

[54] HIGH STRENGTH CORROSION RESISTANT NICKEL-BASE ALLOY 3,728,088 4/1973 Benjamin ..... 29/182.5  
3,778,249 12/1973 Benjamin ..... 75/.5 BC

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[63] Continuation-in-part of Ser. Nos. 375,530, July 2, 1973, abandoned, and Ser. No. 302,201, Oct. 30, 1972, abandoned.

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[58] Field of Search ..... 75/.5 BC, .5 BB, .5 BA, 75/.5 R, 171, 122; 29/182.5

[56] References Cited

UNITED STATES PATENTS

3,591,362 7/1971 Benjamin ..... 75/211 X

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[57] ABSTRACT

Alloys containing controlled percentages of chromium, aluminum, titanium, molybdenum, tungsten, tantalum, zirconium, boron, carbon and a dispersoid such as yttria afford good stress rupture properties at intermediate temperatures, e.g., 1400°F., and at more elevated temperatures, e.g., 1900°F., together with good oxidation and/or control of nitrogen important for enhancing sulfidation resistance.

12 Claims, No Drawings

## HIGH STRENGTH CORROSION RESISTANT NICKEL-BASE ALLOY

The subject application is a continuation-in-part of application Ser. Nos. 375,530 filed 7/2/73 and 302,201, filed 10/30/72 both of which are now abandoned.

The present invention is directed to the so-termed superalloys, and particularly to precipitation hardenable, dispersion-strengthened nickel-base alloys capable of operating exceptionally well at both intermediate and elevated temperatures and under corrosive conditions.

By reason of the many advances in aircraft design, the metallurgical community has been under a continuous challenge to develop alloys capable of withstanding the more severe service conditions inherently imposed, notably increased speeds at higher temperatures and greater load-bearing capacities. In recent years, primary emphasis has probably been addressed to performance characteristics at the more elevated temperature levels, to wit, 1700°–2000°F. There are, however, those components of which more is demanded — witness, for example, the blades of a gas turbine engine. As is known, different sections of the blades are exposed to completely different combinations of temperature and stress. In this regard, the outer portions of the blades operate at temperatures upwards of 1700°F. whereas the platform portion closer to the axis of the engine might operate at temperatures on the level of 1200° to 1400°F., but the latter is subjected to tremendously greater stress due to the centrifugal nature of the loading in a rotating part.

The fact that an alloy might respond favorably at the higher temperature plateaus, does not invoke the corollary that it is also capable of performing satisfactorily at temperatures on the order of 1200°–1400°F. The product known as TD nickel has fairly good strength at the high temperatures but manifests a distinct propensity to undergo premature creep at the intermediate temperature levels.

The problem becomes somewhat compounded where excellent resistance to corrosion, particularly oxidation and/or sulfidation, is of necessity. For as we have found a given alloy may display acceptable values in terms of stress rupture characteristics at temperature only to suffer a pronounced susceptibility to corrosive attack.

The thrust of the subject invention is, accordingly, to bring together in one alloy the capability of delivering outstanding stress rupture strength at both intermediate (1400°F.) and elevated (1900°F.) temperature levels and good resistance to oxidation and/or sulfidation. In this connection and insofar as we are aware, the subject alloys afford the highest combination of strength and corrosion resistance known in the superalloy art.

Generally speaking, alloys contemplated in accordance herewith contain (weight percent) about 13 to 17%, e.g., 13.25 to 16.25%, chromium; about 2.5 to 6%, e.g., 2.75 to 5.25%, aluminum; about 2 to 4.25% titanium, the sum of the aluminum plus titanium being preferably at least about 5%; about 1.75 to about 4.25% or 4.5% molybdenum; about 3.75 to about 6.25% tungsten; up to 4%, e.g., up to 3%, tantalum, about 0.02 to 0.5%, e.g., 0.05 to about 0.175%, zirconium; about 0.001 to 0.025% boron, a small but effective amount, e.g., 0.2% or 0.5%, and up to about 2% of

yttria; up to 0.2% and advantageously not more than 0.125% carbon; and the balance essentially nickel.

Within the foregoing ranges, where the emphasis is on oxidation resistance as well as stress-rupture strength, the alloys should contain at least 3.5% aluminum, 13.75% or more of chromium and not more than about 3% titanium. In striving for the optimum by way of resistance to sulfidation then the percentages of aluminum, titanium and tungsten should be correlated such that the aluminum is from 2.75% to 4.6%, the titanium is at least 2.4% and the tungsten is at least 4.75%, the sum of the titanium plus tungsten beneficially being at least 7.75%. For both oxidation and sulfidation resistance coupled with high strength the alloys should contain about 3.5 to 5.25% aluminum, about 13.75 to 16.25% chromium, about 2.4 to 3% or 3.25% titanium, and from about 4.75 to 6.25% tungsten, the other constituents being within the ranges first given.

In terms of the individual alloying constituents, it would appear that a number of interactive or conflicting forces are involved, their respective roles being difficult to delineate at best. Seemingly, these interactions are particularly pronounced in respect of both oxidation and sulfidation resistance. For example, chromium, titanium and tungsten impart a most potent effect in achieving optimum resistance to sulfidation. By the same token, titanium and tungsten, for example, tend to detract from 1900°F. stress rupture strength, although not at 1400°F. Chromium and aluminum are indispensable in conferring resistance to oxidation yet aluminum at 1900° is deemed somewhat detrimental whereas chromium impairs stress-rupture properties at both 1400° and 1900°F. Such considerations are indicative of the careful balance of chemistry required. Indeed, this balance is further required to develop a proper grain structure as detailed more fully herein.

With regard to yttria, it confers high stress-rupture strength, particularly at the higher temperature levels (1900°F.). A small amount of this constituent, e.g., 0.4%, is effective in imparting this benefit, though it is preferred that about 0.5 to 1.5% be present. Percentages of yttria above 2% are unnecessary. Tantalum enhances strength characteristics especially in the 1200°–1400°F. Temperature region. From 1.5 to 3% of this element is deemed beneficial.

In referring to nickel as constituting the "balance" or "balance essentially" in respect of the above composition, the presence of other elements in amounts which do not adversely affect the basic characteristics of the alloys is not excluded. In this connection, the alloys may contain up to 3% columbium (although they are preferably columbium free); up to 10% cobalt; up to 3% hafnium; up to 0.75% or 1% oxygen; up to 3% iron (as a contaminant); and up to 0.3% nitrogen. But it is most preferred, as will be shown hereinafter, that nitrogen not exceed about 0.1% particularly in seeking the optimum of sulfidation resistance. Cobalt has a negative effect at 1900°F. and should, if present, be held to less than 8%. In addition, while yttria is very much preferred as the added dispersoid constituent, other refractory dispersoids, e.g., thoria and lanthana, can partially replace or be used in lieu thereof where a lesser combination of overall properties can be tolerated. Other refractory dispersoids can be present aside from the aforementioned yttria, lanthana and thoria, including the oxides, carbides, borides, and nitrides (provided the total nitrogen content does not exceed

about 0.1%) of one or more materials such as thorium, zirconium, hafnium, titanium and oxides of aluminum, yttrium, lanthanum, cerium, etc. It is to be also understood that a given range for a particular element of the alloys can be used with a given range for any other element.

In carrying the invention into practice, the alloys should be produced by the mechanical alloying process as described in U.S. Pat. No. 3,591,362 and incorporated herein by reference. As is known, mechanical alloying involves the dry, intensive high energy milling of a powder charge whereby the initial powder constituents are simultaneously fragmented and cold bonded to provide a homogeneous, intimate interdispersion of alloying elements in the form of composite particles corresponding to the alloy composition desired. In this connection, the impacting elements used are preferably hard and impact resistant such as through hardened 52100 steel. Using a 4 gallon attritor mill, for example, a ball-to-powder ratio of about 15:1 to 25:1 by volume is preferred, the impeller speed being suitably conducted over the range of 250 to 300 rpm for a period of about 12 to 24 hours. For processing in a 10 gal. attritor a speed of 150-200 rpm can be used, a period of 15-40 hours being satisfactory. Larger attritors permit of reduced impeller speeds.

Subsequent to mechanical alloying the composite alloy product particles can be compacted as by hot extrusion. A temperature of about 1800° to 2125°F. is suitable and an extrusion ratio of about 10:1 25:1 is

of the processing, a dynamic atmosphere of air and nitrogen was supplied. In the case of Alloy A, 16 cc per minute of air and 400 cc per minute of nitrogen were used whereas for Alloys B and C 12 and 9 cc of air was employed, the amount of nitrogen being the same.

The coarsest 5% of the powders was removed, the remainder being packed in 3½ inch diameter mild steel cans, sealed, heated to 1950°F. and then extruded through dies (0.75 inch for Alloy A and 0.875 inch for Alloys B and C) using glass and grease as a lubricant. An extrusion speed of approximately 3 to 4 inches per second was measured.

The alloys were then subjected to a germinative grain growth treatment (secondary recrystallization) consisting of heating for one half hour at 2300°F. for Alloys A and B and 2250°F. for Alloy C. After aging at 1550°F. for approximately 24 hours, microstructural examination revealed that the alloys exhibited a desired coarse grain structure elongated in the direction of extrusion.

Each of the three alloys was then stress rupture tested at both 1400°F. and 1900°F. and also tested for cyclic oxidation and sulfidation resistance. The oxidation test was conducted at 1100°C. for 500 hours, the alloys being cycled to room temperature each 24 hours. A crucible sulfidation test was used and this comprised partially immersing a 300 mil diameter specimen of each alloy in a 90% Na<sub>2</sub>SO<sub>4</sub> - 10% NaCl salt solution, the test being conducted at 1700°F. The analyzed compositions and results of the various tests are reported in Tables I - III below

TABLE I

Alloy	Cr %	Al %	Ti %	Mo %	COMPOSITION		Zr %	B %	Fe %	O %	N %
					W %	Y <sub>2</sub> O <sub>3</sub> %					
A*	13.9	4.8	2.4	3.7	3.9	1.1	0.12	0.005	1.1	0.58	0.16
B	13.5	4.2	3	4	6	1.1	0.15	0.01	0.7	0.5	0.14
C**	15.0	4.5	2.75	3.5	5.5	1.1	0.13	0.015	1.6	0.67	0.17

\*contained 2.4% tantalum

\*\*nominal composition plus 2.5% tantalum balance nickel and impurities

TABLE II

Alloy	STRESS RUPTURE DATA				
	Test Temp., °F	Stress, psi	Life Hrs.	El. %	R.R. %
A	1900	25,000	10.8	2.4	2.4
	1900	20,000	113.3	2.4	2.4
	1400	80,000	105.9	3.2	5.7
B	1900	20,000	117.8	0.8	1.6
	1400	85,000	37.2	2.4	3.5
C	1900	20,000	20.1	1.6	0.8
	1900	17,300*	100	—	—
	1400	75,000	100	—	—
	1400	85,000	20.8	0.8	1.6

\*calculated

TABLE III

Alloy	CORROSION DATA			
	Time, Hr.	Oxidation Loss Descaled	Sulfidation Time Hr.	Loss Mils
A	500	11 mg/cm <sup>2</sup>	100	80
B	500	227 mg/cm <sup>2</sup>	100	<30
C	500	13 mg/cm <sup>2</sup>	100	21

quite satisfactory. Thereupon, the extruded piece can be hot worked if desired.

It is most important that the alloys then be treated to develop a germinative grain growth such that a microstructure is produced characterized by coarse elongated grains having a high aspect ratio, e.g., 2:1 to upwards of 100:1 This comprises subjecting the alloys to a heat treatment within the temperature range of approximately 2125° to about 2300°F. If lower temperatures are used such as on the order of 2100°F., the alloys will retain the fine grain of the extruded structure and this is undesirable. On the other hand, should the temperature appreciably exceed 2300°F., then incipient liquation will develop and this is also undesirable. Following this treatment within the temperature range of about 1250° to 2000°F., beneficially from 1450° to 1600°F., for a period of from about 16 to 30 hours.

The following will serve to illustrate various aspects of the invention.

A series of three alloys were prepared, Alloys A, B and C, Table I, by mechanical alloying. The charges, which consisted of both elemental and master alloy powders, were placed in a 4 gallon attritor containing about 162-163 pounds of 5/16 inch diameter through hardened steel balls. The charges were processed for about 16½ hours, the impeller speed of the attritor being maintained at about 288 rpm. During the course

With regard to the above data, it will be observed that Alloy A exhibited a stress rupture life of well over 100 hours at 1900°F. under a stress of 20,000 psi. At 1400°F. it similarly displayed a stress rupture life above

100 hours notwithstanding the exceptionally high stress level of 80,000 psi. Moreover, it underwent only a weight loss of but 11 mg/cm<sup>2</sup>. This is deemed to be outstanding in terms of resistance to oxidation, particularly at the strength levels involved. Resistance to sulfidation, comparably speaking, was not as good as it might otherwise be since the alloy underwent a loss of approximately 80 mils during the period of test. By maintaining the total content of titanium plus tungsten over 7.75, e.g., about 8.25%, sulfidation resistance would be enhanced. This is reflected by Alloy B which showed a remarkably low loss less than 30 mils; however, its susceptibility to oxidation was on the high side, this in part being a reflection of high titanium. In contrast, Alloy C had excellent resistance to both oxidation and sulfidation attack in combination with good stress rupture properties. Over an exceptionally severe sulfidation test period of 300 hours, Alloy C corroded virtually completely with Alloy B still showing a loss of less than 30 mils.

As above-indicated, it is to advantage that the alloys be produced by mechanical alloying. In this connection and at least until recently, mechanical alloying was conducted in the presence of a dynamic atmosphere largely, if not completely, comprised of an oxygen-nitrogen mixture. However, such an environment has been found causative of certain problems in respect of both non-dispersion and dispersion strengthened alloys of the superalloy type. In this connection, and given the benefit of retrospective review, scant attention was given to the role of nitrogen in the composite particles produced, probably because the retained amounts thereof, being on the order of 0.15–0.2% or so, were quite low (in contrast to oxygen) and were likely considered inconsequential. In any case and irrespective of what transpired heretofore, we have found that nitrogen, rather than being passive or innocuous, can exercise a most detracting influence.

The difficulty can be minimized by recourse to utilization of non-nitrogen atmospheres. This notwithstanding, nitrogen can nonetheless be introduced through the raw materials used, preprocessing procedures, the occurrence of leaks during the mechanical alloying process itself, etc. Moreover, and still important, nitrogen can lend to the efficiency of the mechanical alloying process. Thus, its specific contemplated use cannot be overlooked. But the point of concern is that it does

tageously not exceed 0.1% in "mechanically alloyed" superalloys.

However, what we were unaware of (as is demonstrated herein) was that an otherwise small percentage of nitrogen, e.g., 0.15%, could subvert resistance to sulfidation. Furthermore, it now appears that by controlling the nitrogen content lower titanium and tungsten levels can be used for a sulfidation resistant alloy. This, in turn, offers the prospect of improving elevated stress-rupture strength.

The following description and data is given as illustrative of what can be accomplished in accordance herewith in terms of further improved sulfidation resistance.

A series of alloys were prepared (compositions given in Table IV) by mechanical alloying using both elemental and master alloy powders placed in a 4 gallon attritor containing about 162–163 pounds of 5/16 inch diameter through hardened steel balls. The charges were processed for about 16½ hours, the impeller speed of the attritor being maintained at about 288 rpm. During the course of the processing a dynamic atmosphere of air and nitrogen was supplied for three of the alloys, but the nitrogen was largely replaced by argon in each of the other alloys (argon –2%. O<sub>2</sub> being used in two instances and argon plus 0.25% oxalic acid in the other, where the first percentage refers to gas volume and the second to the weight of the powder charge).

The coarsest of the powders (approx. 5%) was removed, the remainder being packed in 3½ inch diameter mild steel cans, sealed, heated to 1950°F. and then extruded using an appropriate lubricant. The alloys were then subjected to a germinative grain growth treatment (secondary recrystallization) generally consisting of heating for one half hour at 2250°F. or 2300°F. which was followed by aging at 1500°F. for approximately 24 hours.

Each of the alloys was then subjected to a crucible sulfidation test involving partially immersing a 300 mil diameter specimen of each alloy in a 90% Na<sub>2</sub>SO<sub>4</sub> - 10% NaCl salt solution, the test being conducted at 1700°F. for a time period as given in Table IV. The alloys were also tested for cyclic oxidation and this involved an exposure to air at 1100°C. for 500 hours, the alloys being cycled to room temperature every 24 hours.

TABLE IV

Alloy	Al	Ti	Ta	Cr	Mo	W	Composition by Weight				Fe	Y <sub>2</sub> O <sub>3</sub>	O <sub>2</sub>	N <sub>2</sub>	Time (Hrs)	Sulfidation	Max Attack (Mils)	Oxidation
							Zr	B	C							Loss (Mils)		loss Descaled (mg/cm <sup>2</sup> )
D	3.7	2.3	2.0	14.0	4.0	4.0	.15	0.1	.074	1.6	1.1	.52	.14	100	>300	>300	10	
E*	3.5	2.3	2.0	14.0	4.0	4.0	.15	.01	.075	2.1	1.1	.76	.071	300	67	79	19	
														300	27	42	38	
C	4.5	2.75	2.5	15.0	3.5	5.5	.13	.015	.069	1.6	1.1	.67	.17	100	21	28	13	
														300	>300	>300		
F*	4.5	2.75	2.5	15.0	3.5	5.5	.13	.015	.069	1.9	1.1	.65	.072	200	40	53	15	
														300	28	38		
G	4.0	3.1	2.0	15.0	3.5	5.5	.15	.01	—	1.8	1.1	.60	.23	100	71	70	34	
														300	>300	>300		
H**	4.0	3.2	2.2	15.5	.4	4.2	.15	.01	.11	.95	1.1	.61	.074	300	3	10	19	
														300	4	20	17	

\*Argon - 2% O<sub>2</sub>

\*\*Argon (.25% oxalic acid added to powder)

not require much nitrogen to impair one or more alloy characteristics, for example, corrosion resistance. In accordance herewith, the nitrogen level should advance

With regard to the above data, Alloys D and E are substantially the same in terms of composition except for nitrogen content, the former having a nitrogen level twice that of the latter. Alloys C and F are also similar

compositionally except the respective percentages of nitrogen. Alloys G and H are also different largely by reason of molybdenum and tungsten contents.

In comparing Alloys D and E, low nitrogen Alloy E survived the severe 300-hour sulfidation exposure whereas Alloy D had already manifested virtually total disintegration upon an exposure of but 100 hours. While it is difficult to think that such a small difference in nitrogen would be causative of such a marked disparity in results, Alloys C and F and even Alloys G and H rather confirm this phenomenon.

It is further noteworthy of mention that Alloy E withstood the 300-hour test notwithstanding that the alloy contained but 2.3% titanium and 4% tungsten. As indicated, above 2.4% titanium and 4.75% tungsten should be present in the alloys for optimum resistance to sulfidation. This is deemed beneficial for as also previously indicated, reduced titanium and tungsten levels would be expected to promote enhanced stress-rupture strength at the more elevated temperatures, such as 1900°F.

With regard to the remarkably low sulfidation loss of Alloy No. H (3 to 4 mils), it is considered that this was due to the low molybdenum content in addition to the reduced percentage of nitrogen, the tungsten being but 4.2%.

The controlled use of low nitrogen levels, i.e., not greater than 0.1% and advantageously less than about 0.075%, is deemed applicable to not only the range of "mechanically alloyed" superalloys described herein, but also to such superalloys as those containing up to 65%, e.g., 2 to 35%, chromium; at least 1% of a hardening constituent from the group consisting of up to about 10 or 15%, e.g., 0.5 to 8%, aluminum; up to about 10 or 15%, e.g., 0.5 to 8%, titanium, and up to 15 or 20%, e.g., 0.5 to 10%, columbium; up to 25%, e.g., 0.5 to 12 or 15%, molybdenum; up to 20 or 25%, e.g., up to 3%, tungsten; up to 20%, e.g., 1 to 10%, tantalum, up to 2 or 3% vanadium; up to 15%, e.g., up to 2 or 3%, manganese; up to 1 or 2%, e.g., up to 0.5 or 1%, carbon; up to 1 or 2%, e.g., up to 0.5%, silicon; up to 2%, e.g., 0.05 to 1%, zirconium; up to 1%, e.g., 0.001 to 0.1%, boron; up to 4%, e.g., 0.5 to 3%, hafnium; up to about 25 volume percent, e.g., 0.05 to 10% by volume, of a refractory dispersoid such as yttria, lanthana, thoria, etc.; and at least one metal from the group consisting of nickel, cobalt and iron, preferably in an amount of at least 25 or 30%.

Since nitrogen can have a positive processing effect, a nitrogen level of at least 0.001%, preferably at least 0.01%, and up to 0.075% is considered beneficial in such superalloy compositions.

The attributes of alloys within the invention are deemed all the more surprising from structural stability considerations. By way of explanation — conventional wrought and cast superalloys are normally prone to sigma phase formation in respect of highly alloyed nickel-chromium base alloy compositions having an electron vacancy number,  $N_v$ , equal to or greater than about 2.26 to 2.41. Sigma, of course, is rather synonymous with short term structural stability. Yet, alloys within the invention when mechanically alloyed have shown virtually no loss in room temperature ductility after being heat treated (aged) for 2000 hours at 1500°F., this obtaining notwithstanding  $N_v$  values ranging from 2.39 to 2.59. For example, Alloy C had an  $N_v$  number of 2.57, well above the 2.26–2.41 range. Metallographic examination did not reveal the presence of

sigma. It is believed that mechanical alloying is largely, if not completely, responsible for this phenomenon.

It might be further added that despite the levels of oxidation and sulfidation resistance attainable in accordance herewith, the artisan may wish, as is not uncommon, to provide the alloys with a corrosion resistant coating of aluminum or an alloy containing aluminum and chromium. Even if this be the case, should the coating be ruptured or otherwise penetrated alloys of the instant invention are markedly capable of retarding further corrosion attack.

Although the invention has been described in connection with preferred embodiments, modifications may be resorted to without departing from the spirit and scope of the invention, as those skilled in the art will readily understand. Such are considered within the purview and scope of the invention and appended claims.

We claim:

1. A mechanically alloyed dispersion strengthenable, precipitation hardenable powder consisting essentially of about 13 to 17% chromium, about 2.5 to 6% aluminum, about 2 to 4.25% titanium, about 1.75 to 4.5% molybdenum, about 3.75 to 6.25% tungsten, about 0.02 to 0.5% zirconium, about 0.001 to 0.025% boron, yttria in a small but effective amount to enhance high temperature strength characteristics, up to 4% tantalum, up to 0.2% carbon and the balance essentially nickel.

2. An alloy in accordance with claim 1 characterized by a microstructure having coarse elongated grains.

3. An alloy in accordance with claim 1 containing 13.25 to 16.25% chromium, 2.75 to 5.25% aluminum, 2 to 4.25% titanium, 1.75 to 4.25% molybdenum, about 3.75 to 6.25% tungsten, about 0.05 to 0.175% zirconium, about 0.001 to 0.022% boron, about 0.5 to 2% yttria, up to 3% tantalum, up to about 0.125% carbon and the balance essentially nickel.

4. An alloy in accordance with claim 1 containing about 13.75 to 16.25% chromium, about 3.5 to 5.25% aluminum and about 2 to 3% titanium, said alloy being characterized by a high degree of oxidation resistance at elevated temperature levels.

5. An alloy in accordance with claim 1 containing about 13.75 to 16.25% chromium, about 2.75 to about 4.6% aluminum and about 4.75 to about 6.25% tungsten, said alloy being characterized by good sulfidation resistance at elevated temperatures.

6. An alloy in accordance with claim 5 in which the sum of titanium plus tungsten is at least 7.75%.

7. An alloy in accordance with claim 6 in which the said sum is at least 8.5%.

8. An alloy in accordance with claim 1 containing about 13.75 to 16.25% chromium, about 3.5 to 5.25% aluminum, about 2.4 to about 3.25% titanium, about 1.75 to 4.25% molybdenum, about 4.75 to 6.25% tungsten, about 0.05 to 0.175% zirconium, about 0.001 to 0.022% boron, about 0.4 to 2% yttria, up to 0.125% carbon and the balance essentially nickel.

9. An alloy in accordance with claim 8 containing 0.5 to 1.5% yttria and up to 3% tantalum.

10. An alloy made up of metallic powders consisting essentially of about 13% to 17% chromium, about 2.5 to 6% aluminum, about 2 to 4.25% titanium, about 1.75 to 4.5% molybdenum, about 3.75 to 6.25% tungsten, about 0.02 to 0.5% zirconium, about 0.001 to 0.025% boron, about 0.2 to 2% yttria, up to 4% tantalum, up to 0.2% carbon, up to 10% cobalt, up to 3%

9

columbium, up to 3% hafnium, up to 0.3% nitrogen, up to about 1% oxygen, up to 3% iron and the balance nickel.

11. A dispersion-strengthened mechanically alloyed superalloy powder consisting essentially of nitrogen present in an amount up to 0.1% and from 13 to 17% chromium, about 2.5 to 6% aluminum, about 2 to 4.25% titanium, about 1.75 to 4.5% molybdenum,

10

about 3.75 to 6.25% tungsten, about 0.02 to 0.5% zirconium, about 0.001 to 0.025% boron, yttria in a small but effective amount to enhance strength characteristics, up to 4% tantalum, up to 0.2% carbon and the balance essentially nickel.

12. An alloy in accordance with claim 11 in which the nitrogen does not exceed about 0.075%.

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