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NICKEL BASE ALLOY

Richard R. MacFarlane, Sinking Spring, and Clyde Raymond Whitney, Reading, Pa., assignors to The Carpenter Steel Company, Reading, Pa., a corporation of New Jersey

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6 Claims. (Cl. 75—171)

ABSTRACT OF THE DISCLOSURE

A hot workable nickel base alloy containing 10% to 20% chromium and 10% to 20% cobalt which in its heat treated condition has high creep resistance and good rupture strength at temperatures in the neighborhood of 1300° F.–1500° F. imparted by controlled additions of the elements molybdenum, tungsten, titanium, aluminum and boron.

This application is a continuation-in-part of application Ser. No. 447,056 filed Apr. 9, 1965 and now abandoned.

This invention relates to an alloy for use under stress at high temperatures and more particularly to a nickel base alloy containing substantial amounts of chromium and cobalt, with smaller but highly critical amounts of titanium, aluminum, molybdenum and tungsten.

Nickel base alloys for use under stress at high temperature have long been known and used in which the principal strengthening effect results from the formation of a precipitate identified as gamma prime, Ni_3 (Ti, Al). Such alloys have been used where strength under stress at high temperature for extended periods of time was required. An example of such use is illustrated by jet engine turbine blades. The trend toward higher operating temperatures to increase the output of such engines has imposed more and more stringent requirements upon the parts fabricated from alloys of the type to which the present invention is directed. Thus, alloys of that type have left much to be desired insofar as their strength at elevated temperatures is concerned.

Another serious drawback of such alloys resides in the fact that they are extremely difficult to hot work. The large proportion of defective and waste metal resulting from the hot working of alloys of the type set forth in U.S. Patent No. 2,809,110 has led to the expenditure of considerable effort to improve the hot workability of such alloys without impairing the required high temperature properties. For example, U.S. Patent No. 3,107,167 is concerned with the addition of from 0.1% to 1.3% tungsten to such alloys for the purpose of improving hot workability, but whatever improvement in hot workability was attained it was at the expense of the high temperature strength of the alloy as noted in the patent.

The present invention stems from the discovery that when the titanium and aluminum content is carefully controlled to provide a combined titanium plus aluminum content of from about 5% to 7.5% and when from about 1.5% to 4% tungsten is included in the alloy in which the remaining elements are balanced as will be set forth in detail hereinbelow, then, not only are the high temperature properties of the alloy improved, but there is also an improvement in the hot workability of the alloy. Here and throughout this application percentages are given as percent by weight.

It is therefore a principal object of this invention to provide a nickel base alloy characterized by increased

usefulness at high temperatures and which may be hot worked to fabricate products therefrom with substantially less waste metal than with comparable alloys hitherto available.

It is a further object of this invention to provide products such as jet engine turbine blades and discs as well as other parts for use at elevated temperature under stress characterized by improved resistance to plastic deformation and strength and a long useful life under such adverse conditions.

The foregoing as well as other objects and advantages of the present invention will be apparent from the following detailed description thereof.

In its broader aspects, the present invention provides an alloy consisting essentially of about 10% to 20% chromium, about 10% to 20% cobalt, about 3% to 8% molybdenum, about 3% to 4.5% titanium, about 1.5% to 4% aluminum, with the combined titanium plus aluminum content being from about 5% to 7.5%, about 1.5% to 4% tungsten, about 0.003% to 0.03% boron. To attain the best strength as represented by creep and stress rupture tests at elevated temperatures, the titanium and aluminum content of the alloy must be balanced within the ranges stated so that the titanium content is at least equal to or greater than the aluminum content. The alloy may contain some carbon, manganese, phosphorus and sulfur but not more than 0.08% carbon, 0.5% manganese, 0.5% silicon, 0.01% phosphorus or 0.01% sulfur. The balance of the alloy is essentially nickel except for small amounts of other elements which do not adversely affect the desired properties of the alloy. For example, from a trace to one or two hundredths of a percent of suitable deoxidants and/or grain refiners such as magnesium, zirconium, vanadium or any of the rare earths may be included in the alloy.

The amount of carbon present in the alloy is determined by whether or not carbon is used as a deoxidant. No more carbon is present in the alloy than may be necessary for accomplishing the desired deoxidation of the alloy which is desirably vacuum melted in keeping with good commercial metallurgical practice to minimize impurities. While up to about 0.08% carbon is tolerable, carbon is preferably present in an amount of about 0.02% to 0.05%.

The elements manganese, silicon, phosphorus and sulfur, when present, are present solely as impurities in the alloy. Phosphorus and sulfur are not to exceed 0.01%. While manganese and silicon are each tolerable when present not in excess of 0.5%, preferably no more than 0.2% of each is present.

Chromium is used in this alloy to impart oxidation and corrosion resistance and, for this purpose, from about 10% to 20% chromium is utilized. To the extent that chromium is present, it is added at the expense of nickel in this alloy, and because nickel takes part in the main precipitation reaction which is believed to impart strength to the alloy, the larger amounts of chromium tend to detract from the strength of the alloy. Best results are achieved when from about 14% to 16% chromium is utilized. When chromium is present in this narrow range the desired oxidation and corrosion resistance as well as good strength are attained.

Cobalt works to raise the solvus temperature of the gamma prime precipitate. Cobalt is also believed to have some beneficial effect on the hot workability of the alloy. Thus, from about 10% to 20% cobalt is included in this alloy. However, when present in an amount greater than 20%, cobalt may have an adverse effect upon the oxidation resistance of the alloy. Best results are achieved when cobalt is present in an amount of about 13% to 17%.

Molybdenum works as a solid solution strengthener in the alloy. Below about 3%, molybdenum is not present in a sufficient amount to provide the desired effect, while as the molybdenum content is increased above 8%, the alloy becomes increasingly difficult to hot work. Best results are achieved with molybdenum in an amount of 4% to 6%.

Tungsten also works as a solid solution strengthener in this alloy, but it is not used to replace nor may it be replaced by molybdenum. In this alloy, from about 1.5% to 4% tungsten works to provide an unexpectedly large increase in strength at elevated service temperatures, e.g., 1300° F. to 1400° F., and serves as a solid solution strengthener over an extended service life .The most striking effect is apparent from the high temperature creep strength of the alloy which is representative of the resistance to deformation of the alloy under stress at high temperature. The stress rupture strength of the alloy is also significantly improved over comparable alloys hitherto available. Best results are achieved with about 2% to 3% tungsten.

Titanium and aluminum together with nickel take part in the main strengthening reaction of the alloy by which a precipitate believed to be gamma prime, $Ni_3(Ti, Al)$, is formed. The total titanium plus aluminum content must be controlled within the range of about 5% to 7.5%, with a minimum of 3% titanium or 1.5% aluminum, the larger amounts of titanium or aluminum being used depending upon whether the expected temperature to which the parts fabricated from the alloy will be exposed will be lower or higher. Below those amounts, titanium and aluminum are not present in an amount necessary to provide the desired strengthening effect. As the titanium content exceeds 4.5%, or as the aluminum content exceeds 4%, there is a markedly adverse effect upon the hot workability of the alloy. Preferably about 3.25% to 4.25% titanium and about 2.5% to 3.5% aluminum, but with titanium and aluminum combined no more than 7.5%, is used to attain the better strength with good hot workability. However, for any given amount of aluminum within the ranges stated, to provide maximum strength as represented by creep and stress rupture tests at elevated temperatures of at least about 1300° F. to 1400° F. it is necessary that the amount of titanium present be at least equal to or greater than the amount of aluminum in the alloy.

Boron has a beneficial effect upon the high temperature creep and stress rupture strength of this alloy. For this purpose, from about 0.003% to 0.03% boron may be included, but for best results about 0.015% to 0.025% boron is used.

The remainder of the alloy is preferably nickel except for incidental impurities which, for best results, are kept low by following good vacuum melting practices in preparing the alloy.

Thus, by way of recapitulation, the alloy produced with preferred results has the following composition in percent by weight within the tolerances of good commercial practice:

	Percent
Carbon	0.02–0.05
Chromium	14–16
Molybdenum	4–6
Tungsten	2–3
Cobalt	13–17
Boron	0.015–0.025
Titanium	3.25–4.25
Aluminum	2.5–3.5

the balance consisting essentially of nickel except for incidental impurities.

In practice, vacuum induction melting and casting of an ingot which is then used as a consumable electrode and is remelted under vacuum will give a highly refined ingot of the alloy free of undesired impurities and imperfections. The experimental ingots referred to herein

were vacuum induction heats. Although a preferred heat treatment will be pointed out hereinbelow in connection with the preparation of specific examples of this alloy, standard solution and aging treatments may be used.

As a specific example of this alloy, an ingot was melted and cast containing:

	Percent
Carbon	0.03
Chromium	15.72
Molybdenum	5
Tungsten	2.7
Cobalt	14.8
Boron	0.02
Titanium	3.6
Aluminum	2.9

and the balance nickel except for incidental impurities which included immaterial amounts of manganese, silicon, phosphorus and sulfur. A bar formed from the ingot by hot working was solution treated for two hours at 2075° F. and water-quenched, then heated for six hours at 1600° F. followed by cooling in air, then heated for two hours at 1800° F. and again cooled in air, followed by heating for twenty-four hours at 1200° F. and air-cooled and then heated for eight hours at 1400° F. followed by air-cooling.

Two standard creep test specimens 0.252 inch in diameter with a one inch gauge length were machined from the bar and subjected to a stress of 74,000 p.s.i. at 1300° F. The time for 0.1% plastic creep was found to be 350 hours for one test specimen and 280 hours for the other.

As another specific example of this alloy, an ingot was melted and cast containing:

	Percent
Carbon	0.035
Chromium	15.2
Molybdenum	5
Tungsten	2.4
Cobalt	15.2
Boron	0.02
Titanium	4.2
Aluminum	3

and the balance nickel except for incidental impurities which included immaterial amounts of manganese, silicon, phosphorus and sulfur. A bar was forged from the ingot and heat treated as was described in connection with the preceding example. Similarly, two standard creep test specimens were formed and when tested under a load of 74,000 p.s.i. at 1300° F., the times measured for 0.1% plastic creep were 258 hours and 280 hours. In addition, a standard smooth-notch type stress rupture specimen was formed having a 0.178 inch diameter, a 0.712 inch gauge length and a stress concentration factor (K_t) of 3.8. At 1400° F., a stress load of 85,000 p.s.i. was sustained for 74 hours before rupture with 15.3% elongation and 27.3% reduction in area, the failure occurring in the smooth part of the specimen.

On the other hand, tests carried out with similarly prepared and tested specimens of commercially available analyses of the type hereinabove referred to were characterized by much lower creep strength and inferior stress rupture strength. Furthermore, the inferior hot workability of such alloys as compared to the present alloy was readily apparent.

The terms and expressions which have been empolyed are used as terms of description and not of limitation, and there is no intention, in the use of such terms and expressions, of excluding any equivalents of the features described or portions thereof, but it is recognized that various modifications are possible within the scope of the invention claimed.

We claim:

1. A hot workable nickel base alloy which in its heat treated condition has high creep resistance and good rupture strength at temperatures in the neighborhood of 1300°

F. to 1400° F. and above and which by weight consists essentially of about:

	Percent
Carbon (max.)	0.08
Manganese (max.)	0.5
Silicon (max.)	0.5
Phosphorus (max.)	0.01
Sulfur (max.)	0.01
Chromium	10–20
Molybdenum	3–8
Tungsten	1.5–4
Cobalt	10–20
Boron	0.003–0.03
Titanium	3–4.5
Aluminum	1.5–4

the balance consisting essentially of nickel, and in which the combined total of titanium and aluminum is not less than about 5% and is not materially greater than 7.5%.

2. A hot workable nickel base alloy as set forth in claim 1 in which the titanium content is at least equal to the aluminum content.

3. A hot workable nickel base alloy which in its heat treated condition has high creep resistance and good rupture strength at temperatures in the neighborhood of 1300° F. to 1400° F. and above and which by weight consists essentially of about:

	Percent
Carbon	0.02–0.05
Manganese (max.)	0.2
Silicon (max.)	0.2
Phosphorus (max.)	0.01
Sulfur (max.)	0.01
Chromium	14–16
Molybdenum	4–6
Tungsten	2–3
Cobalt	13–17
Boron	0.015–0.025

	Percent
Titanium	3.25–4.25
Aluminum	2.5–3.5

the balance consisting essentially of nickel, and in which the combined total of titanium and aluminum is not materially greater than 7.5%.

4. A hot workable nickel base alloy as set forth in claim 3 in which the titanium content is at least equal to the aluminum content.

5. A hot workable nickel base alloy which in its heat treated condition has high creep resistance and good rupture strength at temperatures in the neighborhood of 1300° F. to 1400° F. and above and which by weight consists essentially of about 0.03% carbon, 15.7% chromium, 5% molybdenum, 2.7% tungsten, 14.8% cobalt, 0.02% boron, 3.6% titanium, 2.9% aluminum, and the balance consisting essentially of nickel except for incidental impurities.

6. A hot workable nickel base alloy which in its heat treated condition has high creep resistance and good rupture strength at temperatures in the neighborhood of 1300° F. to 1400° F. and above and which consists by weight of essentially about 0.035% carbon, 15.2% chromium, 5% molybdenum, 2.4% tungsten, 15.2% cobalt, 0.02% boron, 4.2% titanium, 3% aluminum, and the balance consisting essentially of nickel except for incidental impurities.

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CHARLES N. LOVELL, *Primary Examiner.*