening. Such strengthening can be more effective with larger elements such as, e.g., molybdenum as compared to, e.g., cobalt. For example, the atomic radius difference between Ni and Mo is +12%, whereas that between Ni and Co is +3%. However, the large mismatch between Ni and Mo can lead to formation of incoherent precipitates under certain conditions, e.g. at higher concentrations of Mo. In contrast, Co tends to exhibit greater solubility in the nickel lattice and thus may be more stable at elevated temperatures, in part because the lower lattice mismatch between Ni and Co results in a lower driving force for precipitate coarsening processes at elevated temperatures.

Element	Nominal wt%	Range of wt%
Cr	7.5	7.25-7.75
Co	9.0	8.6-9.4
Mo	0.8	0.6-1.0
W	8.8	8.5-9.1
Al	6.2	6.0-6.4
Ti	0.8	0.6-1.0
Ta	4.1	3.8-4.4
C	0.08	0.06-0.10
B	0.015	0.010-0.020
Hf	0.5	0.4-0.6
Re	0.5	0.4-0.6
Ni	Balance	---

Table 2: Nominal composition and composition ranges for a nickel-based alloy in accordance with further embodiments of the disclosure.

[00037] One of the advantages of the alloy compositions described herein is a limitation of the overall γ/γ' lattice mismatch. A large lattice mismatch between these phases can increase the rate of precipitate coarsening at high temperatures (e.g., driven by a reduction in the mechanical strain energy that can be achieved by formation of larger, discontinuous precipitates). Accordingly, limiting the overall lattice mismatch can improve long-term stability of the alloy in service, thereby facilitating longer component lifetimes and a reduced likelihood of mechanical failure.

[00038] Accordingly, embodiments of the present disclosure can provide nickel-based alloys that have effective solid-solution strengthening in the gamma phase while also maintaining desirable levels of the gamma-prime phase. For example, desirable material properties of the alloy such as, e.g., creep resistance, tensile strength, ductility, damage tolerance, and low-cycle fatigue resistance, can be optimized by the presence of high-temperature solid-solution strengthening elements in the alloy composition. Elements that contribute to solid-solution strengthening in nickel-based alloys include, e.g., cobalt, chromium, molybdenum, tantalum, tungsten, and rhenium.

[00039] In the embodiments of the present disclosure illustrated in Table 1 (nickel alloys that do not contain rhenium), the total wt % of W+Ta+Mo+Cr+Co is 30.6 wt%. In the further embodiments of the present disclosure illustrated in Table 2 (nickel alloys that contain rhenium), the total wt % of W+Ta+Mo+Cr+Co+Re is 30.2 wt%. Such total percentages of these elements in the disclosed alloys can provide desirable solid-solution strengthening at elevated temperatures while balancing the effects of such elements on other properties of the alloy.

[00040] In further embodiments, a rotor blade or guide vane used in gas turbines can be provided, where such blade or vane can be formed of an alloy having one of the exemplary compositions described herein. For example, third- and fourth-row blades in large gas turbines tend to be exposed to higher temperatures in service as the firing (max inlet temperature increases. Such blades can perform more reliably and safely when formed of nickel-based alloys such as those described herein, e.g., alloys having compositions as shown in Tables 1 and 2.

[00041] FIG. 1 shows a perspective view of a typical rotor blade 130 of a gas turbine, which extends along a longitudinal axis 121. The gas turbine may be, e.g., a gas turbine of an aircraft or of a power plant for generating electricity, a steam turbine, or a compressor. The blade 130 includes a securing region 400, an adjoining blade platform 403, an airfoil 406, and a blade tip 415. A blade root 183 can be provided in the fastening region 400, which may be used to secure the rotor blade 130 to a shaft or a disk (not shown).

[00042] The blade 130 has a leading edge 409 and a trailing edge 412 for a medium (e.g., hot combustion gases) to flow past. The blade 130 can be either hollow or solid in form. If the blade 130 is hollow, it can include cooling holes 418 to facilitate flow of internal cooling gases.

[00043] The blade 130 can be formed of a nickel-based alloy such as those described herein, e.g., using conventional directional solidification or equiaxed casting techniques. Such blade 130 can provide the benefits associated with the alloy compositions described herein, e.g., improved creep resistance and corrosion resistance while in service.

[00044] In some embodiments, a guide vane for a gas turbine can be provided, where the vane is made from an alloy having one of the compositions described herein. The vane can be similar in appearance to the blade 130 shown in FIG. 1, with a further blade platform 403 provided at the blade tip 415. Other specific configurations of turbine vanes and/or blades can be provided in still further embodiments of the disclosure.

[00045] In other embodiments of the disclosure, a gas turbine system can be provided, in which the gas turbine system includes at least one blade or vane formed using an alloy having one of the compositions described herein.

[00046] The foregoing merely illustrates the principles of the exemplary embodiments of the present disclosure. Other variations to the disclosed exemplary embodiments can be understood and effected by those skilled in the art in practising the claimed disclosure from a study of the drawings, the disclosure, and the appended claims. In the claims, the word “comprising” does not exclude other elements or steps and the indefinite article “a” or “an” does not exclude a plurality. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used advantageously. Any reference signs in the claims should not be construed as limiting the scope of the claims. Various modifications and alterations to the described exemplary embodiments will be apparent to those skilled in the art in view of the teachings herein. All patents and publications cited herein are incorporated herein by reference in their entireties.

WHAT IS CLAIMED IS:

1. A nickel-based alloy comprising:

    7.25-7.75 wt% Cr;
    0.6-1.0 wt% Mo;
    8.5-9.1 wt% W;
    6.0-6.4 wt% Al;
    0.6-1.0 wt% Ti;
    0.06-0.10 wt% C;
    0.01-0.02 wt% B;
    0.4-0.6 wt% Hf; and

    one of:

    8.6-9.6 wt% Co and 4.0-4.8 wt% Ta; or
    8.6-9.4 wt% Co, 3.8-4.4 wt% Ta, and 0.4-0.6 wt% Re,

    with the balance consisting of Ni and trace impurities.

2. The alloy of claim 1, comprising:
    8.6-9.6 wt% Co and 4.0-4.8 wt% Ta.

3. The alloy of claim 1, comprising:
    8.6-9.4 wt% Co, 3.8-4.4 wt% Ta, and 0.4-0.6 wt% Re.

4. The nickel-based alloy of claim 1, having a composition of:

7. 5 wt% Cr;
0.8 wt% Mo;
8.8 wt% W;
6.2 wt% Al;
0.8 wt% Ti;
0.08 wt% C;
0.015 wt% B;
0.5 wt% Hf; and

one of:

9.1 wt% Co and 4.4 wt% Ta; or
9.0 wt% Co, 4.1 wt% Ta, and 0.5 wt% Re,

with the balance consisting of Ni and trace impurities.

5. The alloy of claim 4, comprising:
9.1 wt% Co and 4.4 wt% Ta.

6. The alloy of claim 4, comprising:
9.0 wt% Co, 4.1 wt% Ta, and 0.5 wt% Re.

7. The alloy of claim 4, wherein an amount of Al+Ta+Ti is between 10.6 and 12.2 wt %.

8. A gas turbine component comprising a nickel-based alloy comprising:

7.25-7.75 wt% Cr;
0.6-1.0 wt% Mo;
8.5-9.1 wt% W;
6.0-6.4 wt% Al;
0.6-1.0 wt% Ti;
0.06-0.10 wt% C;
0.01-0.02 wt% B;
0.4-0.6 wt% Hf; and

one of:

8.6-9.6 wt% Co and 4.0-4.8 wt% Ta; or
8.6-9.4 wt% Co, 3.8-4.4 wt% Ta, and 0.4-0.6 wt% Re,

with the balance consisting of Ni and trace impurities,

wherein the gas turbine component comprises at least one of a blade, a vane, or a ring segment.

9. The gas turbine component of claim 8, wherein the nickel-based alloy comprises 8.6-9.6 wt% Co and 4.0-4.8 wt% Ta.

10. The gas turbine component of claim 8, wherein the nickel-based alloy comprises 8.6-9.4 wt% Co, 3.8-4.4 wt% Ta, and 0.4-0.6 wt% Re.

11. The gas turbine component of claim 8, wherein the nickel-based alloy has a composition of:

7. 5 wt% Cr;
0.8 wt% Mo;
8.8 wt% W;
6.2 wt% Al;
0.8 wt% Ti;
0.08 wt% C;
0.015 wt% B;
0.5 wt% Hf; and

one of:

9.1 wt% Co and 4.4 wt% Ta; or
9.0 wt% Co, 4.1 wt% Ta, and 0.5 wt% Re,

with the balance consisting of Ni and trace impurities.

12. The gas turbine component of claim 11, wherein the nickel-based alloy comprises 9.1 wt% Co and 4.4 wt% Ta.

13. The gas turbine component of claim 10, wherein the nickel-based alloy comprises 9.0 wt% Co, 4.1 wt% Ta, and 0.5 wt% Re.

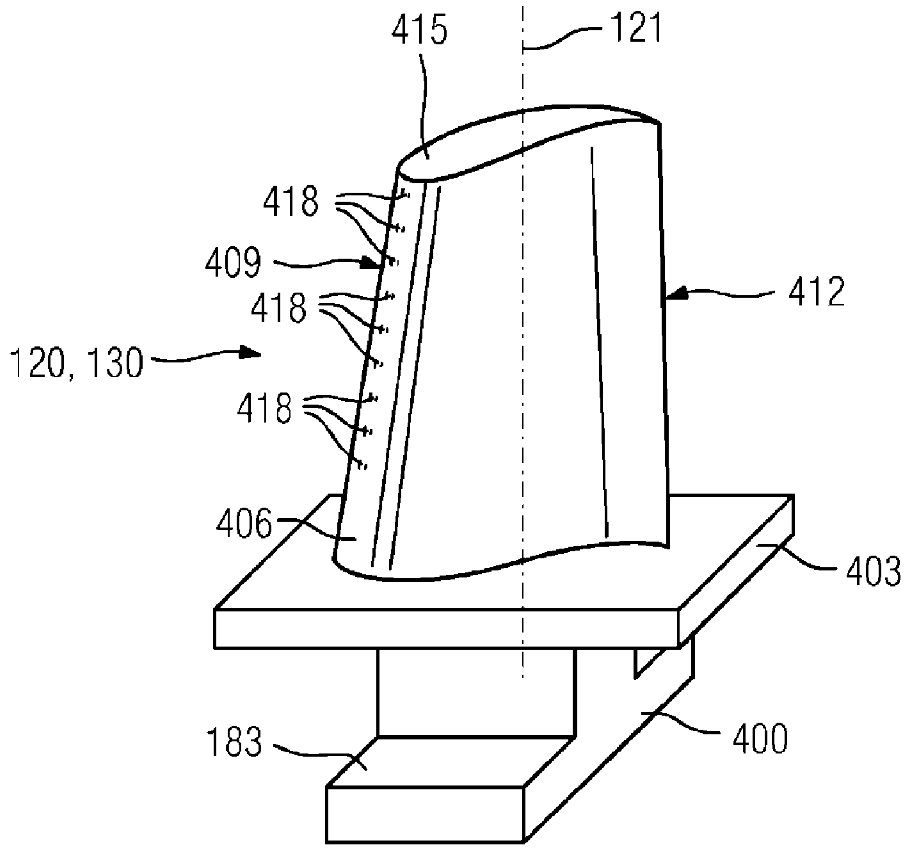

FIG. 1

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/023677

A. CLASSIFICATION OF SUBJECT MATTER
INV. C22C19/05
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2011/076181 A1 (SUZUKI AKANE [US] ET AL) 31 March 2011 (2011-03-31) the whole document -----	1-13
A	US 5 611 670 A (YOSHINARI AKIRA [JP] ET AL) 18 March 1997 (1997-03-18) the whole document -----	1-13
A	GB 2 235 697 A (GEN ELECTRIC [US]) 13 March 1991 (1991-03-13) the whole document -----	1-13
A	JP H11 310839 A (HITACHI LTD; HITACHI METALS LTD) 9 November 1999 (1999-11-09) the whole document ----- -/--	1-13

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

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Information on patent family members

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