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NICKEL-BASE ALLOYS

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This invention relates to nonferrous alloys. More particularly, it relates to nickel-base casting alloys having improved strength. Still more particularly, it relates to nickel-base alloys which include alloying metal additives capable of imparting to the resultant alloys corrosion resistance and great mechanical work strength at temperatures up to about 2000° F.

This application is a continuation-in-part of my application Serial No. 791,276, filed February 5, 1959, now abandoned, and entitled "Metal Alloy."

In accordance with the present invention, alloys are prepared which can be cast into forms useful for high stress applications and under oxidizing conditions, comprising a chromium-containing nickel-base alloy having tungsten, columbium, titanium, and aluminum present in proportions and in a relationship one to the other necessary to attain the properties at high temperatures of rupture strength, resistance to oxidation, high impact and high fatigue strength, resistance to grain boundary deformation and intergranular cracking.

One form of prior art commercially available nickel-base casting alloy is indicated to have a life of 100 hours at temperatures of about 1800° F. and at loads of about 15,000 p.s.i. This alloy falls off rapidly in rupture life if either the stress is increased while maintaining a temperature of 1800° F. or if the temperature is increased appreciable above this 1800° F. level. Data presented by the inventors of this alloy shows that one containing 4.05% of titanium and critical amounts of cobalt, chromium, boron, and zirconium at 1800° F. and 25,000 p.s.i. has a rupture life of only 17.2 hours. Blades for gas turbine engines cast from alloys of this type containing amounts of titanium in the range of about 3.5% to 5%, appear to be sensitive to cracking and have up to the present time not been accepted for use under the highly stressed, high temperature (about 1800° F.) conditions under which they are designed to operate. This operating temperature is currently being specified by designers because performance of gas turbine engines operating at such higher temperature is improved, in that with this higher temperature the total thrust of the engine is increased.

Basically, the metal alloy of this invention is comprised by weight of: from about 6% to about 17% of chromium; from about 5% to about 20% of tungsten; from about 0.25% to about 3% of columbium or tantalum or mixtures thereof; from about 2% to about 8% of aluminum; from about 0.1% to about 3% of titanium with the provision that the amount of titanium does not exceed the amount of aluminum; from about 2% to about 15% of cobalt; at least one of the metals in the amounts indicated selected from the group consisting of from about 0.001% to about 0.5% of zirconium and from about 0.001% to about 0.2% of boron; from about 0.02% to about 0.35% of carbon; and the remainder being nickel and incidental impurities, the nickel content being in the range of about 45% to about 77%.

The alloys of this invention consist essentially of a nickel-base solid solution matrix containing tungsten to attain thermal stability and a relatively high melting point. A nickel-tungsten system containing up to 20% tungsten tolerates substantial alloying with other metals without becoming embrittled.

Aluminum and chromium are added to this basic composition for the purposes of improving oxidation resistance. Aluminum serves a dual purpose. In addition to imparting oxidation resistance, it functions to form an intermetallic compound with nickel, which is an excellent hardener and strengthener of the alloy. Chromium serves primarily to impart oxidation resistance. Too large quantities of chromium detracts from the strength of the alloy. Chromium in quantities of about 17% is optimum for oxidation resistance, but above 15%, the deleterious effect of chromium on strength tends to become apparent and above 17% the reduction in strength becomes objectionable. Preferably, chromium is used in quantities in the range between about 8% and about 12%.

Titanium is an important element in determining the strength of the alloys of this invention, both at room temperature and at elevated temperatures. Small amounts of titanium are useful in the alloy because of a strengthening effect on the matrix. Quantities above about 3% are deleterious because alloys of the higher titanium content show a tendency to cracking. Preferably, titanium is used in quantities in the range between about 0.75% and about 2.5%. Inasmuch as the alloys contain titanium and aluminum, a balance must be maintained whereby formation of an intermetallic compound Ni_3 (AlTi) is favored. In order to accomplish this result, it is preferable that the aluminum to titanium weight ratio be in the range between about 2:1 and about 6:1.

In the alloys of this invention, columbium and tantalum can be used interchangeably. Columbium and tantalum serve to stabilize the carbon which is present in the matrix, and to be effective should be present in amounts between about 7 and about 10 times the weight percent of carbon, when operating under conditions of casting designed to give rapid solidification and uniform grain size.

Carbon is required in this alloy in quantities to produce stable carbide hardeners. The strength and the ductility of the alloy is highest when the carbon content is above about 0.1% and in proportions to combine with the columbium or tantalum due to its preferential affinity therefor, thereby leaving the titanium to form predominantly an intermetallic hardening compound with nickel.

The high temperature metallurgical stability and strength characteristics of the alloys of this invention are improved by the addition to the alloys of boron and/or zirconium in the respective specified amounts. In many instances it is preferred to maintain the weight ratio of zirconium to boron in the alloy at about 4:1, although other weight ratios have also been found stable. It has been found that if the boron content of the alloy exceeds 0.2%, then the alloy may be unsatisfactory, particularly in those applications where thermal shock requirements are important.

Molybdenum is an optional element in this alloy and may only be present without deleteriously affecting the properties of the alloy if the amount thereof does not exceed 3% by weight of the alloy.

While silicon, manganese, and iron are not essential ingredients of the alloys of the present invention, it has been found that the addition of small percentages of any one or more of these ingredients, that is, up to about 1% of silicon, up to about 2% of manganese, and up to about 5% of iron, may in certain instances somewhat improve certain properties of the alloy.

The interstitial and impurity elements, such as nitrogen, hydrogen, tin, lead, and the like, should be kept as low in concentration in the alloys as possible. In addition, no more than about 0.5% total of the deoxodizers, such as calcium, magnesium, and the like, should be present.

A preferred range of proportions of constituents of

the alloy of this invention in percentages by weight is as follows: from about 8.75% to about 10.25% of chromium; from about 11% to about 16% of tungsten; from about 0.8% to about 1.8% of columbium or tantalum or mixtures thereof; from about 4.75% to about 5.5% of aluminum; from about 0.75% to about 2.5% of titanium with the provision that the titanium does not exceed the amount of aluminum; from about 8% to about 12% of cobalt; at least one metal in the amounts indicated selected from the elements consisting of from about 0.03% to about 0.12% of zirconium and from about 0.01% to about 0.03% of boron; from about 0.12% to about 0.17% of carbon; about 1.5% maximum of iron; about 0.10% maximum of silicon; about 0.10% maximum of manganese and the remainder being nickel and incidental impurities, the nickel content being in the range of about 50% to about 77%.

In preparing the alloys of this invention, it has been found that a balance is required between the amounts of chromium, tungsten, columbium or tantalum, titanium and aluminum present in the alloy if the desired high temperature characteristics are to be developed. Particularly when varying the amounts of the specified components within the specified ranges, the improved oxidation and strength properties characterizing the alloys will be maintained if the alloy formulations are prepared in accordance with the foregoing, and, furthermore, in accordance with the following equation:

$$1X\%\ Cr+1.1X\%\ W+3.4X\%\ Cb\ or\ Ta+4.3X\%\ Ti+6X\%\ Al=60-70$$

with the percentages by weight of the respective constituents of the alloy substituted into the equation.

Following are examples of the preparation and test results of various formulations of the nickel-base metal alloy of this invention, in the approximate weight percentages indicated.

Example I

A 5 pound alloy melt of a nickel-base metal alloy composition containing 6 percent of chromium, 15 percent of tungsten, 1 percent of columbium, 4 percent of aluminum, 3 percent of titanium, 0.05 percent of boron, 0.15 percent of carbon, 10 percent of cobalt, and the balance essentially nickel, all by weight, was prepared by melting a chromium-nickel mix in a magnesia crucible under high vacuum conditions, following which the tungsten, columbium, aluminum, titanium, boron, cobalt and carbon were added, the latter in the form of graphite. The composition had an equivalency value of 62.8.

A cluster of 6 test bars was formed from the 5 pound melted alloy heated by the usual investment casting technique under high vacuum conditions. These bars were each 3 inches long and ¼ inch in diameter.

At room temperature the test bars had at rupture an elongation of about 3.5 percent and a tensile strength of 150,000 p.s.i.

The test bars had an elongation of 2 percent with a rupture life in excess of 400 hours under a load of 17,000 p.s.i. at a temperature of 1800° F. in air, and an elongation of 6 percent with a rupture life in excess of 300 hours under a load of 20,000 p.s.i. at a temperature of 1800° F. in air. The test bars had an elongation of about 3 percent with a rupture life in excess of 150 hours under a load of 12,500 p.s.i. at a temperature of 1900° F. in air, and an elongation of 5 percent with a rupture life in excess of 100 hours under a load of 15,000 p.s.i. at a temperature of 1900° F. in air.

Example II

A 5 pound alloy melt and test bars of the same dimensions as set forth in Example I of a nickel-base metal alloy composition containing 7 percent of chromium, 12.5 percent of tungsten, 1 percent of columbium, 6 percent of aluminum, 1 percent of titanium, 0.05 percent of boron, 0.15 percent of carbon, 10 percent of cobalt, and the balance essentially nickel, all by weight, were prepared in the same manner as set forth in Example I. The composition had an equivalency value of 64.5.

At room temperature the test bars had at rupture an elongation of 3.3 percent and a tensile strength of 127,000 p.s.i.

The test bars had an elongation of 4.1 percent with a rupture life in excess of 460 hours under a load of 17,000 p.s.i. at a temperature of 1800° F. in air, and an elongation of 2.5 percent with a rupture life in excess of 165 hours under a load of 12,500 p.s.i. at a temperature of about 1900° F. in air.

Example III

A 5 pound alloy melt and test bars of the same dimensions as set forth in Example I of a nickel-base metal alloy composition containing 9 percent of chromium, 12.5 percent of tungsten, 1 percent of columbium, 5.0 percent of aluminum, 2 percent of titanium, 0.05 percent of zirconium, 0.015 percent of boron, 0.15 percent of carbon, 10 percent of cobalt, and the balance essentially nickel, all by weight, were prepared in the same manner as set forth in Example I. The composition had an equivalency value of 64.75.

At room temperature the test bars had at rupture an elongation of 4.0 percent and a tensile strength of 139,000 p.s.i.

The test bars had an elongation of 7.5 percent with a rupture life of 86.8 hours under a load of 29,000 p.s.i. at a temperature of 1800° F. in air.

Example IV

A 5 pound alloy melt and test bars of the same dimensions as set forth in Example I of a nickel-base metal alloy composition containing 7 percent of chromium, 12 percent of tungsten, 1 percent of columbium, 4 percent of aluminum, 3 percent of titanium, 3 percent of molybdenum, 0.05 percent of boron, 0.15 percent of carbon, 10 percent of cobalt, and the balance essentially nickel, all by weight, were prepared in the same manner as set forth in Example I. The composition had an equivalency value of 60.5.

At room temperature the test bars had at rupture an elongation of 2.7 percent and a tensile strength of 150,000 p.s.i.

The test bars had an elongation of 1.9 percent with a rupture life in excess of 350 hours under a load of 17,000 p.s.i. at a temperature of 1800° F. in air.

Example V

A 5 pound alloy melt and test bars of the same dimensions as set forth in Example I of a nickel-base metal alloy composition containing 7 percent of chromium, 20 percent of tungsten, 1 percent of columbium, 4 percent of aluminum, 3 percent of titanium, 0.05 percent of boron, 0.15 percent of carbon, 10 percent of cobalt, and the balance essentially nickel, all by weight, were prepared in the same manner as set forth in Example I. The composition had an equivalency value of 69.3.

At room temperature the test bars had at rupture an elongation of 2.0 percent and a tensile strength of 150,000 p.s.i.

The test bars had an elongation of 1.3 percent with a rupture life in excess of 350 hours under a load of 17,000 p.s.i. at a temperature of 1800° F. in air.

Example VI

A 5 pound alloy melt and test bars of the same dimensions as set forth in Example I of a nickel-base metal alloy composition containing 9 percent of chromium, 12.5 percent of tungsten, 1 percent of columbium, 5.25 percent of aluminum, 2 percent of titanium, 0.12 percent of zirconium, 0.03 percent of boron, 0.15 percent of carbon, 10 percent of cobalt, and the balance essentially nickel, all by weight, were prepared in the same

manner as set forth in Example I. The composition had an equivalency value of 66.25.

At room temperature the test bars had at rupture an elongation of 4.1 percent and a tensile strength of 149,000 p.s.i.

The test bars had an elongation of 7.5 percent with a rupture life of 398 hours under a load of 20,000 p.s.i. and an elongation of 3.3 percent with a rupture life of 160 hours under a load of 25,000 p.s.i., all at a temperature of 1800° F. The test bars had an elongation of 4.1 percent with a rupture life in excess of 192 hours under a load of 15,000 p.s.i. and an elongation of 2.5 percent with a rupture life in excess of 99 hours under a load of 17,500 p.s.i., all at a temperature of 1900° F.

Example VII

A 5 pound alloy melt and test bars of the same dimensions as set forth in Example I of a nickel-base metal alloy composition containing 9 percent of chromium, 12.5 percent of tungsten, 1 percent of columbium, 6 percent of aluminum, 1 percent of titanium, 0.05 percent of zirconium, 0.05 percent of boron, 0.15 percent of carbon, 10 percent of cobalt, and the balance essentially nickel, all by weight, were prepared in the same manner as set forth in Example I. The composition had an equivalency value of 66.7.

At room temperature the test bars had at rupture an elongation of 3.3 percent and a tensile strength of 157,000 p.s.i.

The test bars had an elongation of 1.6 percent with a rupture life in excess of 195 hours under a load of 20,000 p.s.i., and an elongation of 1.6 percent with a rupture life in excess of 140 hours under a load of 25,000 p.s.i., all at a temperature of 1800° F. The test bars had an elongation of 5 percent with a rupture life in excess of 350 hours under a load of 15,000 p.s.i. and an elongation of 2.5 percent with a rupture life in excess of 119 hours under a load of 17,500 p.s.i., all at a temperature of 1900° F.

Example VIII

A 5 pound alloy melt and test bars of the same dimensions as set forth in Example I of a nickel-base metal alloy composition containing 16 percent of chromium, 8 percent of tungsten, 1 percent of columbium, 4 percent of aluminum, 3 percent of titanium, 0.05 percent of zirconium, 0.05 percent of boron, 0.15 percent of carbon, 10 percent of cobalt, and the balance essentially nickel, all by weight, were prepared in the same manner as set forth in Example I. The composition had an equivalency value of 65.1.

At room temperature the test bars had at rupture an elongation of 0.8 percent and a tensile strength of 147,100 p.s.i.

The test bars had an elongation of 6.6 percent with a rupture life in excess of 180 hours under a load of 17,000 p.s.i. at a temperature of 1800° F. in air, and an elongation of 11.6 percent with a rupture life in excess of 40 hours under a load of 12,500 p.s.i. at a temperature of 1900° F. in air.

Example IX

A 5 pound alloy melt and test bars of the same dimensions as set forth in Example I of a nickel-base metal alloy composition containing 16 percent of chromium, 18 percent of tungsten, 1 percent of columbium, 2.0 percent of aluminum, 2.0 percent of titanium, 0.05 percent of zirconium, 0.05 percent of boron, 0.15 percent of carbon, 10 percent of cobalt, and the balance essentially nickel, all by weight, were prepared in the same manner as set forth in Example I. The composition had an equivalency value of 59.8.

At room temperature the test bars had at rupture an elongation of 2.1 percent and a tensile strength of 150,000 p.s.i.

The test bars had an elongation of 7.6 percent with a rupture life in excess of 240 hours under a load of 17,000 p.s.i. at a temperature of 1800° F. in air.

Example X

A 5 pound alloy melt and test bars of the same dimensions as set forth in Example I of a nickel-base metal alloy composition containing 15 percent of chromium, 10 percent of tungsten, 1 percent of columbium, 4 percent of aluminum, 3 percent of titanium, 0.05 percent of zirconium, 0.05 percent of boron, 0.15 percent of carbon, 10 percent of cobalt, and the balance essentially nickel, all by weight, were prepared in the same manner as set forth in Example I. The composition had an equivalency value of 66.4.

At room temperature the test bars had at rupture an elongation of 0.8 percent and a tensile strength of 157,800 p.s.i.

The test bars had an elongation of 5 percent with a rupture life in excess of 180 hours under a load of 20,000 p.s.i., and an elongation of 3.3 percent with a rupture life in excess of 63 hours under a load of 25,000 p.s.i., all at a temperature of 1800° F. The test bars had an elongation of 6.6 percent with a rupture life in excess of 36 hours under a load of 17,500 p.s.i. at a temperature of 1900° F.

Example XI

A 5 pound alloy melt and test bars of the same dimensions as set forth in Example I of a nickel-base metal alloy composition containing 9 percent of chromium, 15 percent of tungsten, 1.25 percent of columbium, 5.25 percent of aluminum, 1 percent of titanium, 0.08 percent of zirconium, 0.02 percent of boron, 0.15 percent of carbon, 10 percent of cobalt, and the balance essentially nickel, all by weight, were prepared in the same manner as set forth in Example I. The composition had an equivalency value of 65.55.

At room temperature the test bars had at rupture an elongation of 2.5 percent and a tensile strength of 140,000 p.s.i.

The test bars had an elongation of 8.0 percent with a rupture life in excess of 34.1 hours under a load of 27,500 p.s.i. at a temperature of 1800° F. in air.

Example XII

A 5 pound alloy melt and test bars of the same dimensions as set forth in Example I of a nickel-base metal alloy composition containing 9 percent of chromium, 15 percent of tungsten, 2 percent of tantalum, 5.25 percent of aluminum, 1 percent of titanium, 0.08 percent of zirconium, 0.02 percent of boron, 0.15 percent of carbon, 10 percent of cobalt, and the balance essentially nickel, all by weight, were prepared in the same manner as set forth in Example I. The composition had an equivalency value of 68.1.

At room temperature the test bars had at rupture an elongation of 2.5 percent and a tensile strength of 155,000 p.s.i.

The test bars had an elongation of 8.0 percent with a rupture life of 46 hours under a load of 27,500 p.s.i. at a temperature of 1800° F. in air. The test bars had an elongation of 10 percent with a rupture life in excess of 17.8 hours under a load of 20,000 p.s.i. at a temperature of 1900° F. in air.

Example XIII

A 5 pound alloy melt and test bars of the same dimensions as set forth in Example I of a nickel-base metal alloy composition containing 9 percent of chromium, 12.5 percent of tungsten, 1 percent of columbium, 5.25 percent of aluminum, 0 percent of titanium, 0.02 percent of boron, 0.08 percent of zirconium, 0.15 percent of carbon, 10 percent of cobalt, and the balance essentially nickel, all by weight, were prepared in the same manner as set forth in Example I. The composition had an equivalency value of 57.65.

At room temperature the test bars had at rupture an elongation of 1.5 percent and a tensile strength of 121,200 p.s.i.

The test bars had an elongation of 4.6 percent with a rupture life of 75.7 hours under a load of 20,000 p.s.i. at a temperature of 1800° F. in air, and an elongation of 5.3 percent with a rupture life of 12.3 hours under a load of 17,500 p.s.i. at a temperature of 1900° F. The test bars had an elongation of 13 percent with a rupture life of 0.9 hour under a load of 15,000 p.s.i. at a temperature of 2000° F.

Example XIV

A 5 pound alloy melt of nickel-base metal alloy composition containing 9 percent chromium, 12.5 percent tungsten, 1 percent columbium, 5.25 percent aluminum, 0.5 percent titanium, 0.08 percent zirconium, 0.02 percent boron, 0.15 percent carbon, 10 percent cobalt, and the balance essentially nickel, all by weight, was prepared by melting a chromium-nickel mix in a magnesia crucible under high vacuum conditions, following which the tungsten, columbium, aluminum, titanium, boron, cobalt and carbon were added, the latter in the form of graphite. The composition had an equivalency value of 59.9.

A cluster of 6 test bars were formed from the 5 pound melted alloy heated by the usual investment casting technique under high vacuum conditions. These bars were each 3 inches long and ¼ inch in diameter.

At room temperature the test bars had at rupture an elongation of 3.0 percent and a tensile strength of 151,000 p.s.i.

The test bars had an elongation of 4.6 percent with a rupture life of 397.9 hours under a load of 20,000 p.s.i. at a temperature of 1800° F. in air, and an elongation of 9.2 percent with a rupture life of 54 hours under a load of 17,500 p.s.i. at a temperature of 1900° F. in air. The test bars had an elongation of about 10 percent with a rupture life in excess of 4.2 hours under a load of 15,000 p.s.i. at a temperature of 2000° F. in air.

Example XV

A 5 pound alloy melt and test bars of the same dimensions as set forth in Example I of a nickel-base metal alloy composition containing 9 percent of chromium, 12.5 percent of tungsten, 1 percent of columbium, 5.25 percent of aluminum, 2 percent of titanium, 0.08 percent zirconium, 0.02 percent of boron, 0.15 percent of carbon, 10 percent of cobalt, and the balance essentially nickel, all by weight, were prepared in the same manner as set forth in Example I. The composition had an equivalency value of 66.25.

At room temperature the test bars had at rupture an elongation of 2.3 percent and a tensile strength of 139,500 p.s.i.

The test bars had an elongation of 4.6 percent with a rupture life of 1,045 hours under a load of 20,000 p.s.i. at a temperature of 1800° F. in air, and an elongation of 4.5% with a rupture life of 58.8 hours under a load of 29,000 p.s.i. at a temperature of 1800° F., and an elongation of 3 percent with a rupture life of 147 hours under a load of 17,500 p.s.i. at a temperature of 1900° F. in air. The test bars had an elongation of 3 percent with a rupture life of 19.3 hours under a load of 15,000 p.s.i. at a temperature of 2000° F.

Example XVI

A 5 pound alloy melt and test bars of the same dimensions as set forth in Example I of a nickel-base metal alloy composition containing 9 percent of chromium, 12.5 percent of tungsten, 1 percent of columbium, 5.25 percent of aluminum, 2.5 percent of titanium, 0.08 percent zirconium, 0.02 percent of boron, 0.15 percent of carbon, 10 percent of cobalt, and the balance essentially nickel, all by weight, were prepared in the same manner as set forth in Example I. The composition had an equivalency value of 68.4.

At room temperature the test bars had at rupture an elongation of 2.3 percent and a tensile strength of 140,500 p.s.i.

The test bars had an elongation of 3 percent with a rupture life of 656.8 hours under a load of 20,000 p.s.i. at a temperature of 1800° F. in air, and an elongation of 2.3 percent with a rupture life of 173.2 hours under a load of 17,500 p.s.i. at a temperature of 1900° F. in air. The test bars had an elongation of 2.3 percent with a rupture life in excess of 20.3 hours under a load of 15,000 p.s.i. at a temperature of 2000° F.

Example XVII

A 5 pound alloy melt of nickel-base metal alloy composition containing 9 percent chromium, 12.5 percent tungsten, 1 percent columbium, 5.25 percent aluminum, 3.5 percent titanium, 0.08 percent zirconium, 0.02 percent boron, 0.15 percent carbon, 10 percent cobalt, and the balance essentially nickel, all by weight, was prepared by melting a chromium-nickel mix in a magnesia crucible under high vacuum conditions, following which the tungsten, columbium, aluminum, titanium, and zirconium, boron, cobalt and carbon were added, the latter in the form of graphite. The composition had an equivalency value of 72.7.

A cluster of 6 test bars were formed from the 5 pound melted alloy heated by the usual investment casting technique under high vacuum conditions. These bars were each 3 inches long and ¼ inch in diameter.

At room temperature the test bars had at rupture an elongation of 3.8 percent and a tensile strength of 141,600 p.s.i.

The test bars had an elongation of 6.2 percent with a rupture life of 142.8 hours under a load of 20,000 p.s.i. at a temperature of 1800° F. in air, and an elongation of 3 percent with a rupture life of 88.9 hours under a load of 17,500 p.s.i. at a temperature of 1900° F. in air. The test bars had an elongation of about .76 percent with a rupture life of 15.7 hours under a load of 15,000 p.s.i. at a temperature of 2000° F. in air.

Example XVIII

A 5 pound alloy melt of nickel-base metal alloy composition containing 10 percent chromium, 15 percent tungsten, 1.5 percent tantalum, 5.0 percent aluminum, 1.0 percent titanium, 0.015 percent boron, 0.05 percent zirconium, 0.15 percent carbon, 10 percent cobalt, and the balance essentially nickel, all by weight, was prepared by melting a chromium-nickel mix in a magnesia crucible under high vacuum conditions, following which the tungsten, tantalum, aluminum, titanium, boron, zirconium, cobalt and carbon were added, the latter in the form of graphite. The composition had an equivalency value of 65.9.

A cluster of 6 test bars were formed from the 5 pound melted alloy heated by the usual investment casting technique under high vacuum conditions. These bars were each 3 inches long and ¼ inch in diameter.

At room temperature the test bars had at rupture an elongation of 3.0 percent and a tensile strength of 135,000 p.s.i.

The test bars had an elongation of 5.0 percent with a rupture life of 200 hours under a load of 25,000 p.s.i. at a temperature of 1800° F. in air.

Comparison of Examples I, V, VIII, and IX shows the adverse effect of high chromium content and the counterbalancing effect possible through changes in composition provided the equivalency factor does not exceed 70. Example 4 shows that up to 3 percent molybdenum can be tolerated without appreciable deleterious effect. Examples XIII to XVII inclusive show the effect of changes in titanium content in otherwise identical compositions and the reduction in rupture life when the titanium is increased to

3.5 percent and higher. This reduction in rupture life is in addition to other deficiencies such as cracking, brittle mode of fracture and decreased oxidation resistance.

The above detailed description of this invention has been given for clearness of understanding only. No unnecessary limitations should be understood therefrom, as modifications will be obvious to those skilled in the art.

I claim:

1. A metal alloy consisting essentially of, by weight, from about 6% to about 17% of chromium, from about 5% to about 20% of tungsten, from about 0.25% to about 3% of at least one of the metals selected from the group consisting of columbium and tantalum, from about 2% to about 8% of aluminum, from about 0.1% to about 3% of titanium with the provision that the amount of titanium does not exceed the amount of aluminum, from about 2% to about 15% of cobalt, at least one of the metals in the amounts indicated selected from the group consisting of from about 0.001% to about 0.5% of zirconium and from about 0.001% to about 0.2% of boron, from about 0.02% to about 0.35% of carbon, and the remainder being nickel and incidental impurities, said nickel content being in the range of about 45% to about 77%, and said chromium, tungsten, titanium, aluminum and metal selected from the group consisting of columbium and tantalum being present in said alloy in weight percentages corresponding to the following equation:

1 Cr+1.1 W+3.4Cb (Ta)+4.3 Ti+6 Al=60–70

2. A metal alloy consisting essentially of, by weight, from about 8.75% to about 10.25% of chromium, from about 11% to about 16% of tungsten, from about 0.8% to about 1.8% of at least one of the metals selected from the group consisting of columbium and tantalum, from about 4.75% to about 5.5% of aluminum, from about 0.75% to about 2.5% of titanium with the provision that the amount of titanium does not exceed the amount of aluminum, from about 8% to about 12% of cobalt, at least one of the metals in the amounts indicated selected from the group consisting of from about 0.03% to about 0.12% of zirconium and from about 0.01% to about 0.03% of boron, from about 0.12% to about 0.17% of carbon, and the remainder being nickel and incidental impurities, said nickel content being in the range of about 50% to about 77%, and said chromium, tungsten, titanium, aluminum and metal selected from the group consisting of columbium and tantalum being present in said alloy in weight percentages corresponding to the following equation:

1 Cr+1.1 W+3.4 Cb (Ta)+4.3 Ti+6 Al=60–70

3. A metal alloy consisting essentially of, by weight, from about 6% to about 17% of chromium, from about 5% to about 20% of tungsten, from about 0.25% to about 3% of at least one of the metals selected from the group consisting of columbium and tantalum, from about 2% to about 8% of aluminum, from about 0.1% to about 3% of titanium with the provision that the amount of titanium does not exceed the amount of aluminum, from about 2% to about 15% of cobalt, at least one of the metals in the amounts indicated selected from the group consisting of from about 0.001% to about 0.5% of zirconium and from about 0.001% to about 0.2% of boron, from about 0.02% to about 0.35% of carbon, from about 0% to about 5% of iron, from about 0% to about 1% of silicon, from about 0% to about 2% of manganese, from about 0% to about 3% of molybdenum, the remainder being nickel and incidental impurities, said nickel content being in the range of about 45% to about 77%, and said chromium tungsten, titanium, aluminum and metals selected from the group consisting of columbium and tantalum being present in said alloy in weight percentages corresponding to the following equation:

1 Cr+1.1 W+3.4 Cb (Ta)+4.3 Ti+6 Al=60–70

4. A metal alloy consisting essentially of, by weight, from about 8.75% to about 10.25% of chromium, from about 11% to about 16% of tungsten, from about 0.8% to about 1.8% of at least one of the metals selected from the group consisitng of columbium and tantalum, from about 4.75% to about 5.5% of aluminum, from about 0.75% to about 2.5% of titanium with the provision that the amount of titanium does not exceed the amount of aluminum, from about 8% to about 12% of cobalt, at least one of the metals in the amounts indicated selected from the group consisting of from about 0.03% to about 0.12% of zirconium and from about 0.01% to about 0.03% of boron, from about 0.12% to about 0.17% of carbon, from about 0% to about 5% of iron, from about 0% to about 1% of silicon, from about 0% to about 2% of manganese, from about 0% to about 3% of molybdenum, the remainder being nickel and incidental impurities, said nickel content being in the range of about 50% to about 77%, and said chromium, tungsten, titanium, aluminum and metals selected from the group consisting of columbium and tantalum being present in said alloy in weight percentages corresponding to the following equation:

1 Cr+1.1 W+3.4 Cb (Ta)+4.3 Ti+6 Al=60–70

5. A metal alloy consisting essentially of, by weight, from about 6% to about 17% of chromium, from about 5% to about 20% of tungsten, from about 0.25% to about 3% of at least one of the metals selected from the group consisting of columbium and tantalum, from about 2% to about 8% of aluminum. from about 0.1% to about 3% of titanium with the aluminum to titanium weight ratio in the alloy being between about 2:1 and 6:1, from about 2% to about 15% of cobalt; at least one of the metals in the amounts indicated selected from the group consisting of from about 0.001% to about 0.5% of zirconium and from about 0.001% to about 0.2% of boron, from about 0.02% to about 0.35% of carbon, the remainder being nickel and incidental impurities, said nickel content being in the range of about 45% to about 77%, and said chromium, tungsten, titanium, aluminum and metals selected from the group consisting of columbium and tantalum being present in said alloy in weight percentages corresponding to the following equation:

1 Cr+1.1 W+3.4 Cb (Ta)+4.3 Ti+6 Al=60–70

6. A metal alloy consisting esesntially of, by weight, from about 6% to about 17% of chromium, from about 5% to about 20% of tungsten, from about 0.25% to about 3% of at least one of the metals selected from the group consisting of columbium and tantalum, from about 2% to about 8% of aluminum, from about 0.1% to about 3% of titanium with the provision that the amount of titanium does not exceed the amount of aluminum, from about 2% to about 15% of cobalt, from about 0.001% to about 0.5% of zirconium, from about 0.02% to about 0.35% of carbon, the remainder being nickel and incidental impurities, said nickel content bieng in the range of about 45% to about 77%, and said chromium, tungsten, titanium, aluminum and metal selected from the group consisting of columbium and tantalum being present in said alloy in weight percentages corresponding to the following equation:

1 Cr+1.1 W+3.4 Cb (Ta)+4.3 Ti+6 Al=60–70

7. A metal alloy consisting essentially of, by weight, from about 8.75% to about 10.25% of chromium, from about 11% to about 16% of tungsten, from about 0.8% to about 1.8% of at least one of the metals selected from the group consisting of columbium and tantalum, from about 4.75% to about 5.5% of aluminum, from about 0.75% to about 2.5% of titanium with the provision that the titanium does not exceed the amount of aluminum, from about 8% to about 12% of cobalt, from about 0.01% to about 0.03% of boron, from about 0.12% to

about 0.17% of carbon, the remainder being nickel and incidental impurities, said nickel content being in the range of about 50% to about 77%, and said chromium, tungsten, titanium, aluminum and metal selected from the group consisting of columbium and tantalum being present in said alloy in weight percentages corresponding to the following equation:

$$1\ Cr+1.1\ W+3.4\ Cb\ (Ta)+4.3\ Ti+6\ Al=60\text{–}70$$

8. A metal alloy consisting essentially of, by approximate weight, 9% of chromium, 12.5% of tungsten, 1% of columbium, 0.05% of zirconium, 0.015% of boron, 2% of titanium, 0.15% of carbon, 5.0% of aluminum, 10% of cobalt, and the balance essentially nickel.

9. A metal alloy consisting essentially of, by approximate weight, 10% of chromium, 15% of tungsten, 1.5% of tantalum, 0.05% of zirconium, 0.015% of boron, 1% of titanium, 0.15% of carbon, 5.0% of aluminum, 10% of cobalt, and the balance essentially nickel.

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