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STABLE NICKEL BASE ALLOY

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ABSTRACT OF THE DISCLOSURE

A nickel base alloy having a balance of the elements chromium, tungsten, molybdenum, columbium, tantalum, titanium and aluminum to provide strength and stability at high temperatures, ductility at intermediate temperatures and resistance to sulfidation when the components have a hardening factor as follows:

1X% Cr+1.1X% W+1.8X% Mo+3.4X% Cb+1.7X%
Ta+4.3X% Ti+6X% Al=55 to 67

and a stability factor as follows:

.66 Ni Matrix+1.70 Co Matrix+4.66 Cr Matrix
+5.66 (W Matrix+Mo Matrix)=less than 2.50

This invention relates to non-ferrous alloys. More particularly, it relates to nickel base alloys that include alloying metal additives which make the resultant alloy resistant to sulfidation and suitable for use under stress conditions over a wide range of temperatures.

In accordance with the present invention, alloys are prepared which comprise nickel base alloys containing chromium, tungsten, molybdenum, titanium, aluminum and nickel in proportions and in relationship one to the other, necessary to attain the properties at high temperatures of strength, stability and resistance to sulfidation coupled with ductility at intermediate temperatures.

It is well known that various nickel base alloys have been found effective for high temperature uses such as in gas turbines employed in aircraft and in other applications. The higher operating temperatures allowed, for example, in the turbine section of the engine by the use of these alloys improve performance since the higher gas temperatures translate to higher thrust and/or lower fuel consumption per unit thrust.

While these newer nickel base alloys appeared initially to satisfy the more rigorous requirements of withstanding higher operating temperatures and higher stresses to which the airfoil portion of turbine blades was being subjected, the temperature conditions brought into play other conditions which prevented taking full advantage of the high temperature strength of the alloy. One of the conditions is the susceptibility of the blades to sulfidation at the higher temperature, i.e., a form of catastrophic corrosion. Another condition is instability of the compositions at the operating temperatures which in service leads to loss of the stress rupture properties which induced the acceptance of the nickel base alloys in the first place. Still another condition is unreliability in operation due to brittleness in the highly stressed root section of turbine blades as a result of their operation at intermediate temperatures, i.e., 1200° F. to 1500° F. Such intermediate temperature conditions exist as a result of the hotter airfoil sections having to operate at temperatures in the range of 1600° F. to 2000° F.

Sulfidation is a form of high temperature corrosion which occurs when combustion chamber gases contain

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products resulting from reaction of sulfur contained in the fuel with ingested sea salt. The products, generally considered to be sulfates, formed in the combustion process contact the turbine components and destroy the protective oxide layer so that sulfur can penetrate into the base metal. Such attack is evidenced by the formation of dark raised blisters on the airfoils.

The blisters reduce the cross-sectional thickness of the blade or airfoil body upon which they are formed. In addition, the sulfur penetration effects rapid destructive reduction of the effective cross-sectional area of alloy parts retaining their original stress-rupture properties. When sulfidation occurs, the structural elements are prone to fail prematurely and unpredictably and to create increased servicing problems due to the need for inspection at periods less than the normal expected overhaul service periods to be sure that blades remain in serviceable condition and do not become so weakened as to constitute a serious safety hazard.

A second factor which, during service, reduces the initially acceptable stress-rupture properties of some of the currently available nickel base alloys is the instability of the alloy at elevated temperatures. Instability of an alloy composition results in the formation of intermetallic compounds, such as the predominant one known as "sigma phase" which forms in a plate-like geometry, at temperatures from about 1500° F. to 1900° F. The "sigma phase" contains elements such as tungsten, molybdenum and chromium, and when formed, diverts these elements from their normal roles as solid solution strengthening elements. "Sigma phase" itself does not strengthen the alloy due to its plate-like morphology.

A third factor which is a serious defect in some of the nickel base alloys currently available is brittleness and notch sensitivity, because these phenomena contribute to unpredictable failure and unreliability. Most superalloy compositions have adequate rupture ductility at the higher temperatures, i.e., 1600° F. to 2000° F. and are not notch sensitive. In contrast, at intermediate temperatures on the order of 1200° F. to 1500° F., all nickel base alloys show a ductility trough. If the loss of rupture ductility is too great, notch sensitivity will result. Higher operating temperatures utilized in the combustion chambers of, for example, advanced turbine engines results in the turbine disc and associated turbine blade roots coming to an equilibrium temperature in the intermediate range. The root portions of blades made from alloys which have low ductility and are notch sensitive are highly susceptible to cracking and subsequent failure under the stresses developed during high speed rotation.

Attempts have been made to overcome sulfidation through changing the composition of the turbine blade surfaces by depositing on and diffusion of a protective coating into the surface of a base metal, for example, by brazing a resistant sheet to the base, by pouring cladding layers, and the like.

These base metals having surfaces altered to have a protective composition have not been completely acceptable, because a diffusion coating usually continues to diffuse under high temperature operating conditions and does not remain as a protective layer of constant composition.

Now it has been discovered that structural members such as turbine blades which do not require protective surface layers but possess resistance to sulfidation, high strength and stability at high temperatures and ductility at intermediate temperatures, can be produced in which basically the metal alloy comprises by weight from about .03% to .2% carbon, from about 14% to 18% chromium,

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from about 5% to 20% cobalt, from about 2% to 4.5% tungsten, from about 0.5% to 3% molybdenum, from about 1% to 4% tantalum or from about 0.5% to 2.5% columbium or a combination thereof in which the percentages of tantalum plus two times percent columbium does not exceed 5%, from about 1% to 3% titanium, from about 2.5% to 4.75% aluminum, from about .01% to .2% zirconium, from about .005% to .05% boron and the balance nickel.

The alloys of this invention consist essentially of a nickel base solid-solution matrix containing refractory carbides and a precipitate of gamma prime (Ni_3Al , Ti) in which specific balances are required between the amounts of chromium, tungsten, molybdenum, titanium and aluminum, if sulfidation resistance is to be maintained while developing high temperature strength and avoiding the unstabilizing effect of proportions of elements favoring "sigma phase" development during high temperature operation.

Chromium is an essential element of this alloy but is required in very specific proportions. Resistance to sulfidation requires the presence of at least 14% of chromium. Increased amounts of chromium improve the sulfidation resistance. Above about 16%, the deleterious effect of chromium on strength tends to become apparent and above about 18%, the reduction in strength detracts from its utility as a high temperature structural alloy. Accordingly, chromium is used in quantities in the range between 14% and 18% and preferably in the range between about 15% and 16.5%.

When varying amounts of the specified components within the specified ranges, if chromium is limited as outlined, the high temperature strength properties will be maintained if the alloy formulations are prepared in accordance with the following hardening factor equation:

$$1\text{X}\% \text{ Cr} + 1.1\text{X}\% \text{ W} + 1.8\text{X}\% \text{ Mo} + 3.4\text{X}\% \text{ Cb} + 1.7\text{X}\% \text{ Ta} + 4.3\text{X}\% \text{ Ti} + 6\text{X}\% \text{ Al} = 55 \text{ to } 67, \text{ preferably } 58 \text{ to } 64$$

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

High temperature strength is only one of the necessary properties in an alloy of the type herein described. Short time stress-rupture specifications can be met without any guarantee of stability of the alloy. In fact, it has been discovered that only some of the alloys having a hardener index between 55 and 67 have stability and when varying the amounts of components within the specified ranges, stability will only be maintained if the alloy formulations are prepared in accordance with the foregoing and furthermore in accordance with the following stability equation:

$$.66 \text{ Ni Matrix} + 1.70 \text{ Co}$$

$$\text{Matrix} + 4.66 \text{ Cr Matrix} + 5.66$$

$$(\text{W Matrix} + \text{Mo Matrix}) = \text{or less than } 2.50$$

A preferred range for stability factor is between 2 and 2.5.

This third parameter is based upon a determination of the matrix atomic percentages of the elements present. The matrix atomic fractions are arrived at through the following series of calculations. First, the composition of the alloy is converted from weight percent to atomic percent. This is accomplished by dividing the weight percent of each element by its atomic weight and summing up the resultant factors. The factor for each element is divided by the above-mentioned sum and the resulting number when multiplied by 100 is the atomic percent for each element in the gross composition. To calculate the matrix atomic fractions, the amount of nickel which is consumed through its reaction with aluminum and titanium must first be determined based upon the formula $\text{Ni}_3(\text{Al}, \text{Ti})$.

This figure is three times the sum of the aluminum and titanium atomic percentages and when this number is subtracted from the atomic percent nickel of the gross

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composition, the remaining atomic percent of nickel has been determined. The matrix atomic fractions are determined by adding the remaining atomic percent of nickel, the atomic percent of chromium, the atomic percent of cobalt, the atomic percent of tungsten and the atomic percent of molybdenum, and dividing the atomic percent figures for the various elements by the above sum. The matrix atomic fractions when substituted in the above formula provide a measure of stability of the alloy. Alloys with factors over 2.50 will form "sigma phase" which detracts from the alloys high temperature strength.

Tantalum and columbium serve in this alloy to stabilize the carbon content and thus are present predominantly as carbides and any free tantalum or columbium is of such an insignificant factor that it need not be included in the above calculation.

A test for stability consists of aging a specimen of the alloy at 1650° F. for 288 hours, a time and temperature which will cause "sigma phase" to form if the composition is not a stable one. The sample is then cooled, sectioned, polished, etched and examined under the microscope for plate-like constituents. If the structure is free of these, the alloy is considered to be a stable one.

In dealing with the stability factor, especially when working with close tolerances in properties, compositional control can be quite critical. A variation of 1% by weight in the amount present of each of the following elements will change the stability by the listed amounts:

Tungsten	-----	0.04
Molybdenum	-----	0.052
Chromium	-----	0.06

The variations for titanium and aluminum are not linear and thus do not have such a formal relationship, although a change from 3% to 4% aluminum will change the stability factor by 0.125 and a change of 2% to 3% of titanium will change the factor by approximately 0.07%. Thus, when a composition is considered, care should be taken to take into account the upper melting range of each element present.

In preparing the nickel base alloys of this invention, the amounts of certain elements are of extreme importance. Tungsten is one of these important elements and should be present in amounts between about 1% and 4.5%. Tungsten present in greater amounts while possibly advantageous from a hardener point of view, results in a drastic reduction in intermediate temperature strength and ductility.

Molybdenum is an essential element of the alloy. Even with tungsten in the range of 1% to 4.5% if molybdenum is not present, alloys tend to have poor rupture ductility in the intermediate temperature range. It is not, however, substitutable for tungsten as an equivalent. Alloys containing molybdenum and no tungsten have good intermediate temperature ductility, but do not have equivalent high temperature strength of the tungsten alloys. Molybdenum is used in the alloys of this invention in amounts between about 0.5% and 3% with the amount of molybdenum being no greater than equal to and generally being less than the amount of tungsten. Usually, it is preferred that the ratio by weight of tungsten to molybdenum be in the range between about 1.5:1 and 3:1. The importance to the alloy of molybdenum is illustrated by comparison of alloys substantially identical except one has 0% of molybdenum while the other contained 1.75% molybdenum. The 0% molybdenum content alloy at 1400° F. and 85,000 p.s.i. after heat treatment at 1600° F. for 20 hours shows a rupture life of 20 hours whereas the alloy containing 1.75% molybdenum shows a rupture life of 72 hours indicative of a drastic reduction in stress rupture properties at intermediate temperatures with reduction in molybdenum content of an alloy.

Cobalt is also an important element in these alloys. Absence of cobalt has a deleterious effect upon the rupture strength of the alloys at elevated temperatures. For exam-

pel, comparison of test sample alloys similar except for the presence of 10% cobalt, shows for the zero cobalt alloy at 1400° F. and 85,000 p.s.i. after heat treatment at 1600° F. for 20 hours, a rupture life of 16 hours, whereas the alloy with cobalt shows a rupture life of 53 hours. Similarly at 1800° F./20,000 p.s.i., the cobalt free alloy had a life of only 39 hours as compared to a 94 hour life for the 10% cobalt alloy.

Aluminum serves a dual purpose in this alloy. It contributes to oxidation resistance and functions to form an intermetallic compound with nickel which is an excellent hardener and strengthener of the alloy.

Titanium is also an important element in determining the strength of the alloys of this invention. Small amounts of titanium in cooperation with aluminum are useful in the alloy because of an improved precipitation strengthening effect. 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 1.5% and about 2.5%.

In the alloys of this invention, columbium and tantalum can be used interchangeably provided the amount of tantalum plus two times the percentage of columbium does not exceed a total of 5% of the total alloy composition. Columbium and tantalum serve to stabilize the carbon by forming carbides which act as grain boundary strengtheners. Columbium is preferred to tantalum from a standpoint of density and cost while tantalum is advantageous from the standpoint of oxidation resistance.

Small additions of boron and zirconium are useful in that they improve both rupture strength and ductility. 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.

A preferred range of proportions of constituents of the alloys of this invention in percentages by weight is as follows:

from about 15% to 16.5% of chromium
from about 3% to 4% of tungsten
from about 8% to 12% of cobalt
from about 1% to 2% of columbium
or from about 2% to 4% of tantalum or mixtures thereof
from about 3.5% to 4.75% of aluminum
from about 1.5% to 2.5% of titanium
from about .03% to .10% of zirconium
from about .01% to .03% of boron
from about 0.1% to 0.17% of carbon
and the remainder nickel and incidental impurities, the nickel content being in the range between about 55% and 69%.

Testing of the alloys for rupture life evaluation at intermediate temperatures, for example, 1400° F. and at high temperatures, for example, 1800° F. is accomplished by the conventional stress-rupture test.

Resistance of the alloys to sulfidation may be determined by immersing a weighed sample halfway in a solution in a Vycor crucible, the solution containing a mixture of 9.5 grams of sodium sulfate and 0.5 grams of sodium chloride. The crucibles are positioned in an Inconel tray and placed in a furnace maintained at 1700° F. for 24 hours.

After heating, the salts are dissolved off in boiling water and the samples sandblasted clean and reweighed. The weight loss per unit of surface area is calculated and attack is deemed severe if the loss exceeds 30 mg./cm.². Alloys having weight losses less than 10 mg./cm.² are considered to have good sulfidation resistance. At about 14% chromium content, alloys of this invention will exhibit a weight loss of about 30 mg./cm.² and substantially the same alloy having 18% of chromium will exhibit a weight loss of the order of 4 to 5 mg./cm.². A 12% chromium alloy of similar composition shows a weight loss of the order of 200 mg./cm.².

The invention will be further illustrated by the follow-

ing examples which are given by way of illustration and without any intention that the invention be limited thereto.

EXAMPLE I

A 15 pound alloy melt of a nickel alloy composition containing, on a weight basis, 15.5% chromium, 3.5% tungsten, 1.75% molybdenum, 10% cobalt, 1.75% columbium, 1.75% titanium, 4.25% aluminum, 0.05% zirconium, 0.015% boron, 0.15% carbon and the balance nickel was prepared by melting chromium-nickel cobalt-carbon mix under high vacuum conditions following which the tungsten, molybdenum, columbium, aluminum, titanium, boron and zirconium were added.

This alloy on an atomic percentage basis is as follows:

	Percent
Chromium	17.0
Tungsten	1.12
Molybdenum	1.04
Cobalt	9.70
Columbium	1.07
Titanium	2.09
Aluminum	8.95
Zirconium	.03
Boron	.08
Carbon	.72
Nickel	58.5

A cluster of 16 test bars was formed from the 15 pound melted alloy by the usual investment casting technique under high vacuum conditions. These bars were each 3" long and 1/4" in diameter.

The alloy composition has a hardening factor of 61.3.

It has a stability factor of 2.28.

The test bars had an elongation of 2.5% with a rupture life of 75.5 hours under a stress of 85,000 p.s.i. at 1400° F. and an elongation of 5% with a rupture life of 126.8 hours under a stress of 45,000 p.s.i. at a temperature of 1600° F. and an elongation of 14% with a rupture life of 91.7 hours under a stress of 20,000 p.s.i. at 1800° F. Weight loss after 24 hours at 1700° F. of a sample half immersed in a solution of 95% Na₂SO₄ plus 5% NaCl was 5 mg./cm.². The alloy after being aged for 288 hours at 1650° F. was examined under the microscope and found free of "sigma phase."

EXAMPLE II

A 15 pound alloy melt of a nickel alloy composition containing on a weight basis, 16% chromium, 4% tungsten, 2% molybdenum, 10% cobalt, 2% columbium, 2% titanium, 4.5% aluminum, .05% zirconium, .015% boron, .15% carbon and the balance nickel was prepared by melting chromium-nickel cobalt-carbon mix under high vacuum conditions following which the tungsten, molybdenum, columbium, aluminum, titanium, zirconium and boron were added.

A cluster of 16 test bars was formed from the 15 pound melted alloy by the usual investment casting technique under high vacuum conditions. These bars were each 3" long and 1/4" in diameter.

The alloy composition has a hardening factor of 66.4. It has a stability factor of 2.45.

The test bars had an elongation of 4.5% with a rupture life of 57.7 hours under a stress of 85,000 p.s.i. at 1400° F. and an elongation of 6.0% with a rupture life of 92 hours under a stress of 45,000 p.s.i. at a temperature of 1600° F. and an elongation of 14% with a rupture life of 55.4 hours under a stress of 20,000 p.s.i. at 1800° F. Weight loss after 24 hours at 1700° F. by sulfidation test described was 5 mg./cm.².

Microscopic examination, as described, shows this alloy after aging at 1650° F. for 288 hours to be free of "sigma phase."

EXAMPLE III

A 15 pound alloy melt of a nickel alloy composition containing, on a weight basis, 15.5% chromium, 4% tungsten, 2% molybdenum, 10% cobalt, 4% tantalum, 2% titanium, 4.5% aluminum, 0.05% zirconium, 0.015% boron, 0.15% carbon and the balance nickel was prepared by melting chromium-nickel cobalt-carbon mix under high vacuum conditions following which the tungsten, molybdenum, columbium, aluminum, titanium, boron and zirconium were added.

A cluster of 16 test bars was formed from the 15 pound melted alloy by the usual investment casting technique under high vacuum conditions. These bars were each 3" long and 1/4" in diameter.

The alloy composition has a hardening factor of 65.9. It has a stability factor 2.48.

The test bars had an elongation of 3% with a rupture life of 44 hours under a stress of 85,000 p.s.i. at 1400° F. and an elongation of 6.5% with a rupture life of 47.4 hours under a stress of 45,000 p.s.i. at a temperature of 1600° F. and an elongation of 11% with a rupture life of 94.2 hours under a stress of 20,000 p.s.i. at 1800° F. Weight loss of 24 hours at 1700° F. by the sulfidation test described was 4 mg./cm.².

Microscopic examination, as described, shows this alloy, after aging at 1650° F. for 288 hours to be free of "sigma phase."

EXAMPLE IV

A 15 pound alloy melt of a nickel alloy composition containing, on a weight basis, 13.5% chromium, 10% tungsten, 2% molybdenum, 10% cobalt, 2% titanium, 4.5% aluminum, 0.05% zirconium, 0.015% boron, 0.15% carbon and the balance nickel was prepared by melting chromium-nickel cobalt-carbon mix under high vacuum conditions following which the tungsten, molybdenum, aluminum, titanium, boron and zirconium were added.

A cluster of 16 test bars was formed from the 15 pound melted alloy by the usual investment casting technique under high vacuum conditions. These bars were each 3" long and 1/4" in diameter.

The alloy composition has a hardening factor of 66.9. It has a stability factor of 2.60.

The test bars had an elongation of 2.0% with a rupture life of 28.3 hours under a stress of 85,000 p.s.i. at 1400° F. and an elongation of 2.5% with a rupture life of 42 hours under a stress of 45,000 p.s.i. at a temperature of 1600° F. and an elongation of 3.5% with a rupture life of 67.9 hours under a stress of 20,000 p.s.i. at 1800° F. Weight loss after 24 hours at 1700° F. by the sulfidation test described was 200 mg./cm.².

Microscopic examination, as described, shows this alloy, after aging at 1650° F. for 288 hours, to contain a moderate amount of "sigma phase."

EXAMPLE V

A 15 pound alloy melt of a nickel alloy composition containing on a weight basis, 16% chromium, 6% tungsten, 2.5% molybdenum, 10% cobalt, 2% columbium, 2% titanium, 4.5% aluminum, 0.05% zirconium, 0.015% boron, 0.15% carbon and the balance nickel was prepared by melting chromium-nickel cobalt-carbon mix under high vacuum conditions following which the tungsten, molybdenum, columbium, aluminum, titanium, boron and zirconium were added.

A cluster of 16 test bars was formed from the 15 pound melted alloy by the usual investment casting technique under high vacuum conditions. These bars were each 3" long and 1/4" in diameter.

The alloy composition has a hardening factor of 69.5. It has a stability factor of 2.62.

The test bars had an elongation of 2.5% with a rupture life of 17.3 hours under a stress of 85,000 p.s.i. at 1400°

F. and an elongation of 3% with a rupture life of 18.8 hours under a stress of 45,000 p.s.i. at a temperature of 1600° F. and an elongation of 5% with a rupture life of 37.6 hours under a stress of 20,000 p.s.i. at 1800° F. Weight loss after 24 hours at 1700° F. by the sulfidation test described was 20 mg./cm.².

Microscopic examination, as described, shows this alloy after aging at 1650° F. for 288 hours to contain a moderate amount of "sigma phase."

Comparison of Examples I, II and III alloys of this invention with Examples IV and V, the latter alloys being outside the scope of this invention because of such factors as low chromium and too high tungsten contents or too high a tungsten content shows the importance of balance of metallic elements from both a sulfidation resistance and stability aspect.

The foregoing detailed description is given for clearness of understanding only and no unnecessary limitations should be understood therefrom, for modifications will be obvious to those skilled in the art.

I claim:

1. A metal alloy consisting essentially of by weight about 14% to 18% of chromium, about 2% to about 4.5% of tungsten, about 5% to 20% of cobalt, from about 0.5% to about 3% of molybdenum, one of the metals in the amounts indicated selected from the group consisting of about 0.5% to 2.5% of columbium and about 1.0% to 4% of tantalum, about 1% to 3% of titanium, about 2.5% to 4.75% of aluminum, about 0.01% to 0.2% of zirconium, about 0.005% to 0.05% of boron, about 0.1% to 0.2% of carbon and the balance nickel, said nickel content being in the range between about 50% and about 75%, said chromium, tungsten, molybdenum, columbium, tantalum, titanium, aluminum and nickel being present in said alloy in weight percentages such that the hardening factor corresponds to the following equation:

$$1X\% \text{ Cr} + 1.1X\% \text{ W} + 1.8X\% \text{ Mo} + 3.4X\% \text{ Cb} \\ + 1.7X\% \text{ Ta} + 4.3X\% \text{ Ti} + 6X\% \text{ Al} = 55 \text{ to } 67$$

and the stability factor corresponds to the following equation:

$$.66 \text{ Ni Matrix atomic fraction} + 1.70 \text{ Co Matrix atomic fraction} + 4.66 \text{ Cr Matrix atomic fraction} + 5.66 (\text{W Matrix atomic fraction} + \text{Mo Matrix atomic fraction}) = \text{less than } 2.50.$$

2. An alloy according to claim 1 wherein the nickel content is between 55 and 69.

3. An alloy according to claim 1 wherein the hardening factor is between 58 and 64.

4. An alloy according to claim 1 wherein the stability factor is between 2.1 and 2.45.

5. An alloy according to claim 1 wherein the weight ratio of tungsten to molybdenum is between 1.5:1 and 3:1.

6. An alloy according to claim 1 wherein the alloy consists essentially, on a weight basis, of 15.5% chromium, 3.5% tungsten, 1.75% molybdenum, 10% cobalt, 1.75% columbium, 1.75% titanium, 4.25% aluminum, 0.05% zirconium, 0.015% boron, 0.15% carbon and the balance nickel.

7. A metal alloy consisting essentially of by weight from about 15% to 16.5% of chromium, from about 3% to 4% of tungsten, from about 0.05% to about 3% of molybdenum, from about 8% to 12% of cobalt, one of the metals in the amounts indicated selected from the group consisting of from about 1% to 2% of columbium, and from about 2% to 4% of tantalum, from about 3.5% to 4.75% of aluminum, from about 1.5% to 2.5% of titanium, from about .03% to .10% of zirconium, from about .01% to .03% of boron, from about 0.1% to 0.17% of carbon and the remainder nickel and incidental impurities, the nickel content being in the range of between about 55% and 69%, said chromium, tungsten, molybdenum, columbium, tantalum, titanium, aluminum and

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nickel being present in said alloy in weight percentages such that the hardening factor corresponds to the following equation:

$$1X\% \text{ Cr} + 1.1X\% \text{ W} + 1.8X\% \text{ Mo} + 3.4X\% \text{ Cb} + 1.7X\% \text{ Ta} + 4.3X\% \text{ Ti} + 6X\% \text{ Al} = 55 \text{ to } 67$$

and the stability factor corresponds to the following equation:

$$.66 \text{ Ni Matrix atomic fraction} + 1.70 \text{ Co Matrix atomic fraction} + 4.66 \text{ Cr Matrix atomic fraction} + 5.66 (\text{W Matrix atomic fraction} + \text{Mo Matrix atomic fraction}) = \text{less than } 2.50.$$

8. A structural member formed of an alloy as set forth in claim 1.

9. A cast structural member formed of an alloy as set forth in claim 1.

10. A structural member for use in the combustion

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section of a gas turbine engine formed of an alloy as set forth in claim 1.

11. A cast structural member for use in the combustion section of a gas turbine engine formed of an alloy as set forth in claim 1.

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