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3,526,499
NICKEL BASE ALLOY HAVING IMPROVED
STRESS RUPTURE PROPERTIES
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ABSTRACT OF THE DISCLOSURE

A nickel base superalloy particularly adapted for use in turbine engine blades because of its vastly improved stress rupture properties and other physical characteristics, the alloy containing 0.05 to 0.25% carbon, from 5 to 8% chromium, from 0.5 to 4.0% molybdenum, from 0.5 to 2.0% titanium, from 4.5 to 6.5% aluminum, from 1 to 10% cobalt, from 4 to 8% tungsten, from 0 to 2% rhenium, from 0.2 to 3.0% hafnium, from 0.01 to 0.50% zirconium, from 0.005 to 0.200% boron, from 6 to 10% tantalum, from 0 to 2% columbium, from 0 to 1% vanadium, and the balance being essentially nickel, all percentages being by weight.

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 U.S.C. 2457).

Rights to practice the invention for any use primarily related to aeronautical and space applications are available through the National Aeronautics and Space Administration.

BACKGROUND OF THE INVENTION

The present invention is in the field of nickel base superalloys particularly useful in the manufacture of turbine blading for jet aircraft. These alloys are capable of maintaining their strength and their creep, oxidation, and thermal fatigue resistance at high temperatures while still evidencing a reasonable amount of ductility.

DESCRIPTION OF THE PRIOR ART

The art of nickel base superalloys for jet engine blades has been developed quite substantially in recent years. Typical among the U.S. patents in this field are the following: 2,570,193; 2,945,758; 2,951,757; 2,974,036; 2,977,222; 3,061,426; 3,164,465; 3,166,412.

One of the most recent alloys of this type containing substantial amounts of refractory metals is described in Freche et al. U.S. Pat. 3,276,866, issued Oct. 4, 1966.

Commercially available nickel base superalloys are represented in the following table:

While the art is thus quite highly developed, the stress rupture properties of these alloys can stand a substantial amount of improvement. To our knowledge, the stress rupture life of these alloys at an applied stress of 15,000 p.s.i. and at a temperature of 2,000° F. does not exceed about 10 to 15 hours. In contrast, the alloys of the present invention have a stress rupture life of at least 20 hours under the same conditions and consistently exceed 30 hours. The most preferred embodiments of the invention have an average stress rupture life under these conditions in excess of 60 hours.

SUMMARY OF THE INVENTION

This invention relates to nickel base superalloys particularly useful for jet engine parts including blades, vanes, buckets, and the like, the alloys consisting essentially of the following ingredients:

	Percent
Carbon	0.05-0.25
Chromium	5-8
Molybdenum	0.5-4.0
Titanium	0.5-2.0
Aluminum	4.5-6.5
Cobalt	1-10
Tungsten	4-8
Rhenium	0-2
Hafnium	0.2-3.0
Zirconium	0.01-0.50
Boron	0.005-0.200
Tantalum	6-10
Columbium	0-2
Vanadium	0-1
Nickel	-(1)

¹ Essentially the balance.

The sum of the molybdenum, tungsten, and tantalum contents should be in the range from about 15 to 20%, with the tungsten being present in an amount greater than the molybdenum but less than the amount of tantalum.

Within the broader ranges specified above, particularly improved alloys are provided with the following analyses:

	Percent
Carbon	0.10-0.20
Chromium	5-7
Molybdenum	1-3
Titanium	0.75-1.50
Aluminum	5-6
Cobalt	2-8
Tungsten	5-7
Rhenium	0-1
Hafnium	0.3-2.5
Zirconium	0.02-0.30
Boron	0.01-0.1
Tantalum	7-9
Columbium	0-1
Vanadium	0-1
Nickel	(1)

¹ Essentially the balance.

TABLE 1.—NOMINAL COMPOSITIONS OF CONTEMPORARY NICKEL-BASE SUPERALLOYS

Alloy	Cast or wrought	C	Cr	Mo	Ti	Al	Co	W	Zr	B	Ta	Cb	V	Fe
Nimonic 75	W	0.04	20.0											
Inconel X	W	0.04	15.0		2.5	0.8								6.8
Waspaloy	W	0.08	19.5	4.3	3.0	1.3	13.5		0.06	.006		0.9		
René 41	W	0.09	19.0	10.0	3.1	1.5	11.0			.005				
Udimet 700	W	0.08	15.0	5.0	3.5	4.3	18.5		.005	.025				
Inco 713C	C	0.12	12.5	4.2	0.8	6.1			0.10	.012		2.0		
IN 100	C	0.18	10.0	3.0	4.7	5.5	15.0		0.06	.014			1.0	
Mar M-200	C	0.15	9.0		2.0	5.0	10.0	12.5	0.05	.015		1.0		
TAZ 8	C	0.125	6.0	4.0		6.0		4.0	1.0	.004	8.0		2.5	
TAZ8A	C	0.125	6.0	4.0		6.0		4.0	1.0	.004	8.0	2.5		

DESCRIPTION OF THE PREFERRED EMBODIMENT

The alloys of the present invention use substantial amounts of solid solution strengtheners such as tantalum, tungsten, and molybdenum in proper balance to achieve strength properties without depreciating the oxidation resistance of the alloy. The addition of hafnium has been found to be particularly effective in securing the properties desired. The addition of rhenium is optional but may be used to improve corrosive properties of the alloy in some instances.

In order to illustrate more completely the substantial improvements in physical properties which are achieved by the alloys of the present invention, we are listing below typical stress rupture properties of existing alloys under various conditions:

TABLE 2.—STRESS RUPTURE PROPERTIES OF CONTEMPORARY ALLOYS

(A) 1,800° F. tests				
Hours of life for given stress, 10 ³ p.s.i.				
Alloy	10	100	1,000	10,000
Wrought nickel-base alloys:				
René 41	17	9		
Udimet 700	26	16	7	
Cast nickel-base alloys:				
Inco 713 C	29	21	13	8
IN 100		25	15	
MarM-200	37	28	20	15
TAZ 8	35	23	15	
(B) 1,900° F. tests				
Hours of life for given stress				
Alloy	10	100	1,000	10,000
Wrought nickel-base alloys, Udimet:				
René 41	17	8	3	
Cast nickel-base alloys:				
Inco 713 C		12		
IN 100		16	9	
MarM-200	23	18	11	8
TAZ		15		
TAZ 8A		15		

¹ 1,815° F. ² 1,915° F. ³ 1,895° F.

After considerable experimentation, we determined that the three best alloy compositions coming within the broader analyses recited previously were the following, which we called alloys IV-Y, VI-A and VI-D:

TABLE 3

Alloy IV-Y:	Percent
Carbon	0.15
Chromium	6.0
Molybdenum	2.0
Titanium	1.0
Aluminum	5.4
Cobalt	5.0
Tungsten	5.5
Rhenium	1.0
Hafnium	2.0
Zirconium	0.03
Boron	0.02
Tantalum	8.0
Columbium	1.0
Nickel	Balance
Alloy VI-A:	Percent
Carbon	0.13
Chromium	6.1
Molybdenum	2.0
Titanium	1.0
Aluminum	5.4
Cobalt	7.5
Tungsten	5.8
Rhenium	0.5
Hafnium	0.43
Zirconium	0.13
Boron	0.02
Tantalum	9.0
Columbium	0.5
Nickel	Balance

Alloy VI-D:

Carbon	0.15
Chromium	5.4
Molybdenum	2.0
Titanium	1.0
Aluminum	5.4
Cobalt	5.0
Tungsten	6.0
Hafnium	1.75
Zirconium	0.08
Boron	0.02
Tantalum	8.5
Columbium	0.5
Vanadium	0.5
Nickel	Balance

The average stress rupture life of these three alloys, at 2,000° F. and at an applied stress of 15,000 pounds per square inch was 41.3 hours for alloy IV-Y, 62.9 hours for alloy VI-A, and 67.3 hours for alloy VI-D.

The physical testing of the samples was carried out in the following way. The stress rupture testing was performed in air and in commercially pure argon atmosphere. In the argon tests, the chambers were flushed with argon before heating and then the atmosphere was maintained after the test until the specimen was cooled to less than 1,000° F.

Tensile tests were performed on the specimens as cast and after heat treatment consisting of a 300 hour age at 1,875° F. in an argon atmosphere.

Charpy impact testing was performed on a standard impact tester in accordance with ASTM standards. The pendulum velocity was 17 feet per second. The test specimens were unnotched with dimensions of 2.165 inches by 0.394 inch by 0.394 inch, and were machined from the as cast material.

Thermal fatigue testing was performed in the following manner. The specimens were heated with an oxy-acetylene flame, the specimens being precision cast wedges 2 inches long, 3/8 inch at the large end and 1/32 inch at the pointed end, and 1 1/32 inch wide. Some specimens were run at a test temperature of 2,100° F. and others at 1,875° F. Temperature measurements were made with an optical pyrometer. A reading was made after the first ten cycles, at 20 cycle intervals up to 50 cycles, and at 50 cycle intervals thereafter to the completion of the examination interval. The cycle intervals for crack examination varied for the two test temperatures. At 2,100° F. the specimens were examined at 30 cycle intervals up to 150 cycles, at 50 cycle intervals up to 400 cycles, at 100 cycle intervals up to 1,500 cycles, at 200 cycle intervals up to 3,100 cycles, and at 500 cycle intervals thereafter to failure. The number of cycles to first crack detection were recorded. At 1,875° F., the specimens were examined at 50 cycle intervals up to 200 cycles, at 100 cycle intervals up to 1,000 cycles, at 200 cycle intervals up to 2,400 cycles, and 400 cycle intervals thereafter, to a maximum of 4,000 cycles.

Two methods were employed to evaluate the corrosion resistance of the alloys, consisting of oxidation tests and hot corrosion tests. For oxidation testing, the specimens utilized were 0.5 inch diameter cylinders, 1/2 inch long. The specimens were placed in high purity alumina crucibles and weighed before heating. The specimens in the crucibles were then heated in air at one of the test temperatures and times. A new specimen was used for each test condition. Upon removal from the furnace, the crucibles were covered to prevent loss of scale due to flaking during cooling. After cooling, the crucible and contents were then weighed to determine the change in weight due to oxidation.

Hot corrosion testing was done by means of a gravimetric method using the same size specimen as the oxidation tests. The specimens were weighed and then partially covered with a 1% sodium chloride, 99% sodium

sulfate mixture in silica crucibles. The crucibles with the specimens and salt mixture were heated in air for 1 hour at a temperature of 1,800° F. The scale produced during the corrosion of the specimens was removed by cathodically descaling in molten sodium hydroxide. After descaling,

the specimens were reweighed and the loss of weight used as a measure of the sulfidation attack.

The following tables illustrate representative values obtained when testing the three preferred alloys of the present invention.

TABLE 4.—STRESS RUPTURE FOR CAST ALLOYS IN AIR AT 1,400° F.

Alloy	85,000 p.s.i.			90,000 p.s.i.			94,000 p.s.i.		
	Life, hrs.	Elong., percent	R.A.	Life, hrs.	Elong., percent	R.A.	Life, hrs.	Elong., percent	R.A.
IV-Y-----	355.3	1.6	2.0	146.4	0.6	0.8	0.2	0	0
	777.7	3.7	12.8	617.1	2.5	3.1			
	1,309.6	2.7	7.4	371.8	3.5	3.4	406.2	30	3.9
VI-A-----	592.6	3.1	3.2	72.6	0.4	2.0	144.9	1.8	3.9
	943.6	1.7	3.1	641.1	2.0	2.8	400.4	2.0	2.4
	1,355.5	1.9	2.8	665.4	1.3	2.2	516.7	2.9	7.2
VI-D-----	534.9	1.0	2.4	49.5	1.7	3.7	214.2	1.9	4.0
	1,124.1	3.1	2.0	546.7	2.2	5.5	312.4	2.0	6.1

TABLE 5.—STRESS RUPTURE RESULTS FOR CAST ALLOYS IN AIR AT 1,875° F.

Alloy	15,000 p.s.i.			25,000 p.s.i.			35,000 p.s.i.		
	Life, hrs.	Elong., percent	R.A.	Life, hrs.	Elong., percent	R.A.	Life, hrs.	Elong., percent	R.A.
IV-Y-----	468.2	5.0	5.5	29.9	4.6	3.1	6.3	3.4	0.4
	842.9	3.3	3.9	76.9	4.1	5.6	13.3	7.7	2.8
	252.2	6.5	14.4	78.3	8.6	4.7	11.7	6.9	8.6
VI-A-----	1,174.3	4.0	8.2	69.1	5.9	7.0	9.4	2.4	3.9
	693.4	5.7	9.7	54.4	5.1	3.9	8.7	4.8	2.4
	771.3	8.0	10.0	82.7	8.3	14.4	13.3	4.6	7.0
VI-D-----	721.3	8.5	8.5	10.3	4.1	6.3	6.2	2.5	1.2
	799.0	4.6	4.1	31.9	2.4	3.1	3.8	3.1	0.8
	667.5	4.3	5.6	57.6	6.1	6.6	8.1	4.2	7.8

TABLE 6.—STRESS RUPTURE RESULTS FOR CAST ALLOYS IN AIR AT 1,950° F.

Alloy	15,000 p.s.i.			20,000 p.s.i.			25,000 p.s.i.		
	Life, hrs.	Elong., percent	R.A.	Life, hrs.	Elong., percent	R.A.	Life, hrs.	Elong., percent	R.A.
IV-Y-----	77.7	2.5	1.0	8.4	2.7	1.6	15.7	3.0	2.5
	217.8	0.9	2.7	39.2	5.5	8.0	14.6	3.5	8.2
	101.1	4.3	6.6	2.1	2.3	2.4	6.2	2.7	6.3
VI-A-----	187.9	6.2	5.1	40.6	4.5	7.0	1.2	3.8	5.1
	156.1	5.1	7.4	33.1	6.5	8.0	12.1	6.9	7.4
	208.2	7.5	13.0	55.1	10.3	11.5	83.8	8.6	8.5
VI-D-----	114.3	7.6	11.5	29.6	4.4	5.4	14.6	4.1	9.0
	149.2	2.7	3.9	24.5	1.8	3.1	6.3	2.1	3.1
	151.8	4.5	6.0	28.6	5.1	7.8	0.8	3.1	7.3

TABLE 7.—STRESS RUPTURE RESULTS FOR CAST ALLOYS IN ARGON AT 15,000 P.S.I. LOAD

Alloy	1,875° F.			1,950° F.		
	Life, hrs.	Elongation, percent	R.A., percent	Life, hrs.	Elongation, percent	R.A., percent
IV-Y-----	298.1	4.2	7.7	66.0	1.7	2.0
	907.7	4.1	6.4	177.9	6.4	3.3
	683.7	6.1	6.3	97.2	4.4	6.6
VI-A-----	704.0	5.1	8.5	195.7	6.5	7.6
	650.0	4.4	6.3	140.9	8.0	8.9
	788.5	7.5	18.1	164.9	7.2	4.1
VI-D-----	391.8	2.3	6.8	145.5	7.3	9.3
	0.9	0.6	1.6	109.6	4.1	2.0
	739.5	9.4	14.5	145.0	6.7	10.0

TABLE 8.—TENSILE RESULTS FOR CAST ALLOYS

Alloy	Room temperature				1,200° F.			
	Ultimate (10 ³ p.s.i.)	0.2% offset yield (10 ³ p.s.i.)	Elongation, percent	R.A., percent	Ultimate (10 ³ p.s.i.)	0.2% offset yield (10 ³ p.s.i.)	Elongation, percent	R.A., percent
IV-Y-----	146.0	136.6	1.9	7.4	157.4	132.3	7.0	12.3
	140.9	134.0	3.2	7.4	163.0	134.0	4.7	8.1
VI-A-----	154.6	135.4	4.7	7.4	168.8	137.4	4.8	7.4
	157.0	139.5	4.5	7.0	163.8	137.2	3.0	6.6
VI-D-----	148.2	132.0	2.6	5.5	153.8	136.0	2.9	5.1
	150.6	131.3	3.8	5.5	155.0	138.4	1.4	1.2

Alloy	1,400° F.				1,600° F.			
	Ultimate (10 ³ p.s.i.)	0.2% offset yield (10 ³ p.s.i.)	Elongation, percent	R.A., percent	Ultimate (10 ³ p.s.i.)	0.2% offset yield (10 ³ p.s.i.)	Elongation, percent	R.A., percent
IV-Y-----	155.4	134.8	4.9	8.1	124.2	115.4	7.6	5.9
	163.0	130.1	4.4	6.6	118.3	115.1	4.5	9.6
VI-A-----	159.8	135.0	3.8	5.5	126.5	-----	2.8	5.1
	161.4	139.2	4.0	4.3	162.4	112.0	2.2	4.1
VI-D-----	156.8	104.4	1.3	4.7	128.0	115.0	2.2	4.3
	157.4	137.0	4.3	6.6	125.6	115.6	3.4	3.9

Alloy	1875° F.				1950° F.			
	Ultimate (10 ³ p.s.i.)	0.2% offset yield (10 ³ p.s.i.)	Elongation, percent	R.A., percent	Ultimate (10 ³ p.s.i.)	0.2% offset yield (10 ³ p.s.i.)	Elongation, percent	R.A., percent
IV-Y-----	69.8	61.0	6.5	6.6	58.2	52.0	6.3	8.1
	71.1	61.8	5.9	5.9	58.0	51.9	5.2	6.2
VI-A-----	73.0	62.1	4.4	5.5	57.1	50.0	6.0	5.9
	73.0	63.2	3.9	4.7	57.4	50.4	3.8	2.7
VI-D-----	73.6	65.5	3.3	9.6	60.0	54.8	2.1	2.0
	74.1	66.6	2.2	5.9	61.2	56.1	2.3	2.4

¹ Broke in shoulder.

TABLE 9.—THERMAL FATIGUE RESULTS FOR CAST ALLOYS

Alloy	First cracking observed	Failure	Test temp., ° F.
IV-Y, 1-----	4,100	5,100	2,100
VI-A:-----			
1-----	1,300	3,600	2,100
2-----	1,400	2,900	2,100
3-----	1,500	4,100	2,100
4-----	1,900	3,600	2,100
VI-D:-----			
1-----	700	900	2,100
2-----	200	600	2,100
3-----	1,400	2,100	2,100
4-----	900	2,900	2,100
Inco 713C (virgin):			
1-----	1,000	1,400	2,100
2-----	1,150	1,600	2,100
IN 100 (virgin):			
1-----	450	1,600	2,100
2-----	150	1,600	2,100
IN 100 (revert):			
1-----	450	1,050	2,100
2-----	300	300	2,100
WI 52 (air melt):			
1-----	900	1,250	2,100
2-----	200	350	2,100

TABLE 10.—OXIDATION RESULTS FOR CAST ALLOYS

Alloy	Exposure time, hours	Weight gained in mg./cm. ²		
		1,875° F.	1,950° F.	2,100° F.
IV-Y-----	50	0.7	0.9	0.5
	200	1.2	1.6	0.9
	500	2.2	2.0	1.3
	1,000	2.2	4.1	21.8
VI-A-----	50	0.4	0.6	0.9
	200	0.7	1.2	5.0
	500	1.1	1.8	30.5
	1,000	1.4	3.2	11.4
VI-D-----	50	6.9	4.1	3.9

¹ Surface melting observed.

TABLE 11

Hot corrosion results for cast alloys

Alloy:	Weight loss (grams)
IV-Y-----	0.529
VI-A-----	0.150; 0.271
VI-D-----	1.633; 1.968

In addition to the control of the molybdenum, tungsten and tantalum contents as previously specified, the nickel, aluminum, and titanium contents, for best results, should also be controlled. In this connection, we prefer to use

the relationship between these metals which is specified in U.S. Pat. No. 3,254,994 owned by the assignee of the present invention. As described in that patent, it is desirable to produce an intermetallic compound between the three metals, wherein the compound has the formula $\text{Ni}_3\text{Al}_x\text{Ti}_y$, where $x + y = 1$, but y is not more than 0.6. This intermetallic compound is a face centered cubic structure which constitutes the gamma-prime phase of the nickel-aluminum phase diagram.

From our studies, we have concluded that the preferred alloys of the present invention represent a substantial improvement in stress rupture life over present-day alloys. The alloy identified as VI-A has the best high temperature properties of the three. Its stress rupture life is the highest and represents approximately a 50° F. increase in temperature over the lives of present-day high strength nickel base alloys. Its tensile strength and impact properties are comparable with such alloys. Its ductility appears to be adequate and it does not appear to suffer a severe reduction in tensile ductility in the 1,400° F. to 1,600° F. temperature range. In addition, alloy VI-A has a good thermal fatigue and corrosive resistance for a high strength alloy and does not appear to suffer from microstructural instability, that is, formation of sigma, Laves, or mu phase formation.

We claim as our invention:

1. A nickel-base alloy having improved stress rupture properties and consisting essentially of the following ingredients:

	Percent
Carbon-----	0.05-0.25
Chromium-----	5-8
Molybdenum-----	0.5-4.0
Titanium-----	0.5-2.0
Aluminum-----	4.5-6.5
Cobalt-----	1-10
Tungsten-----	4-8
Rhenium-----	0-2
Hafnium-----	0.2-3.0
Zirconium-----	0.01-0.50
Boron-----	0.005-0.200
Tantalum-----	6-10
Columbium-----	0-2
Vanadium-----	0-1
Nickel-----	(1)

¹ Essentially the balance.

the sum of the molybdenum, tungsten, and tantalum contents being in the range from 15 to 20%, the tungsten being present in an amount greater than the molybdenum but less than the amount of tantalum, the stress rupture life of the alloy at an applied stress of 15,000 p.s.i. at a temperature of 2,000° F. being at least 20 hours.

2. A nickel-base alloy having improved stress rupture properties and consisting essentially of the following ingredients:

	Percent
Carbon	0.10-0.20
Chromium	5-7
Molybdenum	1-3
Titanium	0.75-1.50
Aluminum	5-6
Cobalt	2-8
Tungsten	5-7
Rhenium	0-1
Hafnium	0.3-2.5
Zirconium	0.02-0.30
Boron	0.01-0.1
Tantalum	7-9
Columbium	0-1
Vanadium	0-1
Nickel	(1)

¹ Essentially the balance.

the sum of the molybdenum, tungsten, and tantalum contents being in the range from 15 to 20%, the tungsten being present in an amount greater than the molybdenum but less than the amount of tantalum, the stress rupture lift of the alloy at an applied stress of 15,000 p.s.i. at a temperature of 2,000° F. being at least 20 hours.

3. A nickel-base alloy having improved stress rupture properties and consisting essentially of the following ingredients:

	Percent
Carbon	0.13-0.15
Chromium	5.4-6.1
Molybdenum	1-3
Titanium	0.75-1.50
Aluminum	5.0-6.0
Cobalt	5.0-7.5
Tungsten	5.5-6.0
Rhenium	0-1.0
Hafnium	0.43-2.0
Zirconium	0.03-0.13
Boron	0.01-0.1
Tantalum	8.0-9.0
Vanadium	0-0.5
Nickel	(1)

¹ Essentially the balance.

the sum of the molybdenum, tungsten, and tantalum contents being in the range from 15 to 20%, the stress rupture life of the alloy at an applied stress of 15,000 p.s.i. at a temperature of 2,000° F. being at least 20 hours.

4. The alloy of claim 1 in which there is sufficient nickel present to provide the compound $\text{Ni}_3\text{Al}_x\text{Ti}_y$ where x plus $y=1$, but y is not greater than 0.6.

5. A nickel-base alloy having improved stress rupture properties and consisting essentially of the following ingredients:

	Percent
Carbon	0.15
Chromium	6.0
Molybdenum	2.0
Titanium	1.0
Aluminum	5.4
Cobalt	5.0
Tungsten	5.5
Rhenium	1.0

	Percent
Hafnium	2.0
Zirconium	0.03
Boron	0.02
Tantalum	8.0
Columbium	1.0
Nickel	(1)

¹ Essentially the balance.

said alloy having a stress rupture life at an applied stress of 15,000 p.s.i. at a temperature of 2,000° F. of at least 20 hours.

6. A nickel-base alloy having improved stress rupture properties and consisting essentially of the following ingredients:

	Percent
Carbon	0.13
Chromium	6.1
Molybdenum	2.0
Titanium	1.0
Aluminum	5.4
Cobalt	7.5
Tungsten	5.8
Rhenium	0.5
Hafnium	0.43
Zirconium	0.13
Boron	0.02
Tantalum	9.0
Columbium	0.5
Nickel	(1)

¹ Essentially the balance.

said alloy having a stress rupture life of at least 20 hours at an applied stress of 15,000 p.s.i. and at a temperature of 2,000° F.

7. A nickel-base alloy having improved stress rupture properties and consisting essentially of the following ingredients:

	Percent
Carbon	0.15
Chromium	5.4
Molybdenum	2.0
Titanium	1.0
Aluminum	5.4
Cobalt	5.0
Tungsten	6.0
Hafnium	1.75
Zirconium	0.08
Boron	0.02
Tantalum	8.5
Columbium	0.5
Vanadium	0.5
Nickel	(1)

¹ Essentially the balance.

said alloy having a stress rupture life of at least 20 hours at an applied stress of 15,000 p.s.i. and at a temperature of 2,000° F.

8. A turbine engine blade composed of the alloy of claim 1.

9. A turbine engine blade composed of the alloy of claim 2.

10. A turbine engine blade composed of the alloy of claim 3.

References Cited

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RICHARD O. DEAN, Primary Examiner

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,526,499 Dated September 1, 1970

Inventor(s) Richard J. Quigg and Henry E. Collins

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 7, line 18, (second table of Table 8, in the third column)

"104.4" should read --140.4--.

Column 8, line 35,

"Ni₃Al_xTi_x" should read --Ni₃Al_xTi_y--.

SIGNED AND
SEALED
DEC 8 - 1970

(SEAL)

Attest:

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Attesting Officer

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Commissioner of Patents