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(54) **Nickel-base alloy**

Legierungen auf Nickelbasis

Alliages à base de nickel

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## Description

### BACKGROUND OF THE INVENTION

**[0001]** The present invention generally relates to nickel-base alloys for gas turbine applications, which possess a unique combination of mechanical properties, microstructural stability, and resistance to localized pitting and hot corrosion. More specifically, the invention relates to a class of nickel-base alloys having very low fractions of Eta phase and segregated titanium; resulting in improved yield, manufacturability, and repairability of articles formed therefrom.

**[0002]** The present invention is an improvement to the class of alloys disclosed and claimed in U.S. Pat. No. 6,416,596 B1, issued Jul. 9, 2002 to John H. Wood et al.; which was an improvement to the class of alloys disclosed and claimed in U.S. Pat. No. 3,615,376, issued Oct. 26, 1971 to Earl W. Ross. Both patents are assigned to the assignee hereof. The invention retains the advantageous attributes of those alloys; including high strength and ductility, high resistance to creep and fatigue, excellent microstructural stability, and high resistance to localized pitting and hot corrosion in high temperature corrosive environments. This unique combination of properties makes those alloys attractive for use in gas turbines.

**[0003]** From EP 1 433 865 A1 a high-strength Ni-base superalloy and a gas turbine blade formed from this alloy are known.

**[0004]** From US 2003/0111138 A1 a high-strength hot corrosion and oxidation resistant Ni-base superalloy and articles formed from this alloy are known.

**[0005]** However, an attribute of the alloys disclosed and claimed in U.S. Pat. No. 6,416,596 (hereinafter referred to as the "reference alloys") is the presence of "Eta" phase, a hexagonal close-packed form of the intermetallic $Ni_3Ti$, as well as segregated titanium metal in the solidified alloy. During alloy solidification, titanium has a strong tendency to be rejected from the liquid side of the solid/liquid interface, resulting in the segregation (local enrichment) of titanium in the solidification front and promoting the formation of Eta in the last solidified liquid. The segregation of titanium also reduces the solidus temperature, increasing the fraction of $\gamma$ / $\gamma'$ eutectic phases and resulting micro-shrinkages in the solidified alloy. The Eta phase, in particular, may cause certain articles formed from those alloys to be rejected during the initial forming process, as well as post-forming manufacturing and repair processes. In addition, the presence of Eta phase may result in degradation of the alloy's mechanical properties during service exposure.

**[0006]** It was learned from experimental evaluations that the fractions of both Eta phase and segregated titanium in the solidified alloy are reduced by changing the alloy composition in such a manner that the content of titanium is reduced, and the ratio of aluminum to titanium is increased, relative to the composition of the reference alloys. This results from atom partitioning in the solid/liquid interface during alloy solidification, causing a reduction in the fraction of the $\gamma$ / $\gamma'$ eutectic phase in the solidified alloy. It was also learned in these evaluations that the Eta phase is further reduced by changing the alloy composition in such a manner that the content of tantalum is increased, and the ratio of aluminum to tantalum is reduced, relative to the composition of the reference alloys. Tantalum was known to stabilize the gamma prime ($\gamma'$) phase ($Ni_3Al$), further reducing the availability of titanium in the alloy.

**[0007]** It was also known that advantageous amounts of gamma prime ($\gamma'$) phase are retained when the content of tantalum is reduced and the content of niobium is increased, such that niobium may be entirely substituted for tantalum if desired, as taught in U.S. Pat. No. 6,902,633 B2, issued Jun. 7, 2005 to Warren T. King et al. and assigned to the assignee hereof; and U.S. Pat. Appl. Publ. No. 2007/0095441 A1, published May 3, 2007 by Liang Jiang et al. and assigned to the assignee hereof.

**[0008]** It was also known that increasing the contents of tantalum and tungsten relative to the reference alloys result in improved mechanical properties through a combination of solid solution and precipitation strengthening. These changes produced alloys having tensile strength, yield strength, ductility, and Low Cycle Fatigue (LCF) strength generally comparable to the reference alloys; as well as improved creep strength and lower machining energy relative to the reference alloys for certain embodiments of the present invention.

**[0009]** The totality of these changes produced additional benefits. For example, the alloys exhibit a narrow solidification range (defined as the difference in temperature between the liquidus and solidus of the alloy) and the microstructures of the solidified alloys exhibit a finer $\gamma$ / $\gamma'$ eutectic and carbide structure than the microstructures of the reference alloys.

### BRIEF DESCRIPTION OF THE INVENTION

**[0010]** The invention is defined by the claims, to which reference should now be made.

**[0011]** The present invention provides a class of nickel-base alloys for gas turbine applications, and useful articles of manufacture formed therefrom, which possess a unique combination of mechanical properties, microstructural stability, resistance to localized pitting and hot corrosion in high temperature corrosive environments, and high yields during the initial forming process as well as post-forming manufacturing and repair processes. The invention is further characterized by having very low fractions of Eta phase and segregated Titanium in the solidified nickel-base alloys.

[0012] Other objects and advantages of the present invention will be better appreciated from the following detailed description.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0013] Non-limiting and non-exhaustive embodiments are described with reference to the following drawings.

FIG. 1 is a photomicrograph of Alloy 1, as embodied by the invention.
FIG. 2 is a photomicrograph of Alloy 2.
FIG. 3 is a photomicrograph of Alloy 3.
FIG. 4 is a photomicrograph of Alloy 4, as embodied by the invention.
FIG. 5 is a photomicrograph of Alloy 5, as embodied by the invention.
FIG. 6 is a photomicrograph of Alloy 6.
FIG. 7 is a photomicrograph of Alloy 7.
FIG. 8 is a plot showing normalized tensile strength of Alloys 1 to 4, measured at 20°C (68°F) and 760°C (1400°F), shown as the fraction of the average tensile strength of the reference alloys at those temperatures.
FIG. 9 is a plot showing normalized creep life of Alloys 1 to 4, in terms of the times to 1.0% strain at 732°C (1350°F), shown as the fraction of the average creep life of the reference alloys at the same strain and temperature.
FIG. 10 is a plot showing the machining energy (in Joules) required for Alloys 1 and 2 during a milling operation.

## DETAILED DESCRIPTION OF THE INVENTION

[0014] The present invention was the result of an investigation to develop a class of nickel-base alloys for gas turbine applications, and useful articles of manufacture formed therefrom, which possess a unique combination of mechanical properties, microstructural stability, resistance to localized pitting and hot corrosion in high temperature corrosive environments, and high yields during the initial forming process as well as post-forming manufacturing and repair processes. The invention is further characterized by having very low fractions of Eta phase and segregated Titanium in the solidified nickel-base alloys.

[0015] According to a particular example of the present disclosure, the nickel-base alloy comprises, by weight, about 13.7 to about 14.3 percent chromium, about 5.0 to about 10.0 percent cobalt, about 3.5 to about 5.2 percent tungsten, about 2.8 to about 5.2 percent titanium, about 2.8 to about 4.6 percent aluminum, about 0.0 to about 3.5 percent tantalum, about 1.0 to about 1.7 percent molybdenum, about 0.08 to about 0.13 percent carbon, about 0.005 to about 0.02 percent boron, about 0.0 to about 1.5 percent niobium, about 0.0 to about 2.5 percent hafnium, about 0.0 to about 0.04 percent zirconium, and the balance substantially nickel.

[0016] According to another example of the present disclosure, the nickel-base alloy is characterized by having very low fractions of Eta phase and segregated Titanium; and comprises, by weight, about 13.7 to about 14.3 percent chromium, about 5.0 to about 10.0 percent cobalt, about 3.5 to about 5.2 percent tungsten, about 2.8 to about 5.2 percent titanium, about 2.8 to about 4.6 percent aluminum, about 0.0 to about 3.5 percent tantalum, about 1.0 to about 1.7 percent molybdenum, about 0.08 to about 0.13 percent carbon, about 0.005 to about 0.02 percent boron, about 0.0 to about 1.5 percent niobium, about 0.0 to about 2.5 percent hafnium, about 0.0 to about 0.04 percent zirconium, and the balance substantially nickel.

[0017] According to an embodiment of the present invention, the nickel-base alloy comprises, by weight, about 13.9 percent chromium, about 9.5 percent cobalt, about 4.5 percent tungsten, about 4.2 percent titanium, about 3.7 percent aluminum, about 3.4 percent tantalum, about 1.6 percent molybdenum, about 0.1 percent carbon, about 0.01 percent boron, less than 0.01 percent zirconium, and the balance substantially nickel.

[0018] According to another embodiment of the present invention, the nickel-base alloy comprises, by weight, about 13.9 percent chromium, about 9.5 percent cobalt, about 4.2 percent tungsten, about 3.7 percent titanium, about 3.7 percent aluminum, about 3.2 percent tantalum, about 1.5 percent molybdenum, about 0.1 percent carbon, about 0.01 percent boron, about 0.002 percent zirconium, and the balance substantially nickel.

[0019] According to embodiments of the present invention, wherein the form of the invention is an article of manufacture, the article may be formed by a casting method comprising the following steps: (1) preparing an ingot of the composition in the amounts stated above, (2) remelting the ingot and casting it to a form of the size and shape of the desired article, (3) heat treating the article in a suitable atmosphere and in accordance with a suitable time and temperature schedule, and (4) coating the article, if desired, with a suitable material for thermal or environmental protection. The grain structure of the cast articles may be either equiaxed (having no preferred orientation), directionally solidified (having a preferred orientation), or single crystal (having no grain boundaries). The article may be a gas turbine bucket or other form of rotating airfoil, or a gas turbine nozzle or other form of stationary airfoil, or another gas turbine component, that is located in the gas turbine hot section and designed in such a manner as to take advantage of the beneficial properties of the alloy.

**[0020]** According to a particular example of the present disclosure, concerning an article of manufacture, the nickel-base alloy comprises, by weight, about 13.7 to about 14.3 percent chromium, about 5.0 to about 10.0 percent cobalt, about 3.5 to about 5.2 percent tungsten, about 2.8 to about 5.2 percent titanium, about 2.8 to about 4.6 percent aluminum, about 0.0 to about 3.5 percent tantalum, about 1.0 to about 1.7 percent molybdenum, about 0.08 to about 0.13 percent carbon, about 0.005 to about 0.02 percent boron, about 0.0 to about 1.5 percent niobium, about 0.0 to about 2.5 percent hafnium, about 0.0 to about 0.04 percent zirconium, and the balance substantially nickel; and the article may be formed by a casting method that produces gas turbine airfoils or other components having either an equiaxed, directionally solidified, or single crystal grain structure.

**[0021]** According to another embodiment of the present invention, wherein the form of the invention is an article of manufacture, the nickel-base alloy comprises, by weight, about 13.9 percent chromium, about 9.5 percent cobalt, about 4.5 percent tungsten, about 4.2 percent titanium, about 3.7 percent aluminum, about 3.4 percent tantalum, about 1.6 percent molybdenum, about 0.1 percent carbon, about 0.01 percent boron, less than 0.01 percent zirconium, and the balance substantially nickel; and the article may be formed by a casting method that produces gas turbine airfoils or other components having an equiaxed grain structure.

**[0022]** According to yet another embodiment of the present invention, wherein the form of the invention is an article of manufacture, the nickel-base alloy comprises, by weight, about 13.9 percent chromium, about 9.5 percent cobalt, about 4.2 percent tungsten, about 3.7 percent titanium, about 3.7 percent aluminum, about 3.2 percent tantalum, about 1.5 percent molybdenum, about 0.1 percent carbon, about 0.01 percent boron, about 0.002 percent zirconium, and the balance substantially nickel; and the article may be formed by a casting method that produces gas turbine airfoils or other components having a directionally solidified grain structure.

**[0023]** A feature of embodiments of the present invention is that the contents of aluminum and titanium and their relative ratios may be adjusted in such a manner that reduces the fractions of the $\gamma$ / $\gamma'$ eutectic phase, Eta phase, and segregated titanium that form during alloy solidification. For example, the solidified alloys are substantially free of Eta phase when the ratio of aluminum to titanium is between about 0.8 and about 1.0, by weight. A further benefit is a strengthening effect that may be due to an increase in $\gamma'$ phase in the $\gamma$ matrix.

**[0024]** Another feature of embodiments of the present invention is that the contents of aluminum and tantalum and their relative ratios may be adjusted in such a manner that further reduces the formation of Eta phase, while maintaining the fraction of $\gamma'$ phase, in the solidified alloy. For example, the solidified alloys are substantially free of Eta phase when the ratio of aluminum to tantalum is between about 0.9 and about 1.3, by weight.

**[0025]** Another feature of embodiments of the present invention is that the content of tantalum may be reduced and the content of niobium may be increased, such that niobium may be entirely substituted for tantalum if desired.

**[0026]** Another feature of embodiments of the present invention is that the contents of tantalum and tungsten may be adjusted in such a manner that results in a combination of precipitation and solid solution strengthening.

**[0027]** Four experimental alloys having equiaxed grain structures were formed into test articles using a casting method and comprising the compositions given in Table 1 (in percent weight). Alloys 2 and 3 are variations of the reference alloys, having ratios of aluminum to titanium near the upper limit (Alloy 2) and lower limit (Alloy 3) of the ranges specified for the reference alloys. Alloys 1 and 4 are derivations of the reference alloys, having higher ratios of aluminum to titanium, as well as higher contents of tantalum and tungsten, than the ranges specified for the reference alloys.

TABLE 1

| | Alloy 1 | Alloy 2 | Alloy 3 | Alloy 4 |
|---|---|---|---|---|
| Chromium (Cr) | 13.9 | 13.9 | 13.9 | 14.0 |
| Cobalt (Co) | 9.5 | 9.5 | 9.5 | 9.5 |
| Tungsten (W) | 4.5 | 3.7 | 3.8 | 3.9 |
| Titanium (Ti) | 4.2 | 5.0 | 5.2 | 3.8 |
| Aluminum (Al) | 3.7 | 3.3 | 3.0 | 3.8 |
| Tantalum (Ta) | 3.4 | 2.9 | 2.8 | 3.4 |
| Molybdenum (Mo) | 1.6 | 1.5 | 1.5 | 1.5 |
| Carbon (C) | 0.1 | 0.1 | 0.1 | 0.1 |
| Boron (B) | 0.01 | 0.01 | 0.01 | 0.01 |
| Niobium (Nb) | 0.02 | 0.03 | 0.03 | 0.03 |
| Hafnium (Hf) | 0.02 | 0.01 | 0.02 | 0.02 |
| Zirconium (Zr) | < 0.01 | <0.01 | <0.01 | <0.01 |
| Nickel (Ni) | Balance | Balance | Balance | Balance |

**[0028]** The microstructures of the four experimental alloys from Table 1 are shown in FIGS. **1** to **4,** respectively. The microstructural evaluations showed that Alloy 1 had no visible Eta phase, a low fraction of eutectic phase, and a low fraction of carbides (FIG. **1**); Alloy 2 had no visible Eta phase, an expected fraction of eutectic phase, and an expected fraction of carbides (FIG. **2**); Alloy 3 had visible Eta phase, an expected fraction of eutectic phase, and an expected fraction of carbides (FIG. **3**); and Alloy 4 had no visible Eta phase, a low fraction of eutectic phase, and a low fraction of carbides (FIG. **4**).

**[0029]** Three other experimental alloys having directionally solidified grain structures were formed into test articles using a casting method and comprising the compositions given in Table 2 (in percent weight). Alloy 5 is a derivation of the reference alloys, having a higher ratio of aluminum to titanium, as well as higher contents of tantalum and tungsten, than the ranges specified for the reference alloys; while Alloys 6 and 7 are variations of the reference alloys.

TABLE 2

| | Alloy 5 | Alloy 6 | Alloy 7 |
|---|---|---|---|
| Chromium (Cr) | 13.9 | 13.9 | 13.9 |
| Cobalt (Co) | 9.5 | 9.5 | 9.5 |
| Tungsten (W) | 4.2 | 3.7 | 3.7 |
| Titanium (Ti) | 3.7 | 4.8 | 5.0 |
| Aluminum (Al) | 3.7 | 3.3 | 2.9 |
| Tantalum (Ta) | 3.2 | 2.6 | 2.6 |
| Molybdenum (Mo) | 1.5 | 1.5 | 1.5 |
| Carbon (C) | 0.1 | 0.1 | 0.1 |
| Boron (B) | 0.01 | 0.01 | 0.01 |
| Niobium (Nb) | 0.02 | 0.02 | 0.02 |
| Hafnium (Hf) | 0.01 | 0.01 | 0.01 |
| Zirconium (Zr) | 0.002 | 0.002 | 0.002 |
| Nickel (Ni) | Balance | Balance | Balance |

**[0030]** The microstructures of the three experimental alloys from Table 2 are shown in FIGS. **5** to **7,** respectively. The microstructural evaluations showed that Alloy 5 had no visible Eta phase and a low fraction of eutectic phase (FIG. **5**); Alloy 6 had no visible Eta phase and an expected fraction of eutectic phase (FIG. **6**); and Alloy 7 had visible Eta phase and an expected fraction of eutectic phase (FIG. **7**).

**[0031]** The results of representative mechanical and manufacturing evaluations performed on the test articles prepared from the four experimental alloys from Table 1 are shown in FIGS. **8** to **10,** respectively. These results show that all four experimental alloys have tensile strength that is above 90% of the tensile strength of the reference alloys at both 20°C and 760°C (FIG. **8**). The results also showed that the creep life of Alloy 1 at 732°C is generally equal to or greater than the creep life of the reference alloys at 1.0% strain (FIG. **9**), and that Alloy 1 required less machining energy than Alloy 2 (a variation of the reference alloys) during milling (FIG. **12**).

**[0032]** Summarizing, the present disclosure contemplates the use in a class of nickel-base alloys of the elements aluminum, titanium, tantalum, and tungsten in a novel manner that advantageously improves both manufacturing yield and mechanical properties of alloys having superior microstructural stability and resistance to localized pitting and hot corrosion in high temperature corrosive environments. The broad, preferred, and nominal compositions (by weight) of this class of nickel-base alloys are summarized in Table 3.

TABLE 3

| | Broad | Preferred | Nominal 1 | Nominal 2 |
|---|---|---|---|---|
| Chromium (Cr) | 13.7 to 14.3 | 13.7 to 14.3 | 13.9 | 13.9 |
| Cobalt (Co) | 5.0 to 10.0 | 5.0 to 10.0 | 9.5 | 9.5 |
| Tungsten (W) | 3.5 to 5.2 | 4.0 to 4.6 | 4.5 | 4.2 |
| Titanium (Ti) | 2.8 to 5.2 | 3.6 to 4.3 | 4.2 | 3.7 |
| Aluminum (Al) | 2.8 to 4.6 | 3.5 to 3.9 | 3.7 | 3.7 |
| Tantalum (Ta) | 0.0 to 3.5 | 3.1 to 3.5 | 3.4 | 3.2 |
| Molybdenum (Mo) | 1.0 to 1.7 | 1.0 to 1.7 | 1.6 | 1.5 |
| Carbon (C) | 0.08 to 0.13 | 0.08 to 0.13 | 0.1 | 0.1 |
| Boron (B) | 0.005 to 0.02 | 0.005 to 0.02 | 0.01 | 0.01 |

(continued)

| | Broad | Preferred | Nominal 1 | Nominal 2 |
|---|---|---|---|---|
| Niobium (Nb) | 0.0 to 1.5 | 0.0 to 1.5 | 0.02 | 0.02 |
| Hafnium (Hf) | 0.0 to 2.5 | 0.0 to 2.5 | 0.02 | 0.01 |
| Zirconium (Zr) | 0.0 to 0.04 | 0.0 to 0.04 | <0.01 | 0.002 |
| Nickel (Ni) | Balance | Balance | Balance | Balance |

**[0033]** As used herein, an element or step recited in the singular and proceeded with the word "a" or "an" should be understood as not excluding plural elements or steps, unless such exclusion is explicitly recited. Furthermore, references to "one embodiment" of the present invention are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features.

**[0034]** This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims.

## Claims

**1.** An alloy comprising the following elements, by weight:

a. 13.7 to 14.3 percent chromium,
b. 5.0 to 10.0 percent cobalt,
c. 3.5 to 5.2 percent tungsten,
d. 3.68 to 4.3 percent titanium,
e. 2.8 to 4.6 percent aluminum,
f. 3.1 to 3.5 percent tantalum,
g. 1.0 to 1.7 percent molybdenum,
h. 0.08 to 0.13 percent carbon,
i. 0.005 to 0.02 percent boron,
j. 0.0 to 1.5 percent niobium,
k. 0.0 to 2.5 percent hafnium,
l. 0.0 to 0.04 percent zirconium,
m. the balance nickel.

**2.** The alloy of claim 1, comprising 4.0 to 4.6 percent tungsten.

**3.** The alloy of any preceding claim, comprising 3.5 to 3.9 percent aluminum.

**4.** The alloy of any preceding claim, wherein the ratio of percent aluminum to percent titanium is 0.8 to 1.0, by weight.

**5.** The alloy of any preceding claim, having about zero Eta phase ($Ni_3Ti$) and segregated titanium.

**6.** The alloy of claim 1, comprising the following elements, by weight:

a. about 13.9 percent chromium,
b. about 9.5 percent cobalt,
c. about 4.5 percent tungsten,
d. about 4.2 percent titanium,
e. about 3.7 percent aluminum,
f. about 3.4 percent tantalum,
g. about 1.6 percent molybdenum,
h. about 0.1 percent carbon,
i. about 0.01 percent boron,
j. less than 0.01 percent zirconium,
k. the balance nickel.

7. The alloy of claim 1, comprising the following elements, by weight:

a. about 13.9 percent chromium,
b. about 9.5 percent cobalt,
c. about 4.2 percent tungsten,
d. about 3.7 percent titanium,
e. about 3.7 percent aluminum,
f. about 3.2 percent tantalum,
g. about 1.5 percent molybdenum,
h. about 0.1 percent carbon,
i. about 0.01 percent boron,
j. about 0.002 percent zirconium,
k. the balance nickel.

8. An article of manufacture that may be used in a gas turbine and is formed from the alloy of any preceding claim.

9. The article of claim 8, wherein the method of forming is casting.

10. The article of claim 8, wherein the method of forming is casting performed in such a manner as to produce an equiaxed grain structure.

11. The article of claim 9, wherein the method of forming is casting performed in such a manner as to produce a directionally solidified grain structure.

12. The article of claim 9, wherein the method of forming is casting performed in such a manner as to produce a single crystal grain structure.

**Patentansprüche**

1. Legierung, umfassend die folgenden Elemente, auf das Gewicht:

a. 13,7 bis 14,3 Prozent Chrom,
b. 5,0 bis 10,0 Prozent Kobalt,
c. 3,5 bis 5,2 Prozent Wolfram,
d. 3,68 bis 4,3 Prozent Titan,
e. 2,8 bis 4,6 Prozent Aluminium,
f. 3,1 bis 3,5 Prozent Tantal,
g. 1,0 bis 1,7 Prozent Molybdän,
h. 0,08 bis 0,13 Prozent Kohlenstoff,
i. 0,005 bis 0,02 Prozent Bor,
j. 0,0 bis 1,5 Prozent Niob,
k. 0,0 bis 2,5 Prozent Hafnium,
l. 0,0 bis 0,04 Prozent Zirkonium,
m. den Rest Nickel.

2. Legierung nach Anspruch 1, umfassend 4,0 bis 4,6 Prozent Wolfram.

3. Legierung nach einem der vorstehenden Ansprüche, umfassend 3,5 bis 3,9 Prozent Aluminium.

4. Legierung nach einem der vorstehenden Ansprüche, wobei das Verhältnis von Prozent Aluminium zu Prozent Titan 0,8 bis 1,0, auf das Gewicht, beträgt.

5. Legierung nach einem der vorstehenden Ansprüche, die etwa eine Null-Eta-Phase ($Ni_3Ti$) und segregiertes Titan aufweist.

6. Legierung nach Anspruch 1, umfassend die folgenden Elemente, auf das Gewicht:

a. etwa 13,9 Prozent Chrom,
b. etwa 9,5 Prozent Kobalt,
c. etwa 4,5 Prozent Wolfram,
d. etwa 4,2 Prozent Titan,
e. etwa 3,7 Prozent Aluminium,
f. etwa 3,4 Prozent Tantal,
g. etwa 1,6 Prozent Molybdän,
h. etwa 0,1 Prozent Kohlenstoff,
i. etwa 0,01 Prozent Bor,
j. weniger als 0,01 Prozent Zirkonium,
k. den Rest Nickel.

**7.** Legierung nach Anspruch 1, umfassend die folgenden Elemente, auf das Gewicht:

a. etwa 13,9 Prozent Chrom,
b. etwa 9,5 Prozent Kobalt,
c. etwa 4,2 Prozent Wolfram,
d. etwa 3,7 Prozent Titan,
e. etwa 3,7 Prozent Aluminium,
f. etwa 3,2 Prozent Tantal,
g. etwa 1,5 Prozent Molybdän,
h. etwa 0,1 Prozent Kohlenstoff,
i. etwa 0,01 Prozent Bor,
j. etwa 0,002 Prozent Zirkonium,
k. den Rest Nickel.

**8.** Herstellungsgegenstand, der in einer Gasturbine verwendet werden kann und aus der Legierung eines vorstehenden Anspruchs gebildet ist.

**9.** Gegenstand nach Anspruch 8, wobei das Verfahren zum Formen Gießen ist.

**10.** Gegenstand nach Anspruch 8, wobei das Verfahren zum Formen Gießen ist, das so durchgeführt wird, dass eine gleichachsige Kornstruktur erzeugt wird.

**11.** Gegenstand nach Anspruch 9, wobei das Verfahren zum Formen Gießen ist, das so durchgeführt wird, dass eine gerichtet verfestigte Kornstruktur erzeugt wird.

**12.** Gegenstand nach Anspruch 9, wobei das Verfahren zum Formen Gießen ist, das so durchgeführt wird, dass eine Einkristallkornstruktur erzeugt wird.

## Revendications

**1.** Alliage comprenant les éléments suivants en poids :

a. 13,7 à 14,3 pour cent de chrome,
b. 5,0 à 10,0 pour cent de cobalt,
c. 3,5 à 5,2 pour cent de tungstène,
d. 3,68 à 4,3 pour cent de titane,
e. 2,8 à 4,6 pour cent d'aluminium
f. 3,1 à 3,5 pour cent de tantale,
g. 1,0 à 1,7 pour cent de molybdène,
h. 0,08 à 0,13 pour cent de carbone,
i. 0,005 à 0,02 pour cent de bore,
j. 0,0 à 1,5 pour cent de niobium,
k. 0,0 à 2,5 pour cent d'hafnium,
l. 0,0 à 0,04 pour cent de zirconium,
m. le restant étant du nickel.

**2.** Alliage selon la revendication 1, comprenant 4,0 à 4,6 pour cent de tungstène.

**3.** Alliage selon l'une quelconque des revendications précédentes, comprenant 3,5 à 3,9 pour cent d'aluminium.

**4.** Alliage selon l'une quelconque des revendications précédentes, dans lequel le rapport du pourcentage d'aluminium au pourcentage de titane est de 0,8 à 1,0 en poids.

**5.** Alliage selon l'une quelconque des revendications précédentes, ayant environ zéro phase Eta ($Ni_3Ti$) et du titane séparé.

**6.** Alliage selon la revendication 1, comprenant les éléments suivants en poids :

a. environ 13,9 pour cent de chrome,
b. environ 9,5 pour cent de cobalt,
c. environ 4,5 pour cent de tungstène,
d. environ 4,2 pour cent de titane,
e. environ 3,7 pour cent d'aluminium,
f. environ 3,4 pour cent de tantale,
g. environ 1,6 pour cent de molybdène,
h. environ 0,1 pour cent de carbone,
i. environ 0,01 pour cent de bore,
j. moins de 0,01 pour cent de zirconium,
k. le restant étant du nickel.

**7.** Alliage selon la revendication 1, comprenant les éléments suivants en poids :

a. environ 13,9 pour cent de chrome,
b. environ 9,5 pour cent de cobalt,
c. environ 4,2 pour cent de tungstène,
d. environ 3,7 pour cent de titane,
e. environ 3,7 pour cent d'aluminium,
f. environ 3,2 pour cent de tantale,
g. environ 1,5 pour cent de molybdène,
h. environ 0,1 pour cent de carbone,
i. environ 0,01 pour cent de bore,
j. moins de 0,002 pour cent de zirconium,
k. le restant étant du nickel.

**8.** Article de fabrication qui peut être utilisé dans une turbine à gaz et qui est formé de l'alliage selon l'une quelconque des revendications précédentes.

**9.** Article selon la revendication 8, dans lequel le procédé de formation est une coulée.

**10.** Article selon la revendication 8, dans lequel le procédé de formation est une coulée effectuée de manière à produire une structure granulaire équiaxe.

**11.** Article selon la revendication 9, dans lequel le procédé de formation est une coulée effectuée de manière à produire une structure granulaire à solidification directionnelle.

**12.** Article selon la revendication 9, dans lequel le procédé de formation est une coulée effectuée de manière à produire une structure granulaire monocristalline.

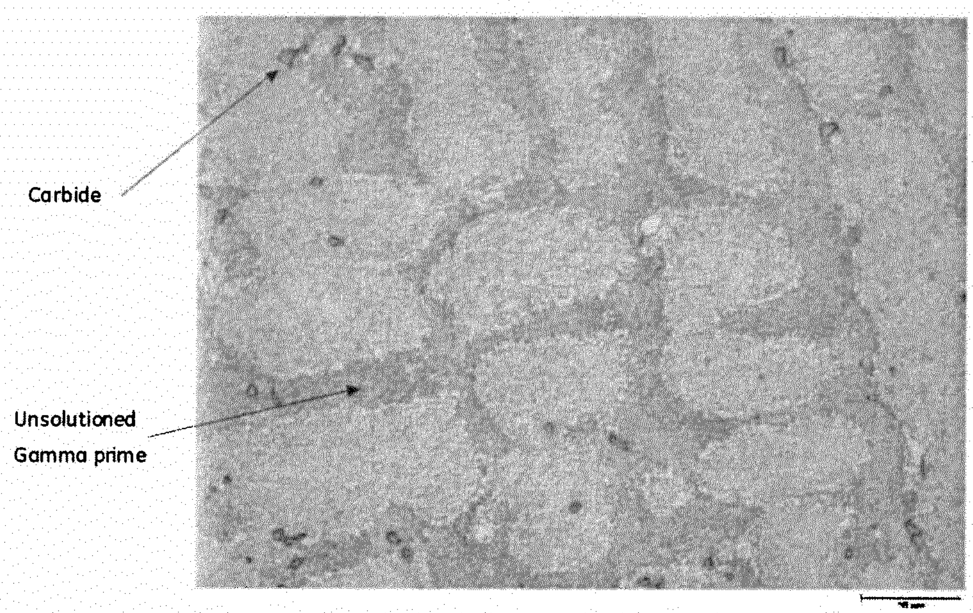
Carbide
Unsolutioned
Gamma prime

FIG. 1

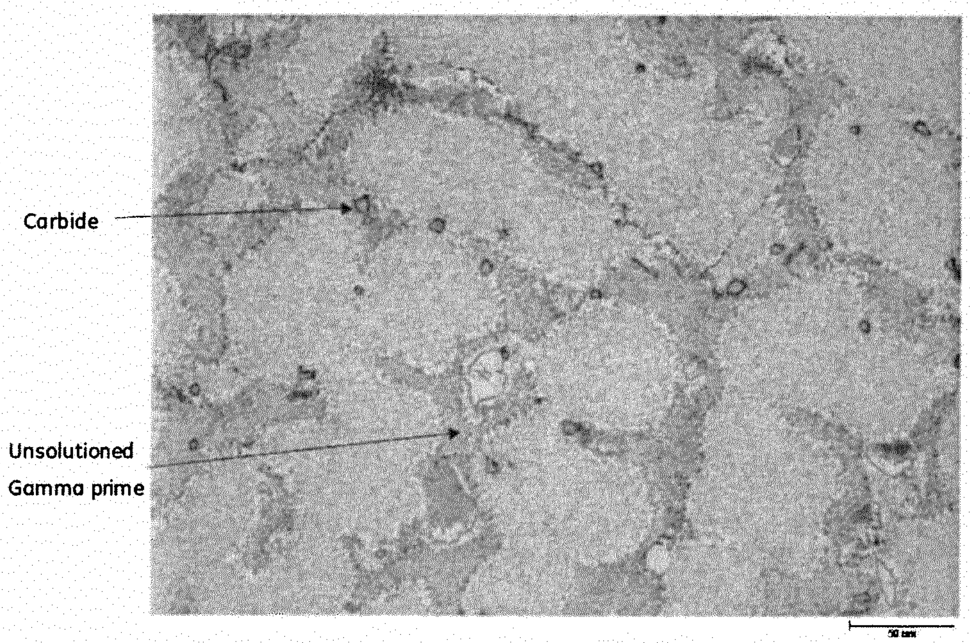
Carbide
Unsolutioned
Gamma prime
50 µm

FIG. 2

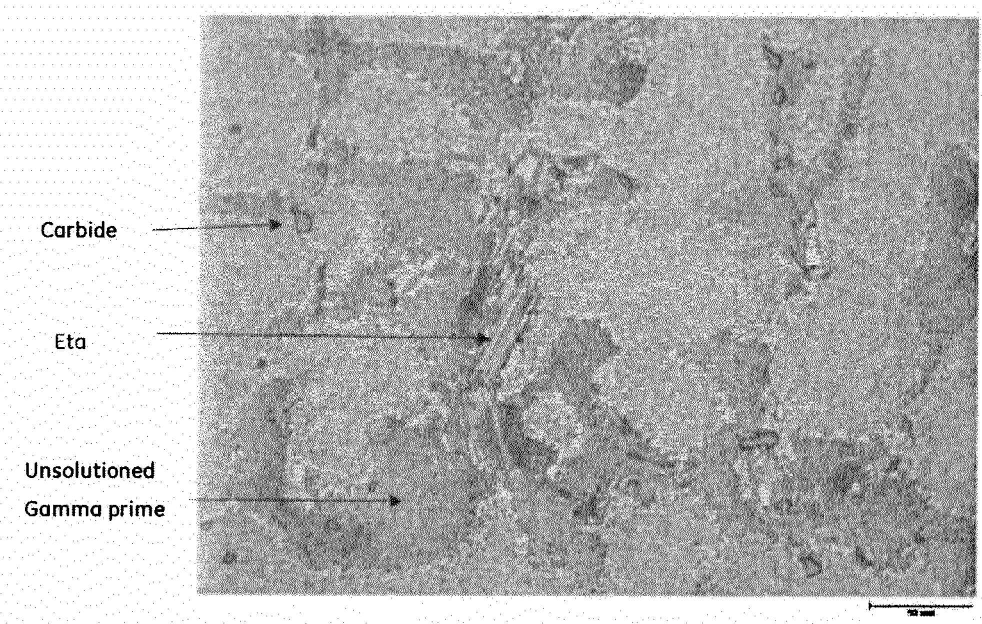
Carbide
Eta
Unsolutioned
Gamma prime

FIG. 3

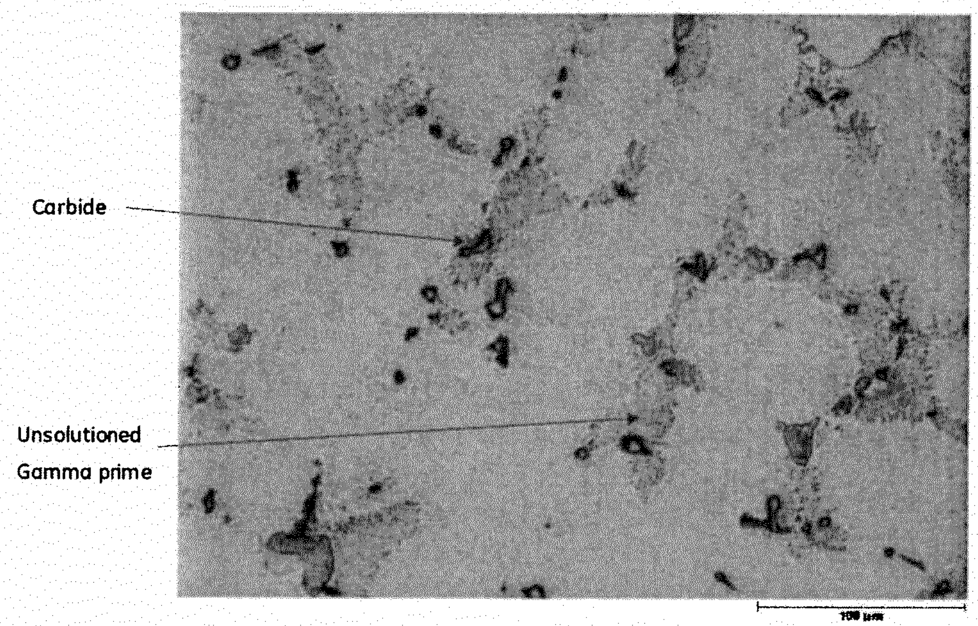
Carbide
Unsolutioned
Gamma prime

FIG. 4

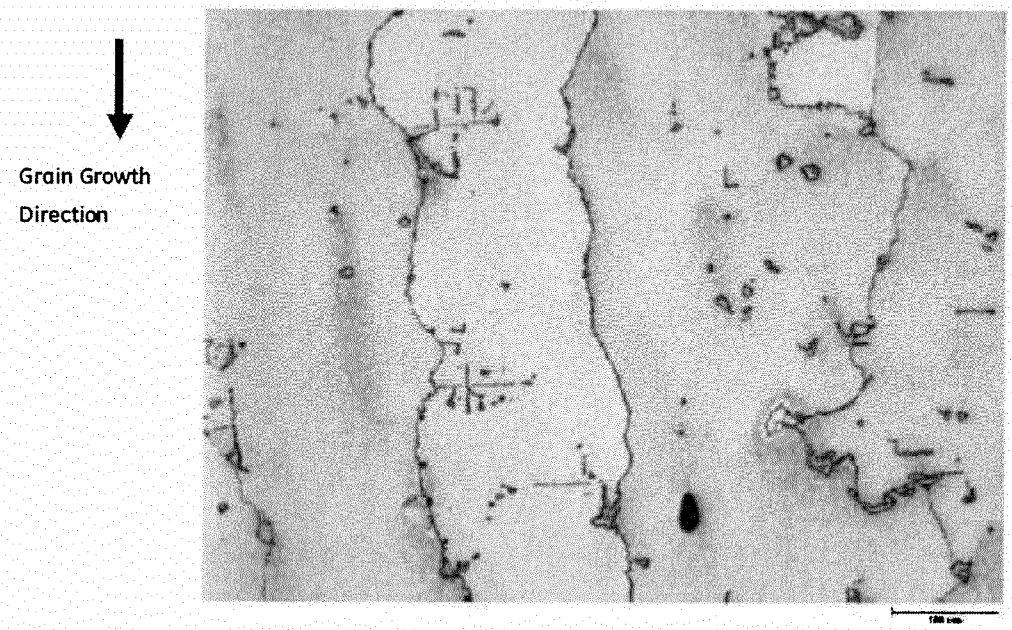


FIG. 5

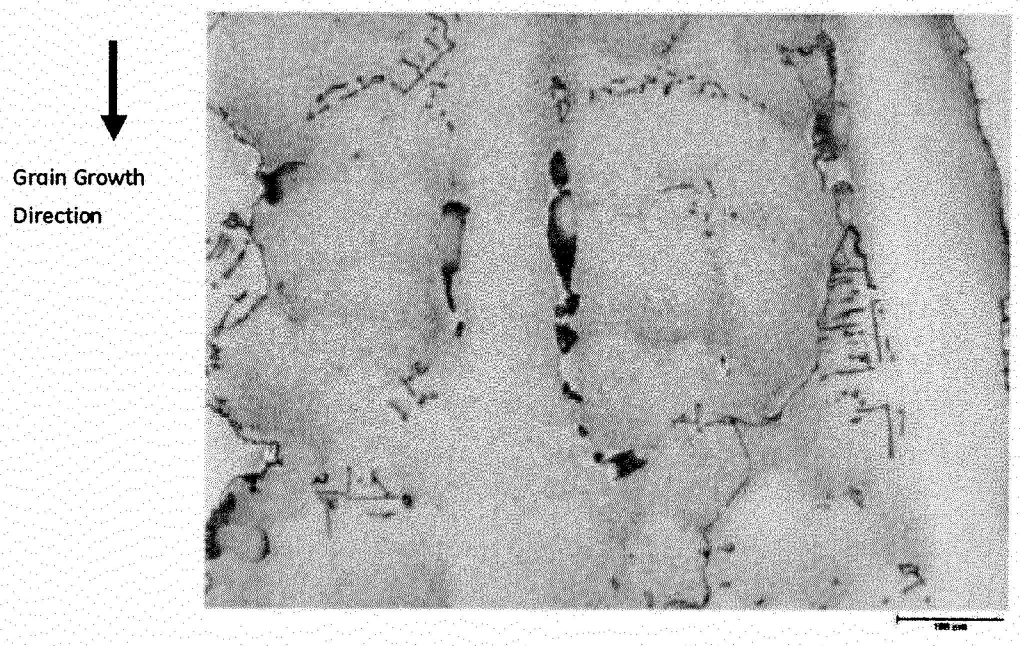


FIG. 6

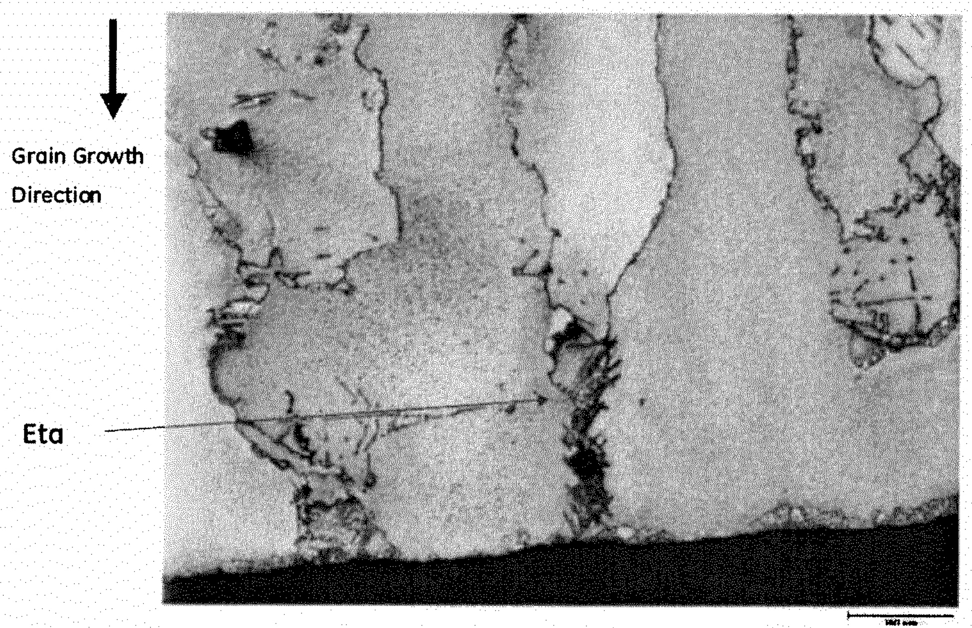
Grain Growth
Direction
Eta

FIG. 7

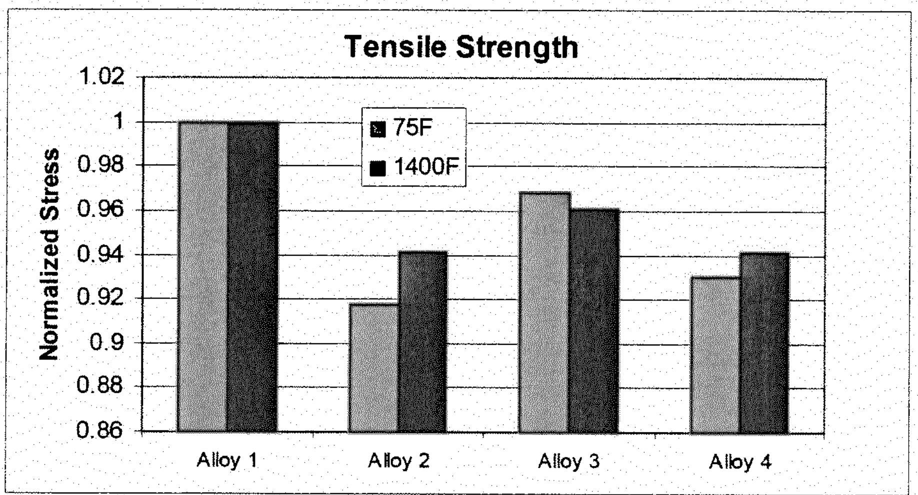
Tensile Strength
Normalized Stress
1.02
1
0.98
0.96
0.94
0.92
0.9
0.88
0.86
75F
1400F
Alloy 1
Alloy 2
Alloy 3
Alloy 4

FIG. 8

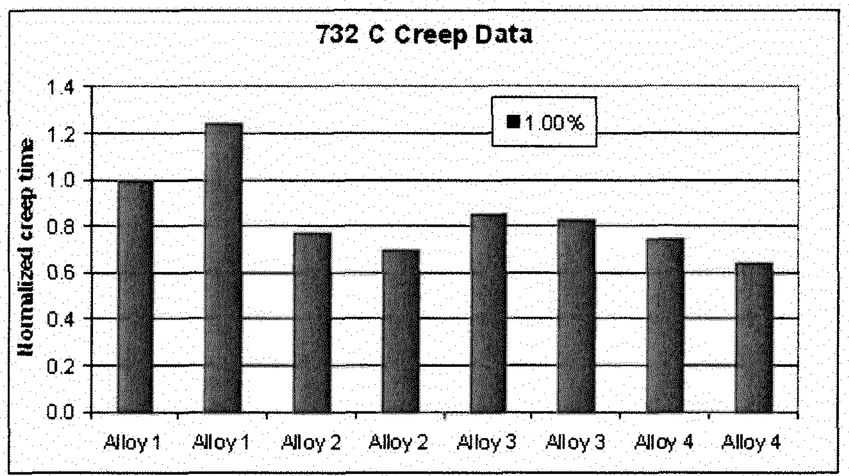
732 C Creep Data
Normalized creep time
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1.00%
Alloy 1
Alloy 1
Alloy 2
Alloy 2
Alloy 3
Alloy 3
Alloy 4
Alloy 4

FIG. 9

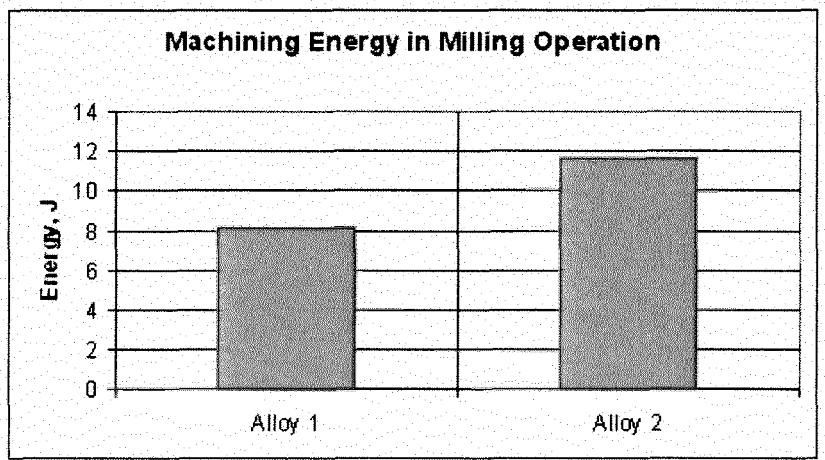
Machining Energy in Milling Operation
Energy, J
14
12
10
8
6
4
2
0
Alloy 1
Alloy 2

FIG. 10

## REFERENCES CITED IN THE DESCRIPTION

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