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HIGH TEMPERATURE NICKEL BASE ALLOY

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This invention relates to a nickel-chromium-cobalt base metal alloy, particularly to one such alloy which includes alloying metal additives which make the resulting alloy corrosion resistant and of great mechanical work strength at temperatures above 1500° F.

Important features of the alloy of this invention are that it may be hot worked, is highly resistant to oxidation and other forms of corrosion and possesses great mechanical work strength at temperatures up to between about 1600° F. and 2000° F. As a result this alloy may be used as blades, vanes, and other parts of high temperature gas turbine engines. Other important uses of the alloy of this invention are as exhaust valves and manifolds in internal combustion engines, in heat exchangers, and as linings for retorts and container vessels used in the chemical and metallurgical industries.

The prior art, nickel and/or cobalt base metal alloys which have been used as blades, vanes, and other parts of high temperature gas turbine engines, have a maximum operating temperature of about 1500° F. For example, a common nickel-cobalt base metal alloy which incorporates molybdenum as a constituent is for all practical purposes non-utilizable as a structural member in a gas turbine engine if the metal temperature is above 1500° F. The oxidation resistance of such an alloy fails above 1500° F.

Since the alloy of this invention when used as a blade or vane in a high temperature gas turbine engine can be operated at markedly higher temperatures than was possible heretofore, the performance of the gas turbine engine is improved, in that the total thrust is increased and the amount of fuel consumed per pound of trust is decreased.

The metal alloy of this invention is comprised by weight of about: 15 to 25 percent chromium, 5 to 30 percent cobalt, 0.5 to 4 percent titanium, 2 to 5 percent aluminum, 1 to 5 percent of columbium or tantalum or mixtures thereof, 5 to 11 percent tungsten, and the balance, essentially nickel.

An alloy having the above composition is particularly resistant to oxidation and has high strength at elevated temperatures above 1500° F., so as to be suitable for use in forming cast liners for retorts and container vessels used in the chemical and metallurgical industries.

When the alloy of this invention is to be used as blades or vanes or other parts in a high temperature gas turbine engine, I have found that if the hardening elements in the alloy, i.e., the tungsten, aluminum, titanium, and columbium or tantalum or mixtures thereof, are so chosen that the sum of (*a*) the percentage by weight of tungsten, plus (*b*) one-and-a-half times the percentage by weight of columbium, or tantalum or mixtures thereof, plus (*c*) two times the percentage by weight of aluminum, plus (*d*) four times the percentage by weight of titanium is equal to a number within a range of about 20 to 30, then the alloy of this invention is capable of being hot worked and has a life to rupture strength (rupture life) in excess of 100 hours under a load of 25,000 pounds per square inch at 1700° F.

The numerical sum of (*a*), (*b*), (*c*) and (*d*) above shall hereafter be referred to as the "equivalent hardening factor." This factor is applicable only if the base constituents of the alloy (the nickel, chromium and cobalt) are present in the proportions set forth above. A preferred range of the equivalent hardening factor is between 23 and 28.

When the alloy of this invention meets the equivalent hardening factor limitation, the desired high temperature creep strength of the alloy is achieved. If the alloy exceeds the equivalent hardening factor limit of 30, hot working of the alloy becomes very difficult and for all practical purposes the alloy cannot be shaped into desired forms. Thus, use of the formula insures that an alloy having the desired high temperature strength can be satisfactorily hot worked.

To achieve the desired properties, the impurities in the alloy must be held to the following limits by weight. The carbon content in the final alloy should be no more than about 0.5 percent; the oxygen content, no more than about 0.3 percent as determined by an increase on ignition technique; the nitrogen content, no more than about 0.5 percent; the hydrogen content, no more than about 0.001 percent; the lead content, no more than about 0.001 percent; and the iron content, no more than about 5 percent. In addition, no more than about .5 percent of the combined elements calcium, magnesium, cerium, and other rare earth metals should be present.

In order to further improve workability of the alloy, particularly when in the form of a large cast ingot, a small quantity of zirconium and/or boron, or compounds thereof, such as zirconium boride may be added to the alloy of this invention. As a result, large ingots can be more readily formed into sheet and other forms than is possible without the addition of zirconium and/or boron. To achieve this effect, an amount of zirconium up to about 0.2 percent by weight and/or an amount of boron up to about 0.1 percent by weight is incorporated in the alloy of this invention.

Following are examples of the preparation and test results of the nickel-chromium-cobalt base metal alloy of this invention:

EXAMPLE 1

A 10 pound ingot of a nickel-chromium-cobalt base metal alloy composition containing 20 percent of chromium, 15 percent of cobalt, one percent of titanium, 2 percent of aluminum, 1.5 percent of tantalum, 10 percent of tungsten, and the balance, substantially all nickel, all by weight, was prepared by melting a nickel, chromium and cobalt mix in a magnesia crucible under a vacuum condition of about 10 microns and held in a molten state until outgassing was essentially completed. Carbon was then added to the molten mix to permit outgassing of the dissolved oxygen in the form of CO_2 and CO. Ten percent of tungsten, 1.5 percent of tantalum, 2 percent of aluminum and one percent of titanium were added to the molten metals in the order named, following which the resulting molten metal alloy was cast under a vacuum of about 10 microns into a 10 pound ingot mold and allowed to solidify under vacuum.

Test bars (¼ inch diameter and 3 inches long) were fabricated from this ingot by hot working procedure and then heat treated in the usual fashion by solution treating and aging which consisted of heating the test bars to a temperature of about 2150° F. and holding at this temperature for about one hour, air cooling the bars, and then heating the bars at a temperature of about 1600° F. for about 8 hours, followed by air cooling.

The test bars of this example had a rupture life of

about 108 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 2

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 20 percent of chromium, 15 percent of cobalt, 1.5 percent of titanium, 2.5 percent of aluminum, 1.5 percent of columbium, 10 percent of tungsten, and the balance, substantially all nickel, all by weight, were prepared and the bars heat treated in the same manner as set forth in Example 1.

The test bars of this example had a rupture life of about 223 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 3

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 20 percent of chromium, 15 percent of cobalt, 2 percent of titanium, 3 percent of aluminum, 1.5 percent of tantalum, 8 percent of tungsten, and the balance, substantially all nickel, all by weight, were prepared and the bars heat treated in the same manner as set forth in Example 1.

The test bars of this example had a rupture life of about 268 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 4

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 20 percent of chromium, 15 percent of cobalt, 1.5 percent of titanium, 2.5 percent of aluminum, 2.0 percent of tantalum, 8.0 percent of tungsten, and the balance, substantially all nickel, all by weight, were prepared and the bars heat treated in the same manner as set forth in Example 1.

The test bars of this example had a rupture life of about 167 hours under a load of 25,000 pounds per square inch at a temperature of 1700° in air.

EXAMPLE 5

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 20 percent of chromium, 15 percent of cobalt, 2 percent of titanium, 3 percent of aluminum, 1.5 percent of columbium, 8 percent of tungsten, and the balance, substantially all nickel, all by weight, were prepared and the bars heat treated in the same manner as set forth in Example 1.

The test bars of this example had a rupture life of about 273 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 6

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 20 percent of chromium, 15 percent of cobalt, 2 percent of titanium, 3.5 percent of aluminum, 1.0 percent of tantalum, 10 percent of tungsten, and the balance, substantially all nickel, all by weight, were prepared and the bars heat treated in the same manner as set forth in Example 1.

The test bars of this example had a rupture life of about 366 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 7

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 20 percent of chromium, 15 percent of cobalt, 2 percent of titanium, 3.5 percent of aluminum, 1 percent of tantalum, 10 percent of tungsten, 0.2 percent of zirconium, and the balance, substantially all nickel, all by weight, were prepared in the same manner as set forth in Example 1, except that the zirconium was added immediately following the addition of titanium to the molten metals.

The test bars of this example had a rupture life of about 362 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 8

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 20 percent of chromium, 15 percent of cobalt, 2 percent of titanium, 3.5 percent of aluminum, 1 percent of tantalum, 10 percent of tungsten, .1 percent of boron, and the balance, substantially all nickel, all by weight, were prepared in the same manner as set forth in Example 1, except that the boron was added immediately following the addition of titanium to the molten metals.

The test bars of this example had a rupture life of about 365 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 9

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 20 percent of chromium, 15 percent of cobalt, 2 percent of titanium, 3.5 percent of aluminum, 1 percent of tantalum, 10 percent of tungsten, .1 percent of zirconium, and the balance, substantially all nickel, all by weight, were prepared in the same manner as set forth in Example 1, except that the zirconium was added immediately following the addition of titanium to the molten metals.

The test bars of this example had a rupture life of about 365 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 10

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 20 percent of chromium, 15 percent of cobalt, 2 percent of titanium, 3.5 percent of aluminum, 1 percent of tantalum, 10 percent of tungsten, .05 percent of boron, and the balance, substantially all nickel, all by weight, were prepared in the same manner as set forth in Example 1, except that the boron was added immediately following the addition of titanium to the molten metals.

The test bars of this example had a rupture life of about 360 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 11

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 20 percent of chromium, 15 percent of cobalt, 2 percent of titanium, 3.5 percent of aluminum, 1 percent of columbium, 10 percent of tungsten, and the balance, substantially all nickel, all by weight, were prepared and the bars heat treated in the same manner as set forth in Example 1.

The test bars of this example had a rupture life of about 356 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 12

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 20 percent of chromium, 15 percent of cobalt, 2.5 percent of titanium, 3 percent of aluminum, 4 percent of tantalum, 5 percent of tungsten, and the balance substantially all nickel, all by weight, were prepared and the bars heat treated in the same manner as set forth in Example 1.

The test bars of this example had a rupture life of about 374 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 13

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 20 percent of chromium, 15 percent of cobalt, 3 percent of titanium, 2 percent of aluminum, 3 percent of columbium, 7 percent of tungsten, and the balance substantially all nickel, all by weight, were prepared and the bars heat treated in the same manner as set forth in Example 1.

The test bars of this example had a rupture life of about 408 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 14

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 20 percent of chromium, 15 percent of cobalt, 2 percent of titanium, 4.5 percent of aluminum, 4.5 percent of tantalum, 6 percent of tungsten, and the balance, substantially all nickel, all by weight, were prepared and the bars heat treated in the same manner as set forth in Example 1.

The test bars of this example had a rupture life of about 493 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 15

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 20 percent of chromium, 15 percent of cobalt, 3.75 percent of titanium, 3 percent of aluminum, 4 percent of columbium, 5 percent of tungsten, and the balance, substantially all nickel, all by weight, were prepared and the bars heat treated in the same manner as set forth in Example 1.

The test bars of this example had a rupture life of about 507 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 16

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 20 percent of chromium, 15 percent of cobalt, .5 percent of titanium, 2 percent of aluminum, 1 percent of tantalum, 9 percent of tungsten, and the balance, substantially all nickel, all by weight, were prepared and the bars heat treated in the same manner as set forth in Example 1.

The test bars of this example had a rupture life of about 24.5 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 17

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 20 percent of chromium, 15 percent of cobalt, 1 percent of titanium, 2 percent of aluminum, 1 percent of columbium, 7 percent of tungsten, and the balance, substantially all nickel, all by weight, were prepared and the bars heat treated in the same manner as set forth in Example 1.

The test bars of this example had a rupture life of about 14 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 18

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 20 percent of chromium, 15 percent of cobalt, 1 percent of titanium, 2 percent of aluminum, 1.5 percent of tantalum, 5 percent of tungsten, and the balance, substantially all nickel, all by weight, were prepared and the bars heat treated in the same manner as set forth in Example 1.

The test bars of this example had a rupture life of about 14.5 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 19

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 20 percent of chromium, 15 percent of cobalt, 1 percent of titanium, 2 percent of aluminum, 2 percent of columbium, 9 percent of tungsten, and the balance, substantially all nickel, all by weight, were prepared and the bars heat treated in the same manner as set forth in Example 1.

The test bars of this example had a rupture life of about 42 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 20

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 15 percent of chromium, 30 percent of cobalt, 2 percent of titanium, 3 percent of aluminum, 1.5 percent of tantalum, 8 percent of tungsten, and the balance, substantially all nickel, all by weight, were prepared and the bars heat treated in the same manner as set forth in Example 1.

The test bars of this example had a rupture life of about 271 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 21

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 25 percent of chromium, 5 percent of cobalt, 2 percent of titanium, 3 percent of aluminum, 1.5 percent of tantalum, 8 percent of tungsten, and the balance, substantially all nickel, all by weight, were prepared and the bars heat treated in the same manner as set forth in Example 1.

The test bars of this example had a rupture life of about 267 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 22

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 17 percent of chromium, 10 percent of cobalt, 4 percent of titanium, 2 percent of aluminum, 2 percent of tantalum, 6 percent of tungsten, and the balance, substantially all nickel, all by weight, were prepared and the bars treated in the same manner as set forth in Example 1.

The test bars of this example had a rupture life of about 466 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 23

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 20 percent of chromium, 15 percent of cobalt, 1 percent of titanium, 5 percent of aluminum, 5 percent of columbium, 8 percent of tungsten and the balance, substantially all nickel, all by weight, were prepared and the bars heat treated in the same manner as set forth in Example 1.

The test bars of this example had a rupture life of about 425 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

EXAMPLE 24

A 10 pound ingot and test bars of the same dimensions as set forth in Example 1 of a nickel-chromium-cobalt base metal alloy composition containing 20 percent of chromium, 15 percent of cobalt, 1 percent of titanium,

2 percent of aluminum, 2 percent of columbium, 11 percent of tungsten, and the balance substantially all nickel, all by weight, were prepared and the bars heat treated in the same manner as set forth in Example 1.

The test bars of this example had a rupture life of about 172 hours under a load of 25,000 pounds per square inch at a temperature of 1700° F. in air.

Table

Example No.	Cr (1)	Co (2)	Ti (3)	Al (4)	Ta (5)	Cb (6)	W (7)	Zr (8)	B (9)	Ni (10)	E.H.F. (11)	R.L. (12)
1	20	15	1	2	1.5	------	10	------	------	Bal.	20.25	108
2	20	15	1.5	2.5	------	1.5	10	------	------	Bal.	23.25	223
3	20	15	2	3	1.5	------	8	------	------	Bal.	24.25	268
4	20	15	1.5	2.5	2	------	8	------	------	Bal.	22	167
5	20	15	2	3	------	1.5	8	------	------	Bal.	24.25	273
6	20	15	2	3.5	1	------	10	------	------	Bal.	26.5	366
7	20	15	2	3.5	1	------	10	0.2	------	Bal.	26.5	362
8	20	15	2	3.5	1	------	10	------	0.1	Bal.	26.5	365
9	20	15	2	3.5	1	------	10	0.1	------	Bal.	26.5	365
10	20	15	2	3.5	1	------	10	------	0.05	Bal.	26.5	360
11	20	15	2	3.5	------	1	10	------	------	Bal.	26.5	356
12	20	15	2.5	3	4	------	5	------	------	Bal.	27	374
13	20	15	3	2	------	3	7	------	------	Bal.	27.5	408
14	20	15	2	4.5	4.5	------	6	------	------	Bal.	29.75	493
15	20	15	3.75	3	------	4	3	------	------	Bal.	30	507
16	20	15	.5	2	1	------	9	------	------	Bal.	16.5	24.5
17	20	15	1	2	------	1	7	------	------	Bal.	14.5	14
18	20	15	1	2	1.5	------	5	------	------	Bal.	15.25	14.5
19	20	15	1	2	------	2	9	------	------	Bal.	18	42
20	15	30	2	3	1.5	------	8	------	------	Bal.	24.25	271
21	25	5	2	3	1.5	------	8	------	------	Bal.	24.25	267
22	17	10	4	2	2	------	6	------	------	Bal.	29	466
23	20	15	1	5	------	5	8	------	------	Bal.	28	425
24	20	15	1	2	------	2	11	------	------	Bal.	22	172

[1] Amount of chromium (Cr) in terms of weight percent
[2] Amount of cobalt (Co) in terms of weight percent
[3] Amount of titanium (Ti) in terms of weight percent
[4] Amount of aluminum (Al) in terms of weight percent
[5] Amount of tantalum (Ta) in terms of weight percent
[6] Amount of columbium (Cb) in terms of weight percent
[7] Amount of tungsten (W) in terms of weight percent
[8] Amount of zirconium (Zr) in terms of weight percent
[9] Amount of boron (B) in terms of weight percent
[10] Amount of nickel (Ni) in terms of weight percent
[11] Equivalent Hardening Factor (E.H.F.)
[12] Rupture Life in hours (R.L.)

It is readily apparent from the above examples and the table that when the equivalent hardening factor of the alloy is below 20, as in Example 16, 17, 18 and 19, the period of time which elapses before rupture is much smaller than is the case when the equivalent hardening factor of the alloy is between about 20 and 30, as in Examples 1 to 15, and 20 to 24.

When the alloys of this invention had an equivalent hardening factor greater than about 30, ingots of such alloys could not be readily hot worked. For example, an ingot comprising by weight about: 20 percent of chromium, 15 percent of cobalt, 3 percent of titanium, 5 percent of aluminum, 3.5 percent of columbium, 8 percent of tungsten, and the balance essentially nickel, having an equivalent hardening factor of 35, broke up and cracked when hot working was attempted. Similar results occurred when an ingot comprising by weight about: 20 percent of chromium, 15 percent of cobalt, 3 percent of titanium, 4 percent of aluminum, 2.5 percent of tantalum, 8 percent of tungsten, and the balance, essentially nickel, having an equivalent hardening factor of 31.75.

I claim:

1. A high temperature, high strength nickel-chromium-cobalt base metal alloy composed by weight of about 15 percent to 25 percent chromium; about 5 percent to 30 percent cobalt; 0.5 percent to 4 percent titanium; 2 percent to 5 percent aluminum; 1 percent to 5 percent of a metal of the class consisting of tantalum, columbium and mixtures thereof; 5 percent to 11 percent tungsten, and the balance, essentially nickel, except for impurities and minor alloying constituents which do not substantially affect the properties of the basic alloy, said alloy being characterized in that the sum of (*a*) the percentage of tungsten, plus (*b*) one and one-half times the percentage of the member of said class, plus (*c*) two times the percentage of aluminum, plus (*d*) four times the percentage of titanium equals a number within the range of about 20 to about 30.

2. A high temperature, high strength nickel-chromium-cobalt base metal alloy composed by weight of about 15 percent to 25 percent chromium; 5 percent to 30 percent cobalt; 0.5 percent to 4 percent titanium; 2 percent to 5 percent aluminum; 1 percent to 5 percent of a metal of the class consisting of tantalum, columbium and mixtures thereof; 5 percent to 11 percent tungsten, and the balance, essentially nickel, except for impurities and minor alloying constituents which do not substantially affect the properties of the basic alloy, said alloy being characterized in that the sum of (*a*) the percentage of tungsten, plus (*b*) one and one-half times the percentage of the member of said class, plus (*c*) two times the percentage of aluminum, plus (*d*) four times the percentage of titanium equals a number within the range of about 23 to about 28.

3. A high temperature, high strength nickel-chromium-cobalt base metal alloy composed by weight of about 15 percent to 25 percent chromium; 5 percent to 30 percent cobalt; .5 percent to 4 percent titanium; 2 percent to 5 percent aluminum; 1 percent to 5 percent of a metal of the class consisting of tantalum, columbium and mixtures thereof; 5 percent to 11 percent tungsten; the impurities oxygen, nitrogen, hydrogen, lead, iron and carbon not exceeding by weight about .001 percent lead; about .3 percent oxygen; about .05 percent nitrogen, about .001 percent hydrogen, about 5 percent iron, and about 0.5 percent carbon; and the balance, essentially nickel, except for impurities and minor alloying constituents which do not substantially affect the properties of the basic alloy, said alloy being characterized in that the sum of (*a*) the percentage of tungsten plus (*b*) one and one-half times the percentage of the member of said class plus (*c*) two times the percentage of aluminum plus (*d*) four times the percentage of titanium equals a number within the range of about 20 to about 30.

4. A high temperature, high strength, nickel-chromium-cobalt base metal alloy composed by weight of about 20 percent chromium; 15 percent cobalt; .5 percent to 4 percent titanium; 2 percent to 5 percent aluminum; 1 percent to 5 percent of a metal of the class consisting

of tantalum, columbium, and mixtures thereof; 5 percent to 11 percent tungsten, and the balance essentially nickel, except for impurities and minor alloying constituents which do not substantially affect the properties of the basic alloy, said alloy being characterized in that the sum of (*a*) the percentage of tungsten plus (*b*) one and one-half times the percentage of the member of said class plus (*c*) two times the percentage of aluminum plus (*d*) four times the percentage of titanium equals a number within the range of about 20 to about 30.

5. A high temperature, high strength nickel-chromium-cobalt base metal alloy composed by weight of about 15 percent to 25 percent chromium; 5 percent to 30 percent cobalt; 0.5 percent to 4 percent titanium; 2 percent to 5 percent aluminum; 1 percent to 5 percent of a metal of the class consisting of tantalum, columbium and mixtures thereof; 5 percent to 11 percent tungsten; a metal of the class consisting of zirconium and boron, the amount of zirconium not exceeding about 0.2 percent and the amount of boron not exceeding about 0.1 percent; and the balance essentially nickel, except for impurities and minor alloying constituents which do not substantially affect the properties of the basic alloy, said alloys being characterized in that the sum of (*a*) the percentage of tungsten, plus (*b*) one and one-half times the percentage of a metal of the class consisting of tantalum, columbium and mixtures thereof, plus (*c*) two times the percentage of aluminum plus (*d*) four times the percentage of titanium, equals a number within the range of about 20 to about 30.

6. A high temperature, high strength nickel-chromium-cobalt base metal alloy composed by weight of about

15 percent to 25 percent chromium; 5 percent to 30 percent cobalt; 0.5 percent to 4 percent titanium; 2 percent to 5 percent aluminum; 1 percent to 5 percent of a metal of the class consisting of tantalum, columbium and mixtures thereof; 5 percent to 11 percent tungsten; a metal of the class consisting of zirconium and boron, the amount of zirconium not exceeding about 0.2 percent and the amount of boron not exceeding about 0.1 percent; and the balance, essentially nickel, except for impurities and minor alloying constituents which do not substantially affect the properties of the basic alloy, said alloys being characterized in that the sum of (*a*) the percentage of tungsten, plus (*b*) one and one-half times the percentage of a metal of the class consisting of tantalum, columbium and mixtures thereof, plus (*c*) two times the percentage of aluminum, plus (*d*) four times the percentage of titanium, equals a number within the range of about 23 to about 28.

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