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(54) Ni-BASED SINGLE CRYSTAL SUPERALLOY AND ALLOY MEMBER USING THE SAME AS BASE

(57) Provided is an Ni-based single crystal superalloy wherein the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to 8.0% by mass of Ta, from 0% by mass to 2.0% by mass of Mo, from 3.0% by mass to 8.0% by mass of W, from 3.0% by mass to 8.0% by mass of Re, from 0% by mass to 0.50% by mass of Hf, from 3.0% by mass to 6.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 1.0% by mass to 14.0% by mass of Ru, and from 0.1 % by mass to 4.0% by mass of Nb, with the balance of Ni and inevitable impurities. The alloy prevents TCP phase precipitation at high temperatures, therefore having improved strength at high temperatures and having oxidation resistance at high temperatures.

Specifically, the invention is to provide a high-performance Ni-based single crystal superalloy having well balanced high-temperature strength and high-temperature oxidation resistance in practical use. The invention is also to provide the Ni-based single crystal superalloy having sufficient characteristics in point of "heat treatment window" that should not be overlooked in practical use.

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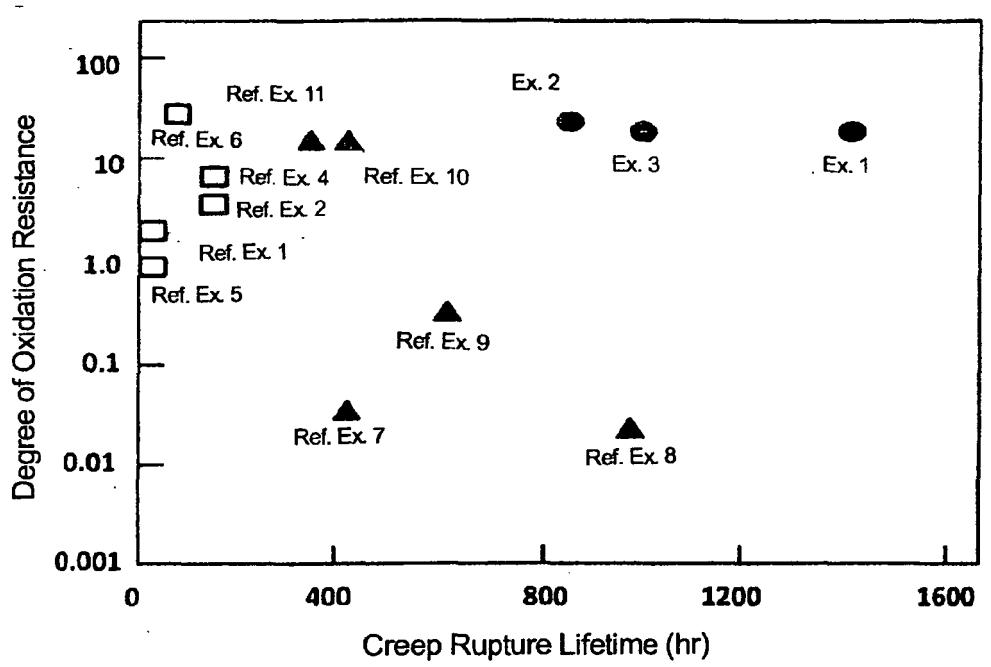
(Cont. next page)

Fig. 1


Degree of Oxidation Resistance
100
10
1.0
0.1
0.01
0.001
0
400
800
1200
1600
Creep Rupture Lifetime (hr)
Ref. Ex. 11
Ref. Ex. 6
Ref. Ex. 4
Ref. Ex. 10
Ref. Ex. 2
Ref. Ex. 1
Ref. Ex. 5
Ref. Ex. 9
Ref. Ex. 7
Ref. Ex. 8
Ex. 2
Ex. 3
Ex. 1

Description

Technical Field

[0001] The present invention relates to an Ni-based single crystal superalloy comprising Al, Ta, W, Re, Cr, Ru and Nb as the main alloying elements, and to a component comprising it as the substrate, and in particular, the invention relates to a technology for improving the high-temperature creep property of the superalloy and improving the environmental resistance such as the high-temperature corrosion resistance thereof.

Background Art

[0002] Typical compositions of an Ni-based single crystal superalloy developed as a material for high-temperature turbine blades/nozzle guide vanes such as aircraft, gas turbines and others are, for example, those shown in Table 1.

Table 1

Generation	Alloy Name	Element (wt.%)											
		Co	Cr	Mo	W	Al	Ti	Nb	Ta	Hf	Re	Ru	Ni
	PWA1480	5.0	10.0	-	4.0	5.0	1.5	-	12.0	-	-	-	balance
	PWA1484	10.0	5.0	2.0	6.0	5.6	-	-	9.0	0.1	3.0		balance
Fourth	MX-4 PWA1497	16.5	2.0	2.0	6.0	5.6	-	-	8.3	0.2	6.0	3.0	balance
Second	CMSX-4	9.6	6.4	0.6	6.4	5.6	1.0	-	6.5	0.1	3.0	-	balance
Third	CMSX-10X	3.3	2.3	0.4	5.5	5.7	0.3	0.1	8.4	0.03	6.3	-	balance
	Rene'N4	8.0	9.0	2.0	6.0	3.7	4.2	0.5	4.0	-	-	-	balance
	Rene'N5	8.0	7.0	2.0	5.0	6.2	-	-	7.0	0.2	3.0	-	balance
Third	Rene'N6	13.0	4.0	1.0	6.0	6.0	-	0.3	7.0	0.2	5.0	-	balance
	RR3010	3.1	1.7	0.5	5.5	5.9	0.1	0.1	8.5	-	6.8	-	balance
Fourth	3B	12.5	5.0		5.5	5.7	0.5	-	8.0	0.15	6.0	3.0	balance

[0003] The above-mentioned Ni-based single crystal superalloy is obtained through solution treatment at a predetermined temperature followed by aging treatment. The alloy is a so-called precipitation-hardened alloy, and has a morphology where a precipitation phase, γ'-phase is precipitated in the matrix phase, γ-phase.

[0004] Of the alloys shown in Table 1, CMSX-2 (by Canon Muskegon, see Patent Reference 1) is a first-generation alloy; CMSX-4 (by Canon Muskegon, see Patent Reference 2) is a second-generation alloy; Rene'N6 (by General Electric, see Patent Reference 3) and CMSX-10K (by Canon Muskegon, see Patent Reference 4) are third-generation alloys; 3B and MX-4 (by General Electric, see Patent Reference 5) are fourth-generation alloys.

[0005] The above-mentioned first-generation alloy CMSX-2 and second-generation alloy CMSX-4 are, though comparable thereto in point of creep strength at low temperatures, inferior to the third-generation alloys in point of creep strength at high temperatures, since a large quantity of eutectic γ'-phase remains therein even after high-temperature solution treatment.

[0006] The above-mentioned third-generation Rene'N6 and CMSX-10K are alloys that are intended to have more increased creep strength at high temperatures than the second-generation alloys. However, since the compositional ratio of Re (5% by mass or more) is over the Re solid solution limit in the matrix phase (γ-phase), the excessive Re may compound with the other elements to form a so-called TCP phase (topologically dose packed phase) through precipitation at high temperatures, therefore bringing about a problem in that the amount of the TCP phase increases in long-term use at high temperatures and the creep strength of the alloy is thereby lowered.

[0007] For improving the creep strength of the Ni-based single crystal superalloy, it will be effective to make the lattice constant of the precipitation phase (γ'-phase) slightly lower than the lattice constant of the matrix phase (γ-phase); however, since the lattice constant of each phase greatly changes depending on the compositional ratio of the alloying elements, it used to be difficult to precisely control the lattice constant and to improve the creep strength. In consideration of the above-mentioned situation, the present inventors have already proposed an Ni-based single crystal superalloy of which the strength is improved by significantly preventing the precipitation of the TCP phase therein at high temperatures

(Patent References 6, 7).

[0008] In general, in case where the above-mentioned Ni-based single crystal superalloy having a high strength at high temperatures is used as a material for high-temperature turbine blades/nozzle guide vanes such as aircraft, gas turbines or the like, the alloy is exposed to oxygen-containing, high-temperature combustion gas for a long period of time, and therefore, along with the above-mentioned strength improvement at high temperatures, the oxidation resistance and the corrosion resistance at high temperatures are also important performance factors of the Ni-based single crystal superalloy that should not be overlooked. None of the above-mentioned patent references have Examples relating to concrete oxidation resistance; but some of them have a qualitative description indicating the effectiveness of Cr, Hf, Ta and the like for oxidation resistance. However, Ru that shows a remarkable effect for strength improvement at high temperatures is, on the other hand, said to lower the oxidation resistance and the corrosion resistance at high temperature (Patent Reference 8). In Fig. 1, the data of the creep rupture lifetime at 1100°C and 137 MP and the oxidation resistance at 1100°C of typical various existing alloys are plotted. Rene'N5 and CMSX-4 shows considerably excellent oxidation resistance; however, these existing alloys could have improved oxidation resistance owing to the high Cr content therein, but their creep life at high temperatures is insufficient. On the other hand, the MX-4 alloy is known as a fourth-generation alloy having considerably excellent high-temperature heat resistance, but its oxidation resistance at high temperatures is poor. General Electric has proposed a coating system including diffusion barrier coating for improving the oxidation resistance of MX-4 (Patent Reference 6). As seen in these examples, it is difficult to develop an Ni-based single crystal superalloy satisfying both life/strength and oxidation resistance at high temperatures, and this will be an important technical theme toward industrialization of heat-resistant alloys in future.

Patent Reference 1: USP 4,582,548
Patent Reference 2: USP 4,643,782
Patent Reference 3: USP 5,455,120
Patent Reference 4: USP 5,366,695
Patent Reference 5: USP 5,151,249
Patent Reference 6: USP 6,966,956
Patent Reference 7: EP 1,262,569
Patent Reference 8: USP 6,921,586

Disclosure of Invention

Problems to be solved by the Invention

[0009] Specifically, an object of the present invention is to provide a high-performance Ni-based single crystal superalloy well balanced in two features of high-temperature strength and oxidation resistance at high temperatures in practical use. Another object of the invention is to provide an Ni-based single crystal superalloy still having sufficient characteristics even in "heat treatment window" that should not be overlooked in practical use.

Means for Solving the Problems

[0010] To attain the above-mentioned objects, the invention employs the following constitution.

[0011] The first aspect of invention is **characterized in that** the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to 8.0% by mass of Ta, from 0% by mass to 2.0% by mass of Mo, from 3.0% by mass to 8.0% by mass of W, from 3.0% by mass to 8.0% by mass of Re, from 0% by mass to 0.50% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 1.0% by mass to 14.0% by mass of Ru, and from 0.1% by mass to 4.0% by mass of Nb, with the balance of Ni and inevitable impurities.

[0012] The second aspect of the invention is **characterized in that** the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Ad, from 4.0% by mass to 10.0% by mass of Ta, from 0% by mass to less than 1.1% by mass of Mo, from 3.0% by mass to 6.0% by mass of W, from 3.0% by mass to 8.0% by mass of Re, from 0% by mass to 0.50% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 1.0% by mass to 8.0% by mass of Ru, and from 0.1 % by mass to 4.0% by mass of Nb, with the balance of Ni and inevitable impurities.

[0013] The third aspect of the invention is **characterized in that** the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to 8.0% by mass of Ta, from 0% by mass to less than 1.1% by mass of Mo, from 3.0% by mass to less than 6.0% by mass of W, from 3.0% by mass to 8.0% by mass of Re, from 0% by mass to less than 0.12% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 1.0% by mass to 8.0% by mass of Ru, and from 0.1% by mass to 4.0% by mass

of Nb, with the balance of Ni and inevitable impurities.

[0014] The for the aspect of the invention is **characterized in that** the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to 8.0% by mass of Ta, from 0% by mass to less than 1.1 % by mass of Mo, from 3.0% by mass to less than 6.0% by mass of W, from 5.8% by mass to 8.0% by mass of Re, from 0% by mass to less than 0.12% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 1.0% by mass to 8.0% by mass of Ru, and from 0.1 % by mass to 4.0% by mass of Nb, with the balance of Ni and inevitable impurities.

[0015] The fifth aspect of the invention is **characterized in that** the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to 8.0% by mass of Ta, from 0% by mass to less than 1.1 % by mass of Mo, from 3.0% by mass to less than 6.0% by mass of W, from 5.8% by mass to 8.0% by mass of Re, from 0% by mass to less than 0.12% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 4.1% by mass to 8.0% by mass of Ru, and from 0.1 % by mass to 4.0% by mass of Nb, with the balance of Ni and inevitable impurities.

[0016] The sixth aspect of the invention is **characterized in that** the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to less than 6.0% by mass of Ta, from 0% by mass to less than 1.1% by mass of Mo, from 3.0% by mass to less than 6.0% by mass of W, from 5.8% by mass to 8.0% by mass of Re, from 0% by mass to less than 0.12% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 4.1% by mass to 8.0% by mass of Ru, and from 0.1 % by mass to 4.0% by mass of Nb, with the balance of Ni and inevitable impurities.

[0017] The seventh aspect of the invention is **characterized in that** the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to less than 6.0% by mass of Ta, from 0% by mass to less than 1.1% by mass of Mo, from 3.0% by mass to less than 6.0% by mass of W, from 5.8% by mass to 8.0% by mass of Re, from 0.0% by mass to less than 0.12% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 4.1% by mass to 8.0% by mass of Ru, and from more than 1.0% by mass to 3.0% by mass of Nb, with the balance of Ni and inevitable impurities.

[0018] The eighth aspect of the invention is **characterized in that** the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to less than 6.0% by mass of Ta, from 0% by mass to less than 1.1 % by mass of Mo, from 4.0% by mass to less than 5.0% by mass of W, from 5.8% by mass to 8.0% by mass of Re, from 0.0% by mass to less than 0.12% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 4.1% by mass to 8.0% by mass of Ru, and from more than 1.0% by mass to 3.0% by mass of Nb, with the balance of Ni and inevitable impurities.

[0019] The ninth aspect of the invention is the Ni-based single crystal superalloy of any one of the invention afore-mentioned, which further contains Ti in an amount, as ratio by mass, of at most 2.0% by mass.

[0020] The tenth aspect of the invention is the Ni-based single crystal superalloy of any one of the invention afore-mentioned, which further contains at least any one of B, C, Si, Y, La, Ce, V and Zr.

[0021] The eleventh aspect of the invention is the Ni-based single crystal superalloy of any one of the invention afore-mentioned, wherein, when the lattice constant of the matrix phase is represented by a1 and the lattice constant of the precipitation phase is represented by a2, then the relation of a1 and a2 satisfies $0.992a1 \leq a2 < a1$.

[0022] The twelfth aspect of the invention is an alloy component comprising an Ni-based single crystal superalloy as the substrate, wherein the Ni-based single crystal superalloy is the Ni-based single crystal superalloy of any of the invention afore-mentioned.

Advantage of the Invention

[0023] Use of the above-mentioned Ni-based single crystal superalloy system enables, in principle, suppression of TCP phase precipitation in use at high temperatures that causes strength reduction, by addition of Ru thereto; and by defining the compositional ratio of the other alloying elements to fall within the optimum range as in the above to thereby control the lattice constant of the mother phase (γ-phase) and the lattice constant of the precipitation phase (γ'-phase) to the optimum value, an alloy excellent in high-temperature strength can be provided.

[0024] On the other hand, however, it is known that Ru lowers oxidation resistance and corrosion resistance at high temperatures. The present invention is directed to optimization of the composition for improving the above-mentioned high-temperature strength and to improvement of the oxidation resistance of the substrate itself of the Ni-based single crystal superalloy, and the inventors have found the practicable Ni-based single crystal superalloy well balanced in both the strength and the oxidation resistance at high temperatures by further optimizing the compositional ratio of Ru and other alloying elements.

[0025] Specifically, in the above-mentioned Ni-based single crystal superalloy system, in case where the ingredients have a composition containing, as ratio by mass, 5.6% by mass of Al, 5.6% by mass of Ta, 1.0% by mass of Mo, 4.8% by mass of W, 6.4% by mass of Re, 0.10% by mass of Hf, 4.6% by mass of Cr, 5.6% by mass of Co, 5.0% by mass of

Ru and 1.1% by mass of Nb with the balance of Ni and inevitable impurities, the creep rupture lifetime of the alloy at 1,100°C and 137 MPa is about 1,400 hours; and in a high-temperature oxidation acceleration test by a cycle at 1,100°C for 1.0 hour, the alloy undergoes little mass change up to 50 cycles.

[0026] The above-mentioned Ni-based single crystal superalloy system may further contain, as ratio by mass, from 0% by mass to 2.0% by mass of Ti.

[0027] The above-mentioned Ni-based single crystal superalloy system may contain at least one of B, C, Si, Y, La, Ce, V and Zr.

[0028] In this case, the individual ingredients are preferably, as ratio by mass, at most 0.05% by mass of B, at most 0.15% by mass of C, at most 0.1% by mass of Si, at most 0.1% by mass of Y, at most 0.1 % by mass of La, at most 0.1% by mass of Ce, at most 1% by mass of V and at most 0.1% by mass of Zr.

[0029] Further, the Ni-based single crystal superalloy of the invention is the above-mentioned Ni-based single crystal superalloy wherein a1 representing the lattice constant of the matrix phase and a2 representing the lattice constant of the precipitation phase satisfy $0.992a1 \leq a2 < a1$.

Best Mode for Carrying out the Invention

[0030] Embodiments of the invention are described in detail hereinunder.

[0031] The Ni-based single crystal superalloy of the invention is an alloy containing Al, Ta, W, Re, Cr, Ru and Nb as the main additives and containing Mo, Hf and Co as regulative additive elements.

[0032] The Ni-based single crystal superalloy of the invention is **characterized in that** the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to 8.0% by mass of Ta, from 0% by mass to 2.0% by mass of Mo, from 3.0% by mass to 8.0% by mass of W, from 3.0% by mass to 8.0% by mass of Re, from 0% by mass to 0.50% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 1.0% by mass to 14.0% by mass of Ru, and from 0.1% by mass to 4.0% by mass of Nb, with the balance of Ni and inevitable impurities.

[0033] The Ni-based single crystal superalloy of the invention is **characterized in that** the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to 10.0% by mass of Ta, from 0% by mass to less than 1.1% by mass of Mo, from 3.0% by mass to 6.0% by mass of W, from 3.0% by mass to 8.0% by mass of Re, from 0% by mass to 0.50% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 1.0% by mass to 8.0% by mass of Ru, and from 0.1% by mass to 4.0% by mass of Nb, with the balance of Ni and inevitable impurities.

[0034] The Ni-based single crystal superalloy of the invention is **characterized in that** the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to 8.0% by mass of Ta, from 0% by mass to less than 1.1% by mass of Mo, from 3.0% by mass to less than 6.0% by mass of W, from 3.0% by mass to 8.0% by mass of Re, from 0% by mass to less than 0.12% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 1.0% by mass to 8.0% by mass of Ru, and from 0.1 % by mass to 4.0% by mass of Nb, with the balance of Ni and inevitable impurities.

[0035] The Ni-based single crystal superalloy of the invention is **characterized in that** the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to 8.0% by mass of Ta, from 0% by mass to less than 1.1% by mass of Mo, from 3.0% by mass to less than 6.0% by mass of W, from 5.8% by mass to 8.0% by mass of Re, from 0% by mass to less than 0.12% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 1.0% by mass to 8.0% by mass of Ru, and from 0.1 % by mass to 4.0% by mass of Nb, with the balance of Ni and inevitable impurities.

[0036] The Ni-based single crystal superalloy of the invention is **characterized in that** the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to 8.0% by mass of Ta, from 0% by mass to less than 1.1% by mass of Mo, from 3.0% by mass to less than 6.0% by mass of W, from 5.8% by mass to 8.0% by mass of Re, from 0% by mass to less than 0.12% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 4.1 % by mass to 8.0% by mass of Ru, and from 0.1% by mass to 4.0% by mass of Nb, with the balance of Ni and inevitable impurities.

[0037] The Ni-based single crystal superalloy of the invention is **characterized in that** the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to less than 6.0% by mass of Ta, from 0% by mass to less than 1.1% by mass of Mo, from 3.0% by mass to less than 6.0% by mass of W, from 5.8% by mass to 8.0% by mass of Re, from 0% by mass to less than 0.12% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 4.1 % by mass to 8.0% by mass of Ru, and from 0.1 % by mass to 4.0% by mass of Nb, with the balance of Ni and inevitable impurities.

[0038] The Ni-based single crystal superalloy of the invention is **characterized in that** the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to less than 6.0% by mass of Ta, from 0% by mass to less than 1.1 % by mass of Mo, from 3.0% by mass to less than 6.0% by mass of

W, from 5.8% by mass to 8.0% by mass of Re, from 0.0% by mass to less than 0.1% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 4.1% by mass to 8.0% by mass of Ru, and from more than 1.0% by mass to 3.0% by mass of Nb, with the balance of Ni and inevitable impurities.

[0039] The Ni-based single crystal superalloy of the invention is **characterized in that** the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to less than 6.0% by mass of Ta, from 0% by mass to less than 1.1 % by mass of Mo, from 4.0% by mass to less than 5.0% by mass of W, from 5.8% by mass to 8.0% by mass of Re, from 0.0% by mass to less than 0.1% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 4.1% by mass to 8.0% by mass of Ru, and from more than 1.0% by mass to 3.0% by mass of Nb, with the balance of Ni and inevitable impurities.

[0040] The above-mentioned alloys all have an austenite phase, γ-phase (matrix phase), and an intermediate order phase, γ'-phase (precipitation phase) dispersed and precipitated in the matrix phase. The γ'-phase mainly comprises an intermetallic compound represented by Ni_3Al, and the γ'-phase improves the high-temperature strength of the Ni-based single crystal superalloy.

[0041] Cr is an element excellent in oxidation resistance, and improves the high-temperature corrosion resistance of the Ni-based single crystal superalloy.

[0042] The compositional ratio of Cr is preferably within a range of from 3.0% by mass to 7.0% by mass, more preferably within a range of from 3.5% by mass to 6.5% by mass, most preferably within a range of from 4.0% by mass to 6.0% by mass.

[0043] When the compositional ratio of Cr is less than 3.0% by mass, then it is unfavorable since the desired high-temperature corrosion resistance could not be secured; but when the compositional ratio of Cr is more than 7.0% by mass, it is unfavorable since the γ'-phase precipitation is suppressed and harmful phases such as σ-phase, μ-phase and the like would be formed to lower the high-temperature strength.

[0044] Mo dissolves in the matrix phase, γ-phase in the co-presence of W and Ta, thereby increasing the high-temperature strength of the alloy, and contributes toward the high-temperature strength through precipitation hardening. In addition, Mo greatly contributes toward the lattice misfit and the dislocation network distance (to be mentioned below) that are the characteristics of the present alloy.

[0045] The compositional ratio of Mo is preferably within a range of from 0.0% by mass to 2.0% by mass, more preferably within a range of from 0.0% by mass to less than 1.1 % by mass.

[0046] When the compositional ratio of Mo is more than 2.0% by mass, then it is unfavorable since the desired oxidation resistance characteristic at high temperatures could not be secured in the composition range of the Ni-based single crystal superalloy exemplified in the above.

[0047] W increases the high-temperature strength of the alloy owing to the effect of solid solution strengthening and precipitation hardening in the co-presence of Ta and Mo as so mentioned in the above. When the compositional ratio of W is less than 3.0% by mass, then it is unfavorable since the desired high-temperature strength could not be secured; but when the compositional ratio of W is too large, it is also unfavorable since the high-temperature corrosion resistance would lower. The compositional ratio of W is preferably within a range of from 3.0% by mass to 8.0% by mass, more preferably within a range of from 3.0% by mass to 6.0% by mass, most preferably within a range of from 4.0% by mass to 5.0% by mass.

[0048] Ta increases the high-temperature strength of the alloy owing to the effect of solid solution strengthening and precipitation hardening in the co-presence of W and Mo as so mentioned in the above, and it partly acts on the γ'-phase for precipitation hardening to thereby increase the high-temperature strength.

[0049] The compositional ratio of Ta is preferably within a range of from 4.0% by mass to 8.0% by mass.

[0050] When the compositional ratio of Ta is less than 4.0% by mass, then it is unfavorable since the desired high-temperature strength could not be secured; but when the compositional ratio of Ta is more than 10.0% by mass, it is also unfavorable since σ-phase and μ-phase would be formed to lower the high-temperature strength. In addition, in practical use, when the compositional ratio of Ta is 8.0% by mass or more, then it is unfavorable since the density of the Ni-based single crystal superalloy would increase. The most preferred compositional ratio of Ta is within a range of from 4.0% by mass to less than 6.0% by mass.

[0051] Al compounds with Ni and forms an intermetallic compound represented by Ni_3Al to form the γ'-phase that is finely and uniformly dispersed and precipitated in the matrix phase in a fraction ratio by volume of from 60 to 70%, thereby increasing the high-temperature strength of the alloy.

[0052] The* compositional ratio of Al is preferably within a range of from 5.0% by mass to 7.0% by mass.

[0053] When the compositional ratio of Al is less than 5.0% by mass, then it is unfavorable since the precipitation amount of the γ'-phase would be low and the desired high-temperature strength of the alloy could not be secured; but when the compositional ratio of Al is more than 7.0% by mass, then it is also unfavorable since a large quantity of coarse γ'-phase called eutectic γ'-phase would be formed to disable the solution treatment and the alloy could not secure sufficient high-temperature strength.

[0054] Hf is an antioxidation-enhancing element. The compositional ratio of Hf is preferably within a range of from

0.00% by mass to 0.50% by mass, most preferably within a range of from 0.01% by mass to less than 0.12% by mass. - When the compositional ratio of Hf is less than 0.01% by mass, then it is unfavorable since the antioxidation-enhancing effect could not be secured. However, depending on the content of Al and/or Cr, the compositional ratio of Hf may be from 0% by mass to less than 0.01% by mass, as the case may be. When the compositional ratio of Hf is too large, it is unfavorable as often causing local melting to lower the high-temperature strength of the alloy.

[0055] Co expands the solid solution limit of Al, Ta and others in the matrix phase at high temperatures thereby to disperse and precipitate fine γ'-phase through heat treatment to increase the high-temperature strength of the alloy.

[0056] The compositional ratio of Co is preferably within a range of from 0.0% by mass to 9.9% by mass, more preferably within a range of from 0.1% by mass to 9.9% by mass. When the compositional ratio of Co is less than 0.1 % by mass, then it is unfavorable since the γ'-phase precipitation would be insufficient and the desired high-temperature strength could not be secured. However, depending on the content of Al and/or Ta, the compositional ratio of Co may be 0% by mass or less than 0.1% by mass, as the case may be. When the compositional ratio of Co is more than 9.9% by mass, then it is unfavorable since the balance with the other elements such as Al, Ta, Mo, W, Hf, Cr and others may be lost and some harmful phases may precipitate to lower the high-temperature strength of the alloy.

[0057] Re dissolves in the matrix phase, γ-phase to improve the high-temperature strength of the alloy through solid solution strengthening. In addition, it has another effect of enhancing the corrosion resistance. On the other hand, addition of too much Re would lower the high-temperature strength as causing precipitation of the harmful phase, TCP phase at high temperatures.

[0058] The compositional ratio of Re is preferably within a range of from 3.0% by mass to 8.0% by mass, more preferably from 5.8% by mass to 8.0% by mass.

[0059] When the compositional ratio of Re is less than 3.0% by mass, then it is unfavorable since the solid solution strengthening for the γ-phase would be insufficient and the desired high-temperature strength could not be secured. When the compositional ratio of Re is more than 8.0% by mass, then it is also unfavorable since the TCP phase would precipitate at high temperatures to lower the high-temperature strength and since the increase in the amount of expensive Re would cause the increase in the alloy material cost.

[0060] Ru prevents the precipitation of the TCP phase, thereby improving the high-temperature strength of the alloy.

[0061] The compositional ratio of Ru is preferably within a range of from 1.0% by mass to 14.0% by mass, more preferably within a range of from 1.0% by mass to 8.0% by mass. Even more preferably, the compositional ratio of Ru is within a range of from 4.1 % by mass to 8.0% by mass.

[0062] When the compositional ratio of Ru is less than 1.0% by mass, then the TCP phase would precipitate at high temperatures and sufficient high-temperature strength could not be secured. Further; when the compositional ratio of Ru is less than 4.1 % by mass, then the high-temperature strength of the alloy would be lower than that of the case where the compositional ratio of Ru is not lower than 4.1% by mass. When the compositional ratio of Ru is more than 8.0% by mass, then it is unfavorable since ε-phase would precipitate and the high-temperature strength of the alloy would be thereby lowered. In addition, the increase in the amount of expensive Ru would cause the increase in the alloy material cost, which is unfavorable from the viewpoint of the practical use of the alloy.

[0063] The compositional ratio of Nb is preferably within a range of from 0.1 % by mass to 4.0% by mass, more preferably within a range of from more than 1.0% by mass to 3.0% by mass. Nb is an element favorable in the point of lowering the density of the Ni-based single crystal superalloy; however, when the compositional ratio of Nb is 3.0% by mass or more, then it is unfavorable since the harmful phase would be readily formed at high temperatures.

[0064] In the invention, the compositional ratio of Al, Ta, Mo, W, Hf, Cr. Co, Re, Nb and Ni is controlled to be an optimum one to thereby make the lattice misfit and the dislocation network distance (to be mentioned below) that are computed from the lattice constant of the γ-phase and the lattice constant of the γ'-phase, fall within an optimum range to increase the high-temperature strength of the alloy, and TCP phase precipitation may be prevented by addition of Ru. In particular, defining the compositional ratio of Al, Cr, Ta and Mo to fall within the above-mentioned compositional range makes it possible to lower the alloy production cost. Further, the invention facilitates increase in the specific strength and definition of the lattice misfit and the dislocation network distance to be the optimum value.

[0065] In addition, in a service environment at high temperatures of from 1273K (1000°C) to 1373K (1100°C), when the lattice constant of the crystal that constitutes the matrix phase, γ-phase is represented by a1 and the lattice constant of the crystal constituting the precipitation phase, γ'-phase is by a2, the relation between a1 and a2 preferably satisfies a2<a1.

[0066] In the following description, the percentage of a1 to the difference between the lattice constant a1 of the crystal of the mother phase and the lattice constant a2 of the crystal of the precipitation phase {(a2 - a1)/a1 × 100 (%)} is referred to as "lattice misfit".

[0067] When the lattice misfit range is more negative so far as the coherency of the matrix phase, γ-phase and the precipitation phase, γ'-phase is kept well, then the dislocation network distance could be smaller therefore bringing about the effect of improving the creep strength of the alloy.

[0068] The lattice misfit is less than 0%, preferably at most -0.1%, more preferably at most -0.15%.

[0069] However, when the numerical value of the lattice misfit is too much shifted to negativity, the coherency could not be maintained and the performance of the alloy would worsen; and therefore, preferably, the value is at least -1%, more preferably -0.8%, even more preferably -0.7%.

[0070] In other words, the relation between the lattice constant a2 of the crystal of the precipitation phase and the lattice constant a1 of the crystal of the matrix phase is $0.990a1 \leq a2 < a1$, preferably $0.992a1 \leq a2 \leq 0.999a1$, more preferably $0.993a1 \leq a2 \leq 0.9985a1$.

[0071] In case where the lattice constants of the two are in the relation as above, the precipitation phase could form and grow in the matrix phase by heat treatment to continuously extend in the perpendicular direction relative to the loading direction thereto, and therefore, the dislocation defects migration in the alloy microstructure is suppressed under stress, and the creep strength of the alloy is thereby increased. For controlling the lattice constant a1 and the lattice constant a2 to be in the above-mentioned relation, the composition of the alloying elements of the Ni-based single crystal superalloy must be suitably controlled.

[0072] The Ni-based single crystal superalloy may further contain Ti. In this case, the compositional ratio of Ti is preferably within a range of from 0% by mass to 2.0% by mass. When the compositional ratio of Ti is more than 2.0% by mass, then it is unfavorable since harmful phases would precipitate to lower the high-temperature strength of the alloy.

[0073] Regarding the compositional ratio of Ta, Nb and Ti, when the total of these (Ta + Nb + Ti) is from 4.0% by mass to 10.0% by mass, then the high-temperature strength of the alloy could be increased.

[0074] The Ni-based single crystal superalloy may contain, for example, B, C, Si, Y, La, Ce, V, Zr and the like, in addition to inevitable impurities. In case where the alloy contains at least one of B, C, Si, Y, La, Ce, V and Zr, the compositional ratio of the individual ingredients is preferably such that B is at most 0.05% by mass, C is at most 0.15% by mass, Si is at most 0.1 % by mass, Y is at most 0.1 % by mass, La is at most 0.1 % by mass, Ce is at most 0.1% by mass, V is at most 1% by mass, Zr is at most 0.1 % by mass. When the compositional ratio of the individual ingredients is more than the above-mentioned range, then it is unfavorable since harmful phases would precipitate to lower the high-temperature strength of the alloy.

[0075] Some existing Ni-based single crystal superalloys undergo reverse partition, but the Ni-based single crystal alloy of the invention does not undergo reverse partition.

[0076] The creep rupture lifetime and the oxidation resistance of the Ni-based single-crystal superalloy of the invention described hereinabove are shown in Fig. 1 along with the characteristics of various typical existing alloys therein. It is obvious that, as compared with Rene'N5, CMSX-4 and MX-4 alloys, the Ni-based single crystal superalloy of the invention has extremely excellent characteristics of creep life and oxidation resistance at high temperatures.

[0077] The degree of oxidation resistance on the vertical axis in Fig. 1 is defined by the following formula. In general, in case where samples of Ni-based single crystal superalloys are oxidized and their oxidation is promoted at high temperatures, the mass of some alloys temporarily increases by oxidation but then decreases, and that of other alloys gradually decreases after the start of oxidation. The formula applies to all cases and indicates the oxidation resistance of the alloys.

Degree of Oxidation Risistance = $\log(1/w_1 \times (|w_{50}-w_1|))$

wherein w1 means the mass increase in one cycle (mg/cm^2),

and $w_{50} - w_1$ means the mass change from 1 cycle up to 50 cycles (mg/cm^2).

Examples

[0078] The effect of the invention is described below with reference to the following Examples.

[0079] Using a vacuum melting furnace, various types of Ni-based single crystal superalloy melts were prepared, and the alloy melts were cast into plural alloy ingots each having a different composition. The compositional ratios of the alloys of the invention (Examples 1 to 3), as well as those of six typical existing heat-resistant alloys (Reference Examples 1 to 6) and four types of fourth-generation and fifth-generation heat-resistant alloys for which the present applicant already filed patent applications (Reference Examples 7 to 11) (Patent References 6 and 7) are shown in Table 2.

Table 2

Sample	Constitutive Element (wt.%)											
	Co	Cr	Mo	W	Al	Ti	Nb	Ta	Hf	Re	Ru	Ni
Ex.1	5.6	4.6	1.0	5.1	5.5	-	1.2	5.6	0.1	6.5	5.0	balance
Ex.2	8.0	4.6	1.0	4.8	5.6	-	1.2	5.6	0.1	6.4	5.0	balance
Ex.3	5.6	4.8	0.8	5.2	5.6	-	1.2	5.6	0.1	6.4	5.0	balance
Ref. Ex. 1	5.0	10.0	-	4.0	5.0	1.5	-	12.0	-	-	-	balance

(continued)

Sample	Constitutive Element (wt.%)											
	Co	Cr	Mo	W	Al	Ti	Nb	Ta	Hf	Re	Ru	Ni
Ref. Ex. 2	10.0	5.0	2.0	6.0	5.6	-	-	9.0	0.1	3.0	-	balance
Ref. Ex. 3	16.5	2.0	2.0	6.0	5.6	-	-	8.3	0.2	6.0	3.0	balance
Ref. Ex. 4	9.6	6.4	0.6	6.4	5.6	1.0	-	6.5	0.1	3.0	-	balance
Ref. Ex. 5	8.0	9.0	2.0	6.0	3.7	4.2	0.5	4.0	-	-	-	balance
Ref. Ex. 6	8.0	7.0	2.0	5.0	6.2	-	-	7.0	0.2	3.0	-	balance
Ref. Ex. 7	5.8	2.9	2.9	5.9	5.9	-	-	5.9	0.1	4.9	2.0	balance
Ref. Ex. 8	5.6	2.8	2.8	5.6	5.6	-	-	5.6	0.1	6.9	5.0	balance
Ref. Ex. 9	5.6	4.6	2.4	5.0	5.6	-	-	5.6	0.1	6.4	5.0	balance
Ref. Ex. 10	12.0	4.6	1.0	4.8	5.6	-	1.2	5.6	0.1	6.4	5.0	balance
Ref. Ex. 11	8.0	7.0	0.0	4.8	5.6	-	1.2	5.6	0.1	6.4	5.0	balance

Ex. Example Ref. Ex. Reference Example

[0080] Next, the alloy ingot was processed for solution treatment and for aging treatment, and the alloy microstructure was observed with a scanning electronic microscope (SEM). For the solution treatment of the alloys of Examples 1 to 3 and Reference Examples 7 to 11, they were kept at 1573K (1300°C) for 1 hour, then heated up to 1603K (1330°C) and kept as such for 5 hours. The aging treatment was continuous treatment of primary aging treatment at 1273K to 1423K (1000°C to 1150°C) for 4 hours followed by secondary aging treatment at 1143K (870°C) for 20 hours. The existing alloys of Reference Examples 1 to 6 were processed for solution treatment and aging treatment under known conditions for each alloy. As a result, no TCP phase was confirmed in the microstructure of every sample.

[0081] Fig. 2 is the transmission electromicroscopic picture of the Ni-based single crystal alloy of Example 1 that was processed for solution treatment at 1335°C for 18 hours followed by aging treatment at 1150°C. Network dislocations are observed and the network distance is about 0.32 μm, which indicates favorable Ni-based single crystal alloys.

[0082] Next, the solution-treated and aging-treated samples were tested in a creep test. In the creep test, each sample (Examples 1 to 3 and Reference Examples 1 to 11) was tested at the temperature and under the stress shown in Table 3, and the creep rupture lifetime thereof was recorded. The results are shown in Table 3.

[0083] Further, the solution-treated and aging-treated samples were tested in an oxidation resistance test. Regarding the oxidation resistance test condition, each sample was exposed to air at a high temperature of 1150°C for 1 hour as one cycle and the mass change thereof was measured. The degree of oxidation resistance after 50 cycles is shown in Table 3.

Table 3

Sample	Creep Rupture Lifetime	Degree of Oxidation Resistance	Type of Alloy
Ex. 1	1400(h)	19.553	
Ex. 2	857(h)	24.105	
Ex. 3	986(h)	20.364	
Ref. Ex. 1	17.8(h)	2.099	(PWA1480)
Ref. Ex. 2	141 (h)	3.998	(PWA1484)
Ref. Ex. 3	142(h)	0.008	(MX-4)

(continued)

Sample	Creep Rupture Lifetime	Degree of Oxidation Resistance	Type of Alloy
Ref. Ex. 4	139(h)	4.276	(CMSX-4)
Ref. Ex. 5	31 (h)	0.892	(Rene'N4)
Ref. Ex. 6	89(h)	33.449	(Rene'N5)
Ref. Ex. 7	412(h)	0.032	previously filed for patent application
Ref. Ex. 8	967(h)	0.021	previously filed for patent application
Ref. Ex. 9	608(h)	0.361	previously filed for patent application
Ref. Ex. 10	443(h)	21.843	previously filed for patent application
Ref. Ex. 11	382(h)	20.364	previously filed for patent application

Creep Rupture Lifetime: Test result at 1373K (1100°C) under 137 MPa.
Ex. Example Ref. Ex. Reference Example

[0084] In Fig. 1, the heat-resistant alloys of the invention (Examples 1 to 3), various typical existing practical alloys (Reference Examples 1 to 6) and heat-resistant alloys already proposed by the present inventors (Reference Examples 7 to 11) (Patent References 6 and 7) were compared with each other in point of their properties, creep rupture lifetime at 1100°C and under 137 MP and oxidation resistance at 1150°C. Typical existing practical alloys are poor in the high temperature mechanical strength; and the alloys already proposed by the inventors are obviously more excellent than the practical alloys in point of the high temperature mechanical strength, but some of them are not always sufficient in point of the oxidation resistance. Though the data thereof are not plotted, the degree of oxidation resistance of the existing alloy MX-4 of Reference 3 was at most 0.01, and was extremely lower than that of the other alloy systems. The results shown in Fig. 1 suggest that the alloy system of the invention is extremely excellent both in the mechanical strength and the oxidation resistance at the high temperature as compared with the above-mentioned existing alloys.

[0085] Fig. 3 comparatively shows the mass change of the alloy of Example 1 and the alloy of Reference Example 4 in a cyclic oxidation test where the alloys were exposed to air at a high temperature of 1100°C for 1 hour as one cycle, and repeatedly for a total of about 600 cycles. The results indicate that the alloy of the invention has much more excellent oxidation resistance than the existing alloy CMSX-4 that is generally known to have excellent oxidation resistance.

[0086] Fig. 4 shows the observation of the surface of the alloy of Example 1 exposed to air at 1100°C for 1 hour. The alloy surface has a multilayer structure of plural dense and thin layers including a protective alumina layer, which indicates excellent oxidation resistance of the alloy

[0087] The lattice misfit value (%) of the alloy of Example 1 and that of the typical existing alloy CMSX-4 (Reference Example 4) were determined through computation, and were -0.28 and -0.14, respectively. The alloy of Example 1 was better for the smaller dislocation network distance and the consequent improvement of the creep strength of the alloy with maintaining the coherency between the matrix phase, γ-phase and the precipitation phase, γ'-phase.

[0088] Fig. 5 shows the data of heat-treatment window of the alloy of Example 1 and the practical alloy of Reference Example 4. The heat-treatment window of the alloy of Example 1 and that of the practical alloy of Reference Example 4 were 47°C and 28°C, respectively. The alloy of the invention has a broader heat-treatment window than the practical alloy of Reference Example 4 with no problem in the industrial blade casting process of producing it, and is expected to have an extremely high blade yield in the casting process.

Brief Description of Drawings

[0089]

Fig. 1 is a view of comparing the heat-resistant alloys of the invention (Examples 1 to 3), typical existing practical alloys (Reference Examples 1 to 6) and alloys for which the present inventors already filed patent application (Reference Examples 7 to 11) with each other in point of the creep rupture lifetime at 1100°C and under 137 MP and the oxidation resistance at 1150°C.

Fig. 2 is a transmission electromicroscopic picture of the solution-treated and aging-treated, Ni-based single crystal alloy of Example 1.

Fig. 3 is a view showing the mass change of the alloy of Example 1 and the practical alloy of Reference Example 4 exposed to air at a high temperature of 1100°C for 1 hour as one cycle and repeatedly for a total of about 600 cycles.

Fig. 4 is a photographic picture to observe the surface of the alloy of Example 1 exposed to air at 1100°C for 1 hour.

Fig. 5 shows thermal analysis results for heat-treatment window of the alloy of Example 1 and the practical alloy of Reference Example 4.

Claims

1. An Ni-based single crystal superalloy comprising Al, Ta, W, Re, Cr, Ru and Nb as the main additive elements, wherein the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to 8.0% by mass of Ta, from 0% by mass to 2.0% by mass of Mo, from 3.0% by mass to 8.0% by mass of W, from 3.0% by mass to 8.0% by mass of Re, from 0% by mass to 0.50% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 1.0% by mass to 14.0% by mass of Ru, and from 0.1% by mass to 4.0% by mass of Nb, with the balance of Ni and inevitable impurities.

2. An Ni-based single crystal superalloy comprising Al, Ta, W, Re, Cr, Ru and Nb as the main additive elements, wherein the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to 10.0% by mass of Ta, from 0% by mass to less than 1.1% by mass of Mo, from 3.0% by mass to 6.0% by mass of W, from 3.0% by mass to 8.0% by mass of Re, from 0% by mass to 0.50% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 1.0% by mass to 8.0% by mass of Ru, and from 0.1 % by mass to 4.0% by mass of Nb, with the balance of Ni and inevitable impurities.

3. An Ni-based single crystal superalloy comprising Al, Ta, W, Re, Cr, Ru and Nb as the main additive elements, wherein the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to 8.0% by mass of Ta, from 0% by mass to less than 1.1 % by mass of Mo, from 3.0% by mass to less than 6.0% by mass of W, from 3.0% by mass to 8.0% by mass of Re, from 0% by mass to less than 0.12% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 1.0% by mass to 8.0% by mass of Ru, and from 0.1% by mass to 4.0% by mass of Nb, with the balance of Ni and inevitable impurities.

4. An Ni-based single crystal superalloy comprising Al, Ta, W, Re, Cr, Ru and Nb as the main additive elements, wherein the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to 8.0% by mass of Ta, from 0% by mass to less than 1.1 % by mass of Mo, from 3.0% by mass to less than 6.0% by mass of W, from 5.8% by mass to 8.0% by mass of Re, from 0% by mass to less than 0.12% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 1.0% by mass to 8.0% by mass of Ru, and from 0.1 % by mass to 4.0% by mass of Nb, with the balance of Ni and inevitable impurities.

5. An Ni-based single crystal superalloy comprising Al, Ta, W, Re, Cr, Ru and Nb as the main additive elements, wherein the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to 8.0% by mass of Ta, from 0% by mass to less than 1.1% by mass of Mo, from 3.0% by mass to less than 6.0% by mass of W, from 5.8% by mass to 8.0% by mass of Re, from 0% by mass to less than 0.12% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 4.1% by mass to 8.0% by mass of Ru, and from 0.1 % by mass to 4.0% by mass of Nb, with the balance of Ni and inevitable impurities.

6. An Ni-based single crystal superalloy comprising Al, Ta, W, Re, Cr, Ru and Nb as the main additive elements, wherein the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to less than 6.0% by mass of Ta, from 0% by mass to less than 1.1% by mass of Mo, from 3.0% by mass to less than 6.0% by mass of W, from 5.8% by mass to 8.0% by mass of Re, from 0% by mass to less than 0.12% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 4.1 % by mass to 8.0% by mass of Ru, and from 0.1% by mass to 4.0% by mass of Nb, with the balance of Ni and inevitable impurities.

7. An Ni-based single crystal superalloy comprising Al, Ta, W, Re, Cr, Ru and Nb as the main additive elements,

wherein the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to less than 6.0% by mass of Ta, from 0% by mass to less than 1.1 % by mass of Mo, from 3.0% by mass to less than 6.0% by mass of W, from 5.8% by mass to 8.0% by mass of Re, from 0.0% by mass to less than 0.12% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 4.1 % by mass to 8.0% by mass of Ru, and from more than 1.0% by mass to 3.0% by mass of Nb, with the balance of Ni and inevitable impurities.

8. An Ni-based single crystal superalloy comprising Al, Ta, W, Re, Cr, Ru and Nb as the main additive elements, wherein the ingredients have a composition containing, as ratio by mass, from 5.0% by mass to 7.0% by mass of Al, from 4.0% by mass to less than 6.0% by mass of Ta, from 0% by mass to less than 1.1% by mass of Mo, from 4.0% by mass to less than 5.0% by mass of W, from 5.8% by mass to 8.0% by mass of Re, from 0.0% by mass to less than 0.12% by mass of Hf, from 3.0% by mass to 7.0% by mass of Cr, from 0% by mass to 9.9% by mass of Co, from 4.1 % by mass to 8.0% by mass of Ru, and from more than 1.0% by mass to 3.0% by mass of Nb, with the balance of Ni and inevitable impurities.

9. The Ni-based single crystal superalloy as claimed in any one of claim 1 to claim 8, which further contains Ti in an amount, as ratio by mass, of at most 2.0% by mass.

10. The Ni-based single crystal superalloy as claimed in any one of claim 1 to claim 9, which further contains at least any one of B, C, Si, Y, La, Ce, V and Zr.

11. The Ni-based single crystal superalloy as claimed in any one of claim 1 to claim 10, wherein, when the lattice constant of the matrix phase is represented by a1 and the lattice constant of the precipitation phase is represented by a2, then the relation of a1 and a2 satisfies $0.992a1 \leq a2 < a1$.

12. An alloy component comprising an Ni-based single crystal superalloy as the substrate, wherein the Ni-based single crystal superalloy is the Ni-based single crystal superalloy of any of claim 1 to claim 11.

Fig. 1

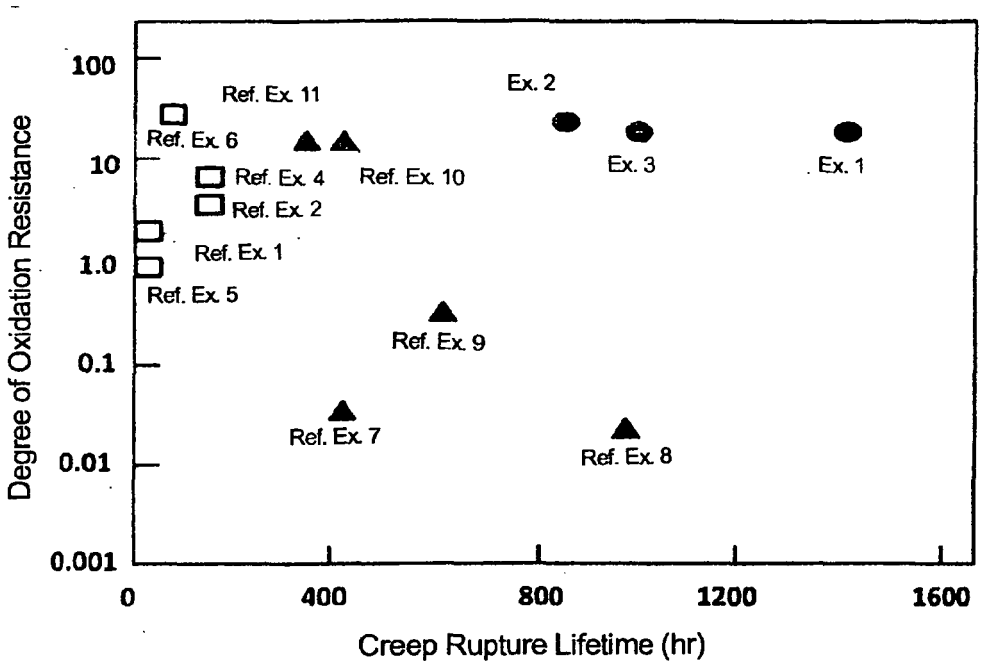
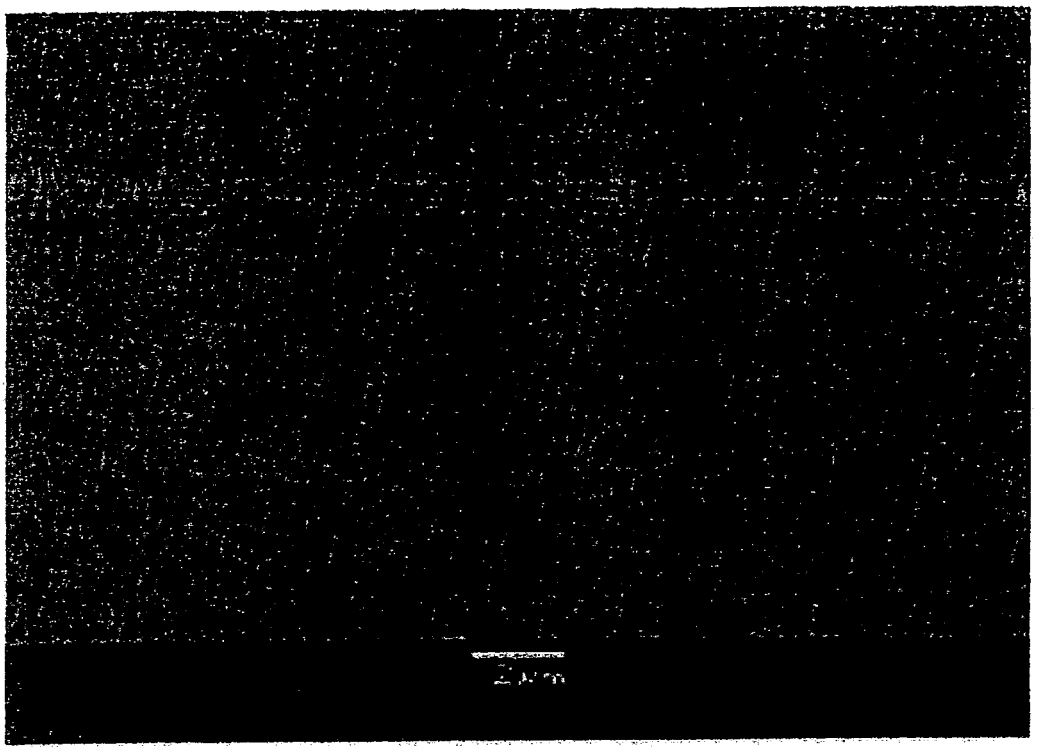

Degree of Oxidation Resistance
100
10
1.0
0.1
0.01
0.001
0
400
800
1200
1600
Creep Rupture Lifetime (hr)
Ref. Ex. 11
Ref. Ex. 6
Ref. Ex. 4
Ref. Ex. 10
Ref. Ex. 2
Ref. Ex. 1
Ref. Ex. 5
Ref. Ex. 9
Ref. Ex. 7
Ref. Ex. 8
Ex. 2
Ex. 3
Ex. 1

Fig. 2



Alloy of Example 1

Fig. 3

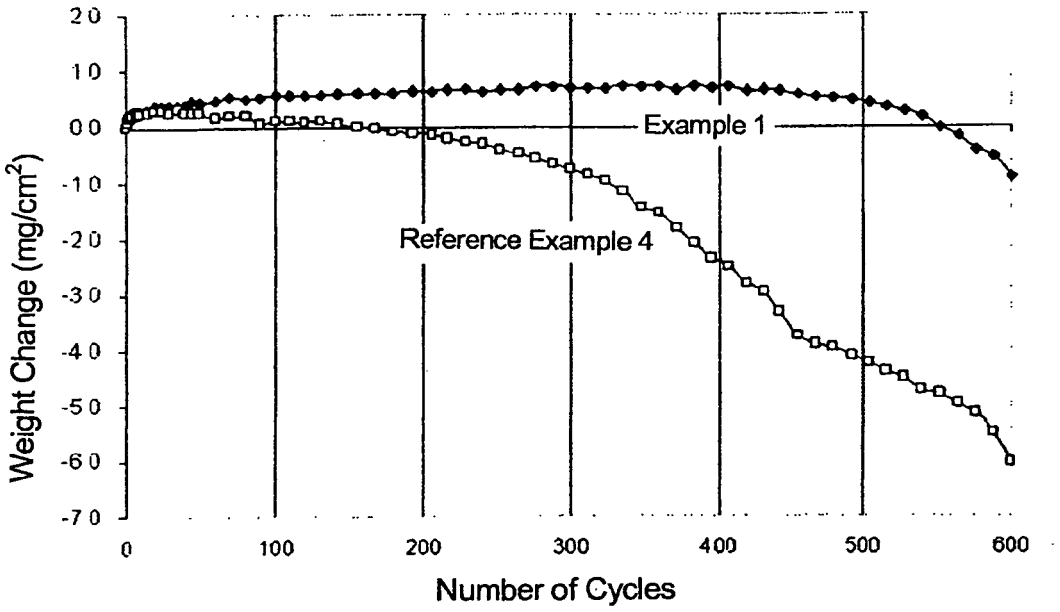

20
10
00
-10
-20
-30
-40
-50
-60
-70
Weight Change (mg/cm2)
0
100
200
300
400
500
600
Number of Cycles
Example 1
Reference Example 4

Fig. 4

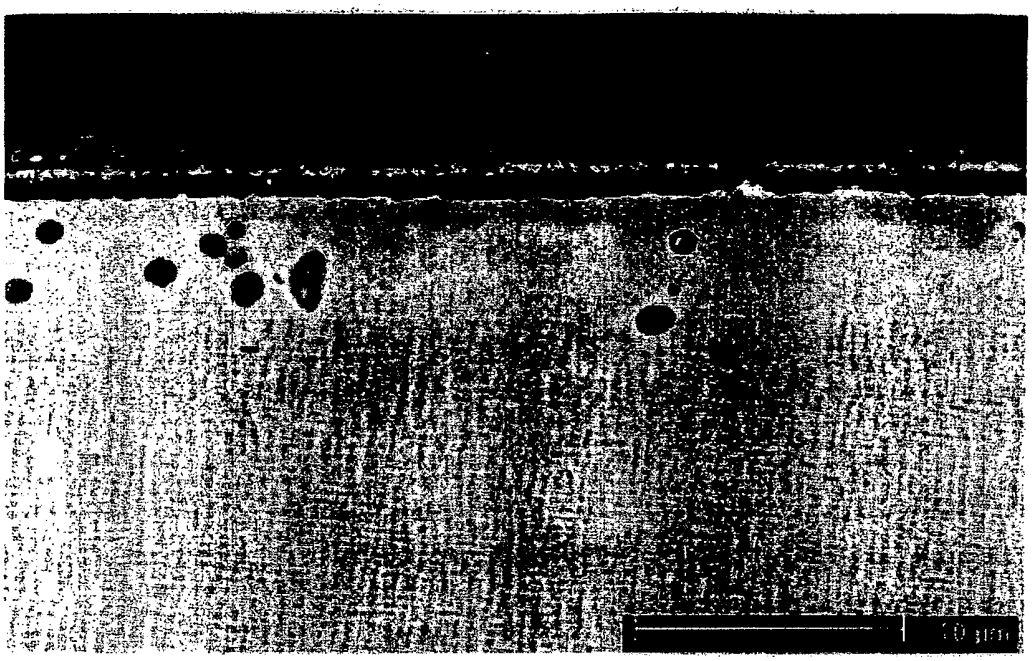
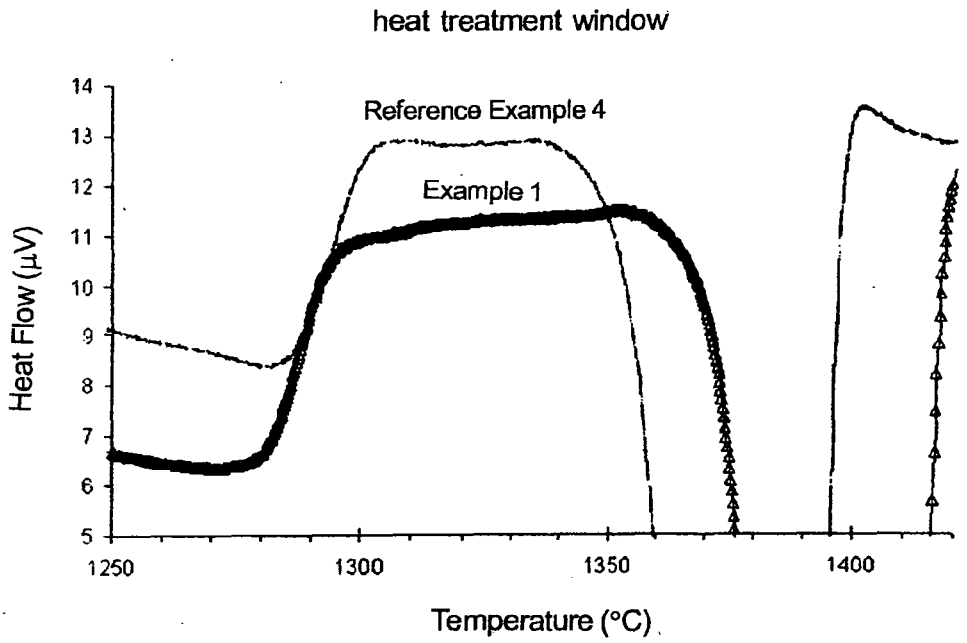


Fig. 5


heat treatment window
Reference Example 4
Example 1
Heat Flow (µV)
14
13
12
11
10
9
8
7
6
5
1250
1300
1350
1400
Temperature (°C)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2009/061762

A. CLASSIFICATION OF SUBJECT MATTER
C22C19/05(2006.01)i

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)
C22C19/05

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2009
Kokai Jitsuyo Shinan Koho 1971-2009 Toroku Jitsuyo Shinan Koho 1994-2009

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 5-5143 A (General Electric Co.), 14 January, 1993 (14.01.93), Par. No. [0033] & EP 434996 A1 & US 5151249 A	1-12
A	JP 11-310839 A (Hitachi, Ltd.), 09 November, 1999 (09.11.99), Claim 5 (Family: none)	1-12
A	WO 2008/032751 A1 (Independent Administrative Institution National Institute for Materials Science), 20 March, 2008 (20.03.08), Table 2 & EP 2062990 A1	1-12

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
01 September, 2009 (01.09.09)	15 September, 2009 (15.09.09)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (April 2007)

REFERENCES CITED IN THE DESCRIPTION

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- US P6966956 B **[0008]**
- EP 1262569 A **[0008]**
- US P6921586 B **[0008]**