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HIGH TEMPERATURE NICKEL-BASE ALLOY

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The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

The present invention relates to a nickel alloy capable of high load carrying capacity at temperatures of 1800° F. and above.

In the operation of today's jet engine, it has been found that suitable turbine blades should preferably have high load carrying capacity at temperatures of 1800° F. and above in order that the thrust increases possible through operation at higher inlet-gas temperatures may be realized. For such an application, a minimum stress rupture life of 100 hours at 15,000 p.s.i. stress, which is comparable to the blade root stresses in latter-day engine turbines, is required. Good impact resistance and good oxidation resistance are also important requirements for such an alloy. Materials currently capable of high load carrying capacity at temperatures of 1800° F. and above are ceramics, cermets, and refractory metals and their alloys. Each of these materials, however, has serious limitations for turbine blade applications. Most commercial alloys which are not subject to these limitations, such as nickel base and cobalt base alloys, do not have adequate strength at 1800° F. Only a very limited number of these alloys can be utilized under high loads at this temperature for a sufficient length of time to be considered for turbine blade application.

Several major disadvantages are found to exist in the previously used materials for high temperature, high stress applications. Ceramics, of course, are of a very brittle nature and lack heat shock and impact resistance, thus severely limiting their usefulness as turbine blade material. Cermets can be said to show a slight improvement over the ceramics but generally are subject to the similar hindrances. High melting point refractory metals can generally be said to have poor oxidation resistance at elevated temperatures. This can also be said to exist for the alloys of such high melting point refractory metals. Consequently, in order to permit their use at elevated temperatures for sufficiently long periods of time, protective coatings are generally required for such metals of their alloys. However, the problem of providing strongly adherent coatings which give uniform coverage, as well as satisfactorily resisting erosion, is so great as to severely curtail the potential of these materials for turbine blade applications. The few commercial alloys available which can possibly be considered for high temperature turbine blade applications need closely controlled vacuum melting techniques in order to achieve the required properties.

An object of the invention is an alloy series which demonstrates elevated temperature stress rupture properties greater than all commercial nickel or cobalt base alloys.

A further object of the invention is an alloy series with impact properties greater than all commercial alloys and most known high temperature materials.

An additional object of the invention is an alloy series which can be readily cast without the need for closely controlled vacuum techniques and still provide the desired high strength, high temperature properties.

A still further object of the invention is a nickel alloy series which has the combination of properties suitable for application to jet engine turbine blades operating at 1800° F. without requiring protective coating to prevent oxidation and without the brittleness inherent in ceramic and cermet turbine blades.

Another object of the invention is an alloy series which has high stress properties at elevated temperatures and yet can be easily worked.

This invention is embodied in alloys having the following intermediate composition range within the foregoing broad range:

Nickel	From about 65% to about 82%.
Molybdenum	From about 0% to about 10%.
Tungsten	From about 0% to about 10%.
Aluminum	From about 4% to about 8%.
Chromium	From about 4% to about 8%.
Zirconium	From about 1% to about 3%.
Vanadium	From about 3% to about 7%.
Carbon	From about .125% to about .30%.

In the alloy composition set forth, molybdenum and tungsten can be used interchangeably so that equal amounts of each may be present or just one element alone. However, either the tungsten or the molybdenum must be present individually on in combination in a quantity of at least 6% and the total amount of either element used separately or the combination of the two elements should not exceed 10% of the alloy.

A preferred alloy has the following composition:

	Percent
Nickel	About 76.375.
Molybdenum	About 8.
Chromium	About 6.
Aluminum	About 6.
Zirconium	About 1.
Vanadium	About 2.5.
Carbon	About .125.

Thus, a more preferred alloy has the following composition:

	Percent
Nickel	76.375
Molybdenum	4
Tungsten	4
Chromium	6
Aluminum	6
Zirconium	1
Vanadium	2.50
Carbon	.125

The subject alloys were prepared with one of the simplest possible casting techniques. The melt was made in a refractory crucible which was placed in a high frequency induction coil. The alloy additions were made as the melting progressed in the following order: nickel, chromium, molybdenum, vanadium, aluminum, and carbon. The zirconium can be picked up as a contaminant in the stabilized zirconia crucible. Argon gas was directed into the oven top crucible continuously during melting to provide an inert gas blanket over the melt. During pouring, which was done at 3150° F.±50° F., the inert gas coverage was removed. Melts were hand-poured into investment molds heated to 1600° F. and were permitted to come to equilibrium temperature naturally without speeding up the cooling process artificially. These alloys may also be prepared by more complex techniques such as closely controlled vacuum melting, which can result in further improvements in properties. In other instances, research has indicated that the improved cleanliness, plus the fact that the effectiveness of such an element as aluminum is not reduced by the reaction with atmospheric gases can also result in better strength, as well as improved ductility. Thus by introducing a higher degree of complexity in the casting process, an improved alloy is likely to result.

The novel alloys of the invention derive their elevated temperature strength from a fine dispersion of stable particles. Such stable particles include aluminum-nickel intermetallic compounds and vanadium carbides. Through the addition of tungsten, a certain degree of matrix strengthening may be achieved.

The major advantage of the invention lies in the properties of the instant alloys as demonstrated in various tests, results of which are shown and compared to existing commercial alloys in Table II below. Table I below sets forth the several commercially available alloys which have similar chemical compositions to those disclosed herein.

It can readily be seen that the instant alloys possess considerably higher rupture strengths at 1800° F. The commercial al'oy which most closely approaches the rupture strength of the alloys of the invention is Inco 713 whose 100-hour rupture strength was at least 5000 p.s.i. less than the subject alloys as seen in Table II. The impact resistance was also shown to be substantially improved over the commercial alloys. New Alloy A, as set forth in Tables I and II, further displayed an as-cast rupture life in air at 1800° F. of 564 hours under a stress of 15,000 p.s.i. New Alloy B, as disclosed in the tables, possessed an as-cast rupture life in air of 768 hours, 300 hours, and 101 hours at 1800° F., 1850° F., and 1900° F., respectively, under a stress of 15,000 p.s.i. Further indication of their remarkable strength is indicated in the various tests run on the disclosed alloys in which the impact resistance in the as-cast condition at room temperature for all of the compositions considered in the series never fell below 40 inch-pounds and usually was greater than 62.5 inch-pounds. Both the stress-rupture values and the impact values cited represent a considerable improvement over those values demonstrated by known commercial nickel and cobalt base alloys. Oxidation resistance of the alloy series was found to be excellent in the tests, even at temperatures of 1800° F. and 1850° F.

TABLE I

Nominal chemical composition

Alloy	C	Mn	Si	Cr	Ni	Co	Mo	Cb	Ti	Al	Fe	Zr	B	V	W
Guy	.1	.5	.5	13.5	Bal.		5.5	2.0		6.2	4.5		.5		
J-1500	.15			20.0	Bal.	10.0	10.0		3.0	1.0					
Rene 41	.09			19.0	Bal.	11.0	10.0		3.1	1.5					
1-1360	.10			10.0	70.5		5.0	2.0		6.0	4.5		.3		
Inco 713	.12	.15	.4	13.0	Bal.		4.5	2.25	.6	6.0	1.0				
New Alloy A	.125			6.0	Bal.		8.0			6.0		1.0		2.5	
New Alloy B	.125			6.0	Bal.		4.0			6.0		1.0		2.5	4.0

TABLE II

	100 hr. Rupture Strengths at 1,800° F., p.s.i.	Impact Resistance, in.-lb.
Guy	<10,000	11.6
J-1500	<10,000	
Rene 41	11,000	
I-1360	9,500	
Inco 713	16,000	
New Alloy A	>21,000	>62.5
New Alloy B	>22,000	>62.5

Having thus described this invention in such full, clear, concise and exact terms as to enable any persons skilled in the art to which it pertains to make and use the same, and having set forth the best mode contemplated of carrying out this invention, it is stated that the subject matter which is regarded as being the invention is particularly pointed out and distinctly claimed in what is claimed, it being understood that equivalents or modifications of or substitutions for parts of the above specifically described embodiments of the invention may be made without departing from the scope of the invention as set forth in what is claimed.

I claim:

1. A nickel base alloy capable of high load carrying capacity at elevated temperatures consisting essentially of 76.375% nickel, 8% molybdenum, 6% chromium, 6% aluminum, 1% zirconium, 2.5% vanadium, and .125% carbon.

2. A nickel base alloy capable of high load carrying capacity at elevated temperatures consisting essentially of 76.375% nickel, 4% molybdenum, 4% tungsten, 6% chromium, 6% aluminum, 1% zirconium, 2.5% vanadium, and .125% carbon.

3. A nickel base alloy capable of high-load carrying capacity at elevated temperatures consisting essentially of from 65 to 82 percent nickel, from 6 to 10 percent molybdenum, from 4 to 8 percent aluminum, from 4 to 8 percent chromium, from 1 to 3 percent zirconium, from 3 to 7 percent vanadium, and from 0.125 to 0.30 percent carbon.

4. A nickel base alloy capable of high-load carrying capacity at elevated temperatures consisting essentially of from 65 to 82 percent nickel, from 6 to 10 percent tungsten, from 4 to 8 percent aluminum, from 4 to 8 percent chromium, from 1 to 3 percent zirconium, from 3 to 7 percent vanadium, and from 0.125 to 0.30 percent carbon.

5. A nickel base alloy capable of high-load carrying capacity at elevated temperatures consisting essentially of from 65 to 82 percent nickel, molybdenum and tungsten in combination such that the total amount of both elements present in the alloy is from 6 to 10 percent, from 4 to 8 percent aluminum, from 4 to 8 percent chromium, from 1 to 3 percent zirconium, from 3 to 7 percent vanadium, and from 0.125 to 0.30 percent carbon.

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