United States Patent

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[54] **CAST NICKEL-BASE ALLOY**
2 Claims, 3 Drawing Figs.

[52] **U.S. Cl.** **148/32.5,** 75/170, 148/162
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[50] **Field of Search** 75/170, 171; 148/32, 32.5, 1.6, 162

[56] **References Cited**
UNITED STATES PATENTS
2,542,962 2/1951 Kinsey 75/170

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ABSTRACT: There is disclosed herein a cast nickel-base alloy having outstanding utility in gas turbine engine applications, particularly as directionally solidified, at a composition consisting essentially of, by weight, 17.5–18.5% molybdenum, 7.75–8.25% aluminum, up to 0.05% carbon, balance nickel.

Ni – Mo – AL
STRESS RUPTURE CAPABILITY AS INFLUENCED BY AL & Mo CONTENT, 1800°F – 15,000 PSI

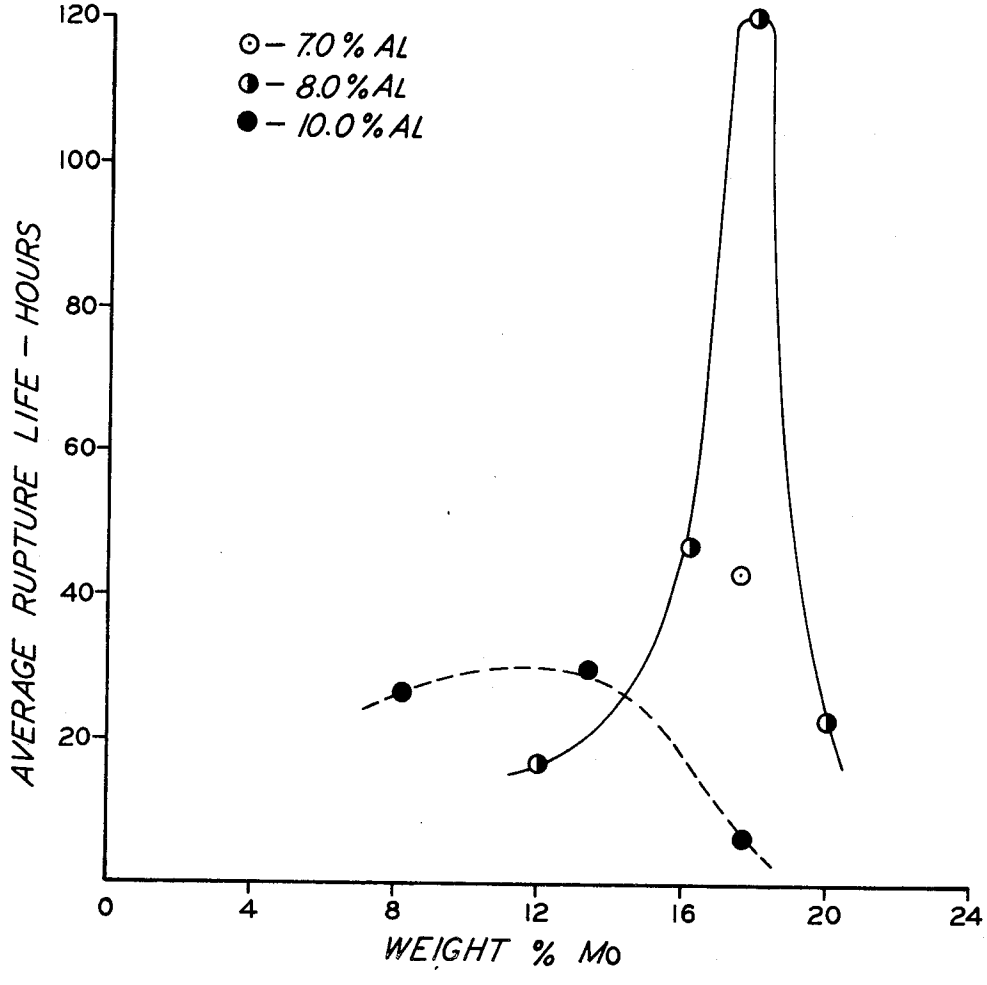
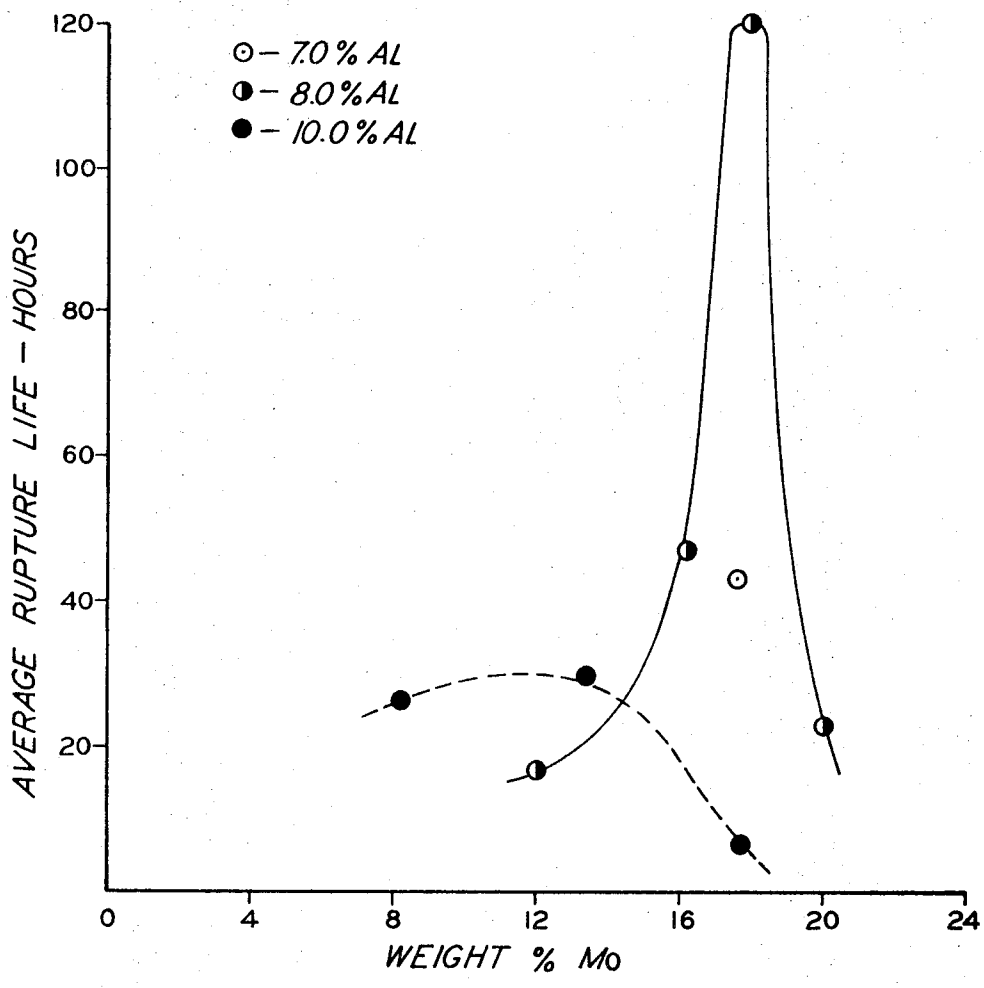


FIG. 1

Ni - Mo - AL

STRESS RUPTURE CAPABILITY AS INFLUENCED BY AL & Mo CONTENT, 1800°F - 15,000 PSI



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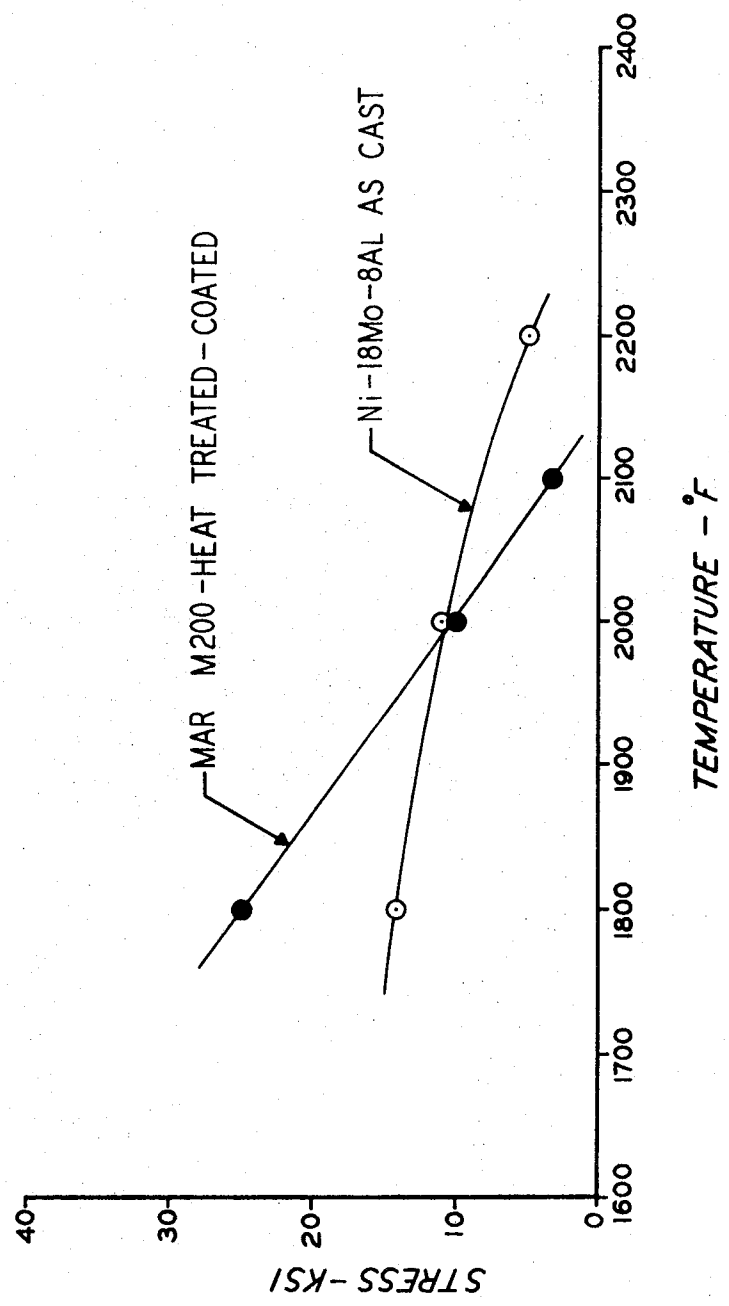
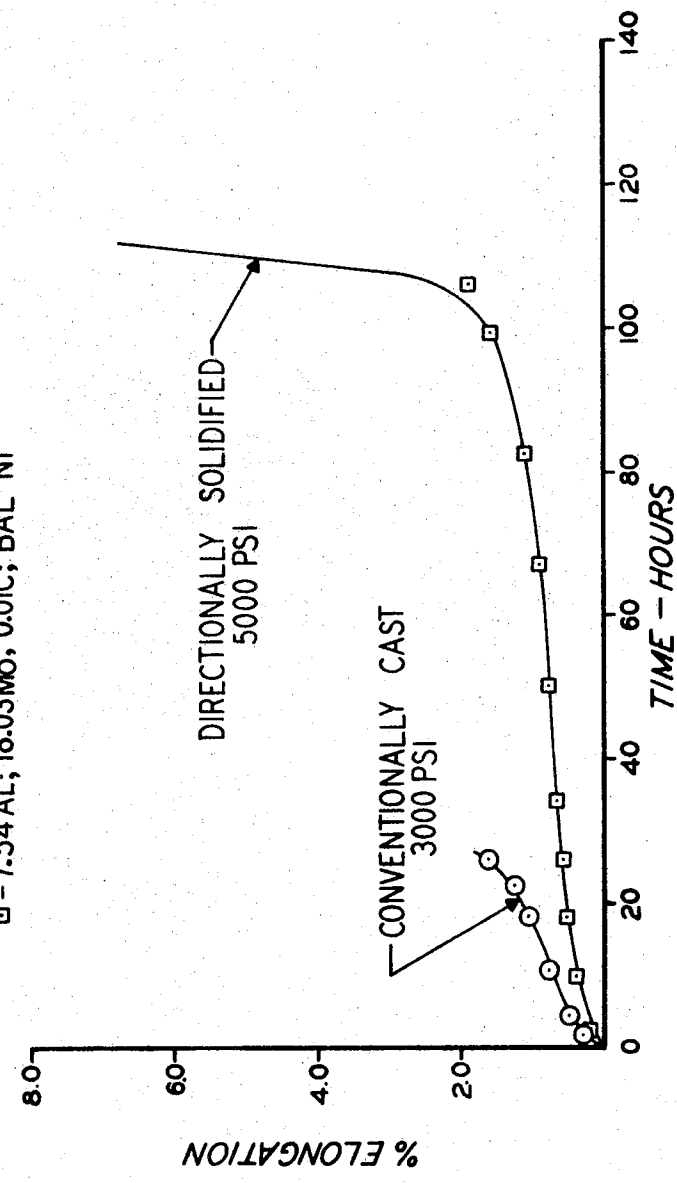

DIRECTIONALLY SOLIDIFIED Ni-Mo-AL & MAR M200
1.0% CREEP IN 100 HOURS
MAR M200-HEAT TREATED-COATED
Ni-18Mo-8AL AS CAST
STRESS-KSI
40
30
20
10
0
1600
1700
1800
1900
2000
2100
2200
2300
2400
TEMPERATURE - °F

FIG. 2

FIG. 3

EFFECT OF DIRECTIONAL SOLIDIFICATION ON THE 2200°F CREEP OF AS CAST Ni-Mo-Al



CAST NICKEL-BASE ALLOY

BACKGROUND OF THE INVENTION

The present invention relates in general to the cast nickel-base alloys, particularly those adapted to high-temperature service in gas turbine temperature applications. It further relates to articles produced from such alloys by directional solidification techniques.

In the design of the more advanced gas turbine engines one of the principal limitations imposed on the designer in terms of providing increased engine performance and efficiency are the high-temperature strength limitations of the available engine alloys. Even in today's operational engines, the various alloys utilized are frequently exposed under high tress to temperatures in excess of 85 percent of their melting points. Accordingly, an urgent need exists for new materials which will not only provide improved high-temperature strength in engine environments, but which will also display such characteristics as oxidation, fatigue and creep resistance.

In the prior art U.S. Pat. to Kinsey No. 2,542,962, there is described a series of alloys within the broad compositional range of, by weight, 10–35 percent molybdenum, tantalum, tungsten and/or columbium, 2.4–12.1 percent aluminum, up to 0.15 percent carbon, balance essentially nickel. It has now been discovered that, within the broad range disclosed by Kinsey, there exists a unique alloy displaying useful properties unexpectedly superior to those of the currently available alloys. As hereinafter discussed in detail, the compositional limits of this new alloy are so critical that any significant variation therefrom results in a totally unsatisfactory material for high-temperature engine use. Indeed, because of the narrowness of the compositional limits involved in this new alloy, it is not surprising that its remarkable properties have not previously been discovered. Despite a similarity in overall chemistry to the prior art alloys, it is only within the narrow compositional limits disclosed herein that the particular advantageous metallurgical structure is achieved as clearly evidenced not only by the startling difference in mechanical properties of this alloy but also by its metallurgical uniqueness as evidenced by metallographic examination.

SUMMARY OF THE INVENTION

The present invention contemplates a cast alloy at the basic composition of, by weight, 17.5–18.5 percent molybdenum, 7.75–8.25 percent aluminum, up to 0.05 percent carbon, balance nickel. In this alloy tantalum may be included on a substitutional basis for the molybdenum in an atomic ratio of up to about 1/1. Similarly, tungsten may be included in this alloy on a substitutional basis for the molybdenum up to about 16 weight percent tungsten based on the total weight of the constituents, although tungsten drastically decreases the fabricability of the alloy and increases its specific weight and, thus, in many instances is not preferred. The total tantalum and tungsten substitutions, if made, should be limited to about 25 weight percent of the total weight. Still further, the alloy is receptive to the addition of reactive metals, such as yttrium, scandium and lanthanum, which are often utilized to foster oxidation-erosion resistance, in weight percentages up to about 1 percent.

In a particular preferred embodiment of the invention as conventionally cast yielding either a substantially equiaxed grain structure, or castings in columnar-grain or monocrystal form the composition comprises, by weight, 17.5–18.5 percent molybdenum, 7.75–8.25 percent aluminum, 0.03–0.05 percent carbon, up to 0.20 percent manganese, up to 0.20 percent silicon, up to 0.015 percent sulfur, up to 0.35 percent iron, up to 0.10 percent copper, balance essentially nickel.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a graph illustrating the stress-rupture capability of the cast alloys of the nickel-molybdenum-aluminum system, at 1,800° F. and 15,000 p.s.i., as a function of their molybdenum and aluminum content and relationship.

FIG. 2 is a graph comparing the alloy of the present invention with the conventional MAR M200 alloy, as directionally solidified, in creep at various temperatures.

FIG. 3 dramatically illustrates the effect of directional solidification on the 2,200° F. creep of the nickel-molybdenum-aluminum alloys.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

As hereinafter used in the description, the alloys of the present invention are often referred to as the Ni-18Mo-8Al alloys.

At a nominal composition of 18 weight percent molybdenum, 8 weight percent aluminum, balance essentially nickel, and within the ranges of 17.5–18.5 percent molybdenum, 7.75–8.25 percent aluminum, up to 0.05 percent carbon, balance essentially nickel, the alloys of this invention comprise a dispersion of the strengthening γ' nickel aluminide precipitate, Ni_3Al, at about 85 volume percent, in a solid solution of nickel and molybdenum.

The extreme criticality and interrelation of the molybdenum and aluminum components of this alloy are dramatically illustrated in FIG. 1, and still further in the following table.

TABLE I

Rupture Life

Composition (wt. percent)			1,800° F./15K s.i.	2,000° F./13K s.i.	2,200° F./6.5K s.i.
Mo	Al	C			
18	6.25	<.02	968+	120	<1.0
18	7.5	<.02	300	15	15.0
18	8.13	<.02	394.7	45.7	33.7
18	9.0	<.02	----------	3.6	7.4

As clearly evidenced by the data, the strength of the present alloy is profoundly influenced by the amount of molybdenum and aluminum present in the alloy particularly in combination. At low aluminum levels, the high-temperature capabilities of the alloy are adversely affected with dramatic suddenness so that at 2,200° F. the alloy is completely lacking in any useable strength. This is unusual in the sense that a relative minor reduction of the low melting component drastically influences its high-temperature strength. Actual analysis of the phenomenon reveals that, at the lower aluminum levels the γ' precipitate is solutioned at lower temperatures.

At the higher aluminum contents, 9 percent by weight for example, the strength of the alloy is suddenly and markedly reduced, as compared to the alloy of the present invention, at all temperatures. The extent of the sudden strength decrease associated with such a small increase in aluminum content is believed to be a direct function of the conversion of at least a portion of the high strength γ' aluminide, Ni_3Al to the lower strength β aluminide, NiAl.

With respect to the molybdenum content of the alloy it is evident, particularly after reference to FIG. 1, that extreme criticality exists in terms of composition and particularly insofar as the molybdenum/aluminum relationship is concerned. At molybdenum contents lower than those associated with the present invention, there is insufficient molybdenum present for adequate solid solutioning strengthening. At the higher molybdenum contents the alloy is susceptible to the formation of brittle intermetallics which prove fatal to the alloy insofar as gas turbine engine applications are concerned.

Carbon, or the absence of carbon, in the present alloy also assumes a rather critical role, particularly in columnar-grain or monocrystal form. In those components formed by conventional casting techniques to provide substantially equiaxed microstructures, carbon in the range of about 0.03–0.05 weight percent is advantageously included to provide creep and tensile ductility. In the directionally solidified components, however, the carbon content is necessarily limited to minimize the occurrence of the M_6C-type carbides. These carbides, which assume considerable size in directional solidification casting because of the relatively slow solidification rates

normally associated therewith, have been formed to be subject to precracking during solidification or to initiate failure sites for cracking during use. Inasmuch as in the columnar-grain or monocrystal form of the alloy, grain boundaries are either aligned in the direction of applied stress or are virtually nonexistent, the presence of carbon for creep and tensile ductility is not required. In one series of tests, involving 24 directionally solidified bars in two heats, F—3367 and F—3368,the following observations were made. The actual chemical analyses of these heats as determined by the supplier were as follows:

Heat	Al(wt.%)	Mo(wt.%)	C(wt.%)	Ni
f-3367	7.57	17.7	0.01	Bal.
F-3368	6.42	18.0	0.006	Bal.

The difference in chemistry between the two heats, although slight, resulted in a difference in microstructure. Both alloy compositions contained a nickel eutectic-type phase in a region of γ' precipitate (Ni_3Al) plus a γ solid solution (Ni, Mo, Al), the eutectic-type phase being identified by electron microprobe analysis as having a composition of about, by weight, 39 percent molybdenum, 4 percent aluminum, balance nickel. However, metallurgically speaking, there was a noticeable difference between the two heats as evidenced by the almost complete absence of the eutectic-type phase in the F—3368 (low aluminum) alloy.

It is, of course, evident from the data that the properties of these alloys are drastically influenced by the alloy composition and within very precise compositional limits. This is the direct result of the fact that, despite somewhat closely, related chemical compositions, the solidified articles at the various compositions are in fact distinctive entities metallurgically.

A number of alloy melts were made in a variety of compositions, the representative results of which are summarized below.

TABLE II

Alloy Chemistry

Element (wt. percent)	Alloy A		Alloy B		Alloy C		Alloy D	
	Aim	Actual	Aim	Actual	Aim	Actual	Aim	Actual
Al	12	11.1	10	9.3	8	7.9	8	7.7
Mo	18	18.5	18	18.0	18	18.0	12	12.0
Ni	Balance							

TABLE III

As Cast Mechanical Properties of Four Ni-Mo-Al Compositions

Alloy	R_c as cast hardness	As cast tensile properties: Test temp., °F.	0.2% YS, K s.i.	UTS, K s.i.	Percent elon.	As cast stress rupture properties: Test temp., °F.	Stress, K s.i.	Hours to rupt.	Percent elon.
Ni-12Al-18Mo	36.0	70	85.0	115.0	2.0	1,800	15.0	.8	9.7
		70	87.7	116.0	2.0				
		1,000	112.9	127.6	2.0				
		1,400	86.5	109.0		2,000	6.0		
		1,800		57.2	3.0				
		2,000	26.3	28.1	5.5				
		2,000		23.1	5.0	2,200	3.0	1.7	24.0
Ni-10Al-18Mo	32.2	70	75.3	124.4	4.0	1,800	15.0	6.3	4.8
		70	77.2	122.2	3.5				
		1,000	98.2	134.5	3.5	2,000	6.0	10.3	15.4
		1,400	94.4	116.8	2.5				
		1,800	59.5	66.4	3.0	2,200	3.0	12.0	6.1
		2,000	33.7	41.7	7.5				
		2,000	30.8	41.6	7.0				
Ni-8Al-18Mo	37.8	70	102.0	163.6	3.5	1,400	85.0	10.3	2.4
		70	102.6	140.2	8.0				
		1,000	121.0	163.0	8.5	1,800	15.0	118.2	4.6
		1,400	111.0	143.9	3.5	1,800	15.0	92.5	4.3
		1,800	73.0	84.7	4.5				
		2,000	49.0	68.3	5.0	2,000	8.0	38.3	4.4
		2,000	56.9	64.3	5.5	2,000	8.0	37.4	1.7
		2,200	16.8	25.4	15.0	2,200	3.0	16.1	5.7
Ni-8Al-12Mo	27.2	70	79.6	143.0	17.5	1,800	15.0	16.8	.76
		70	79.6	136.0	15.5				
		1,000	99.3	111.8	5.5	2,000	8.0	7.2	2.6
		1,400	105.5	108.8	1.0				
		1,800		63.8		2,200	3.0	10.8	3.6
		2,000	43.1	49.5	1.0				

TABLE IV

RT R_c Hardness after Heat Treatment for Alloys A, B, C, and D

Alloy	As cast	Condition: 2,150° F. (8) OQ	2,100° F. (1) OQ
Ni-12Al-18Mo	36.0	35.0	36.1
Ni-10Al-18Mo	32.2	29.5	36.1
Ni-8Al-18Mo	37.8	37.0	39.0
Ni-8Al-12Mo	27.2	28.6	34.0

TABLE V

Effect of Heat Treatment on Ni-18Mo-8Al

Condition	Tensile properties: Temp., °F.	0.2% YS, K s.i.	UTS, K s.i.	Percent elon.
As cast	1,800	73.0	84.7	4.5
2,250° F. (4) OQ	1,800	91.6	102.5	4.0
77° F./hr. cool from 2,300° F	1,800	66.2	73.1	5.5
	Stress rupture properties: Test temp., °F.	Stress, K s.i.	Hours to rupture	Percent elon.
As cast	2,000	8.0	28.3	4.4
Do	2,000	8.0	37.4	1.7
2300° F. (1) OQ	2,000	8.0	32.4	5.1
Do	2,000	8.0	31.5	2.8
77° F./hr. cool from 2,300° F	2,000	8.0	27.5	7.8

TABLE VI

As Cast Impact Data for Ni-18Mo-8Al

Test temp.	Charpy smooth impact strength, ft. lbs.	Charpy notched impact strength, ft. lbs.
70	50.0	9.0
70	53.5	
1,800	80.0	9.0

Alloy C exhibited the best overall properties with useful tensile and stress-rupture strengths to 2,200° F. Alloys A, B and D were not considered satisfactory due either to low rupture strength and/or ductility. Alloy C further showed a major response to homogenization heat treatment at 2,250°–2,300° F. in that elevated temperature tensile strength was significantly improved over the as-case properties. The stress-rupture properties on the other hand did not appear to be influenced by a high homogenization heat treatment. Alloy C further showed excellent potential for hardfacing applications since its hardness after a drastic cooling was observed to be significantly higher than its as-cast hardness. In summary, the results indicate that the Ni-18Mo-8Al alloy is unique, has outstanding tensile strength in the 1,400°–2,200° F. range; and useful stress-rupture strength in the 2,000°–2,200° F. range.

Testing of the alloy in the as-cast or equiaxed condition revealed that both rupture strength and ductility were controlled primarily by the ability of the grain boundaries to resist fissuring and sliding. In the Ni-18Mo-8Al alloy only a fraction of the creep damage incurred during testing could be attributed to plastic deformation within the grain itself. Accordingly, although the alloy has superior properties in the equiaxed condition, the true strength of the alloy could not be approached until all grain boundaries not parallel to the stress axis. This was accomplished by directional solidification of the alloy to produce a columnar grain structure in which the existing grain boundaries were aligned with the axis of applied stress. In directional solidification testing performed with stock from the F—3367 and F—3368 heats previously mentioned, the effect of directional solidification of the 2,200° F. creep of these alloys was observed, as set forth graphically in FIG. 3.

Additionally, 12 test bars were directionally solidified at the following chemistry in two separate heats:

Element	Percent by Weight
Al	8.0
Mo	18.26
C	.01
S	.003
Si	.05
Mg	.05
Fe	.05
Co	.05
Ni	Bal.

This material, tested uncoated in air, displayed the tensile and creep rupture properties reported in tables VII and VIII.

TABLE VII

Tensile Test Results

Temp., ° F	0.2 4S (p.s.i.)	UTS (p.s.i.)	Elong. (percent)	RA (percent)
RT	145,200	158,800	5.0	3.6
1,000	155,800	161,000	4.5	7.4
1,400	186,600	187,000	1.5	0.8
1,800	86,600	87,700	3.0	2.9
2,000	50,300	56,400	3.0	1.6
2,200	23,200	33,200	13.0	32.7

TABLE VIII

Creep Rupture

Condition	Temp. (° F.)	Stress (p.s.i.)	Hours to— 1%	Hours to— Rupture	Final elongation
H.T	1,400	85,000	----------	52.3	1.9
H.T	1,800	15,000	110	394.7	14.5
H.T	1,800	20,000	41	105.4	10.5
H.T	1,800	25,000	5	21.8	11.4
H.T	1,900	22,500	3	9.0	15.6
H.T	2,000	9,000	84	191.8	10.0
A.C	2,000	13,000	5	35.5	36.2
H.T	2,000	13,000	27	49.3	12.6
H.T	2,100	8,000	35	186.5	8.1
H.T	2,100	10,000	43	107.5	8.5
H.T	2,200	5,000	55	109.5	11.9
H.T	2,200	6,500	12	33.7	16.4

NOTE: H.T.=Heat treatment (argon) 2,300° F./2 Hr., air cool rate.

A comparative summary of various materials in several metallurgical forms is reported in the following table.

TABLE IX

Alloy	Rupture Life, Hours 2,000° F./13,000 p.s.i.	2,200° F./5,000 p.s.i.
Ni-18Mo-8Al (columnar grain I)	48	230
Ni-18Mo-8Al (equiaxed)	2.0	1.0
MAR M200 (columnar grain)	20	<0.1
IN 100	10	0
WI 52	<0.5	<0.1
MAR M302	1.0	<0.1

In a supplemental program, the Ni-18Mo-8Al was tested in a coated condition to determine if either the conditions under which the coating was applied or a subsequent diffusion of coating elements would have any deleterious effect on the alloy substrate. Coated specimens (chromium modified aluminide) tested at 1,800° F and 2,000 ° F. revealed no detrimental effects from the coating utilized and, in fact, exhibited improved lifetimes.

In view of the foregoing and within the specific compositional limits set forth, the alloy of the present invention may be seen to possess a uniqueness which renders it particularly suitable for high temperature applications in the advanced gas turbine engines. Its obvious superiority over the currently utilized alloys immediately suggests such use. However, it will be understood that its utility is not so limited, and its use in other applications such as hardfacing, or high-temperature mold or die construction is suggested.

What is claimed is:

1. A nickel-base alloy directionally solidified casting of the columnar-grain or monocrystal type for use at temperatures up to 2,200° F which consists essentially of, by weight, 17.5–18.5 percent molybdenum; 7.75–8.25 percent aluminum; up to 0.05 percent carbon; up to 1 percent yttrium, scandium or lanthanum or mixtures thereof; up to 25 weight percent tantalum plus tungsten on a substitutional basis for molybdenum, the tungsten content not exceeding about 16 weight percent based on the total weight of the alloy, the tantalum content not exceeding 50 atomic percent based on the molybdenum content of the alloy, balance nickel.

2. A nickel-base alloy directionally solidified casting of the columnar-grain or monocrystal type which consists essentially of, by weight, 17.5–18.5 percent molybdenum, 7.75–8.25 percent aluminum, up to 0.05 percent carbon, balance nickel.