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## TANTALUM-CONTAINING PRECIPITATION-STRENGTHENED NICKEL-BASE ALLOY

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5 Claims

### ABSTRACT OF THE DISCLOSURE

Tantalum-bearing precipitation-strengthened hot-workable nickel-base alloys also containing chromium and molybdenum and having an intermetallic phase of stoichiometry  $A_3M$  wherein M consists essentially of Ta and wherein A consists essentially of nickel.

### BACKGROUND OF THE INVENTION

This invention relates to precipitation-strengthened, hot-workable nickel-base alloys and more particularly to precipitation-strengthened tantalum-bearing nickel-base alloys.

Precipitation strengthened hot-workable nickel-base alloys, which are sometimes referred to in the art as age hardenable alloys, are primarily used in high temperature applications, i.e. 1000° F. to 1600° F. such as in wrought alloy components for jet engine parts. The alloys are usually provided as forged components, bars, sheet material, seamless tubing or in other wrought forms obtained by the usual metal working processes, e.g. hot or cold working, extruding, drawing and the like.

Most precipitation strengthened hot-workable nickel-base alloys suggested by the prior art are based upon the formation of the well known aluminum-titanium rich gamma prime phase. This strengthening mechanism requires the presence of aluminum and titanium in an amount ranging from as little as 0.4% total to as much as 8.0% total.

While the prior art has considered the use of tantalum-bearing nickel-base alloys to a very limited extent, these references have never suggested that tantalum be used alone as the strengthening element. Moreover, whenever Ta has been suggested for use as a part of a group of strengthening elements, the Ta content has been restricted to about 4% maximum, apparently in order to avoid losses in ductility at elevated temperatures. The prior art has required, in addition, that whenever Ta participates as a member of a group of precipitation strengthening elements, that it be used in conjunction with Al and Ti as abovementioned in order to achieve the gamma prime phase as stated earlier.

While most of the prior art alloys are admirably suited for use at 1400–1600° F., they are not entirely satisfactory for use in the 1000–1200° F. range because of the absence of adequate strength and ductility. Moreover, the necessity of using Al+Ti as part of the precipitation strengthening means, requires that either vacuum or inert gas melting processes be used in order to avoid the formation of oxide inclusions. While vacuum and inert-gas processes may be employed in the production of the alloys of the present invention they of course greatly increase the production cost when compared with air-melting which can be readily used with satisfactory results.

It is an object of the present invention to provide precipitation strengthened alloy compositions which are particularly well suited for use in the range of 1000–1200° F°.

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Another object is to provide alloy compositions which does not require the presence of Al and Ti as part of the strengthening means.

Yet another object is to provide tantalum-bearing precipitation-strengthened alloy compositions which can be air melted without forming appreciable oxide inclusions.

These and still further objects will become apparent for those skilled in the art after consideration of the remaining disclosure and appended claims.

10 The present invention is based upon the discovery that a phase designated herein as  $A_3M$  wherein A consists essentially of nickel and M consists essentially of tantalum can be precipitated to strengthen a hot-workable nickel-base alloy. It has also been found that this phase may be  
15 precipitated without the presence of aluminum and titanium in the alloy composition. It should be understood that this precipitation phase is distinct from the above mentioned gamma prime phase achieved through the use of aluminum and titanium in combination. It is known  
20 that the gamma prime phase has a crystal structure of the ordered face centered cubic (FCC) type. In marked contrast to this, the  $A_3M$  phase produced within the alloys of the present invention is non-cubic in crystal structure. Although the precise crystal structure of the precipitation-strengthening phase in the alloys of the invention has not  
25 been conclusively established, the best crystallographic evidence suggests that it is a tetragonal structure wherein the axes of the unit cell of the crystal structure are of unequal length and thus the crystal structure is clearly  
30 not of the cubic type.

The alloy composition of the invention consists essentially by weight of 15–22% Cr, 3–12% Mo, 5–10% Ta, the balance being nickel and residual impurities normally found in nickel-base alloys. It is important according to  
35 the invention that the residual impurities have not more than 20% Fe, not more than 10% Co and not more than 0.15% C. This alloy will consist essentially of a solid-solution matrix having dispersed therein an intermetallic phase of the abovementioned  $A_3M$  stoichiometry.

40 Chromium is required in the alloy within the ranges as disclosed herein to provide strengthening and corrosion resistance. Less than 15% Cr yields an alloy with minimal corrosion resistance, over 22% Cr yields an alloy with reduced ductility.

45 Molybdenum is present in the alloy, within the ranges disclosed herein to provide further solution strengthening and corrosion resistance as required in alloys of this class. Molybdenum is preferred in the alloy, although tungsten may replace molybdenum in whole or in part. Tungsten  
50 may be substituted for molybdenum in a ratio of about 2:1 up to a maximum of 16%, but preferably about 12% nominally. For optimum mechanical properties, the alloy should contain an effective amount of molybdenum and tungsten; not less than about 3% molybdenum or the  
55 equivalent. Contents over 16% tungsten or 12% molybdenum result in alloys which may contain undesirable embrittling phases. Tantalum must be present in the alloy in an amount of at least 5% to promote adequate precipitation of the abovementioned  $A_3M$  phase; greater than  
60 10% tantalum tends to limit the usual characteristics of hot-workability of the alloy. Columbium, which is often found associated with the tantalum, may be present in the alloy up to a limit of 25% by weight of the tantalum content. If desired, vanadium may be substituted for part  
65 of the tantalum up to a maximum of 50% by weight of the tantalum content.

As aforementioned, the use of aluminum and titanium in the alloy compositions of the invention is not required. It is desirable that the aluminum plus titanium content

should be as low as possible, and preferably less than 1.4%. If the aluminum plus titanium level is low, it will be possible to produce a good quality alloy with an air melting practice.

Boron, silicon, maganese, magnesium and copper up to a total of about 2.5% may be present in the alloy with in the ranges known in the art to be effective to enhance certain characteristics associated with these elements, i.e. the deoxidation step, casting fluidity, ductility and the like.

The balance of the alloy is nickel and adventitious impurities generally known to be present in this class of alloys.

The invention will now be further illustrated in connection with the following examples:

#### Example I

A five-pound heat of the following composition was electron-beam melted and cast. The resulting ingot was cold worked following homogenization at about 2200° F. and thereafter solution heat treated at 2150° F. Thereafter the material was cold worked with intermediate annealing treatments and reduced to 0.004" thick strip. This strip was solution heat treated at 2150° F., quenched and thereafter aged at temperatures between 1600° F. and 1100° F. to precipitate the A<sub>3</sub>M phase as described hereinbefore. Extensive transmission electron microscopy and the diffraction studies were performed on the aged material. These studies showed the existence of the above-mentioned A<sub>3</sub>M phase in a homogenously nucleated, uniformly dispersed, coherent intragranular morphology in all conditions investigated.

#### EXAMPLE I COMPOSITION

Cr	20.34
Mo	8.90
Ta	8.58
Fe	4.80
C	0.11
Ni	Balance

#### Example II

A 50 lb. heat of the following composition was vacuum induction melted and cast. After homogenization at a temperature of about 2200° F. over a period of 24 hours the ingot was forged to a one inch square bar:

#### EXAMPLE II COMPOSITION

Chromium	20.47
Molybdenum	5.41
Tantalum	9.82
Columbium	--
Iron	5.59
Cobalt	5.02
Carbon	0.089
Nickel	Balance

The as forged material was machined into standard ASTM 1" gauge length test bars for both tensile and stress-rupture tests. These bars were then heat treated in argon in accordance with the following schedules:

Heat treatment condition A: As forged plus one hour at 1750° F., water quenched, then aged for 3.6 hours at 1430° F., then furnace cooled at 1206° F. and aged for 86 hours at 1206° F.

Heat treatment condition B: As forged plus one hour at 2282° F., water quenched, then aged for 86 hours at 1225° F.

Heat treatment condition C: As forged plus 20 minutes at 2282° F., water quenched, then aged for 24 hours at 1250° F.

Table I sets forth the tensile properties of the Example II material after being heat treated according to the above defined conditions:

TABLE I

Heat treatment condition	Test temp.	Yield strength, p.s.i.	Ultimate tensile strength, p.s.i.	El. percent	R.A., percent
A	Room temp.	167,000	197,500	15.00	25.00
A	1,200° F.	143,000	163,500	12.00	20.00
B	Room temp.	90,000	136,500	62.00	46.00
B	1,200° F.	63,500	94,200	48.00	50.50
C	Room temp.	81,000	133,500	73.00	66.00
C	1,200° F.	51,300	89,900	56.00	43.50

The tensile data shown in Table I clearly indicates excellent mechanical strength in fully heat treated condition A. Excellent ductility characteristics are also demonstrated as shown in this table. Typical stress rupture life at 1200° F. and at a loading stress of 110,000 p.s.i. was about 98 hours for the alloy of Example II after being heat treated under condition A as described above. In addition to the mechanical tests performed as above stated, a portion of the as forged material was reduced by cold work to 0.004 inch thick sheet. Specimens from this sheet were heat treated under various conditions, including those designated above as A, B and C. In all cases, thin foil electron microscopy and diffraction tests showed the formation of the desired A<sub>3</sub>M phase as described in connection with Example I.

While the alloys of the invention have been described in connection with certain heat treatment conditions, it should be understood that these conditions are only intended as illustrative of typical conditions under which the alloys can be made. In addition, various changes can be made to the alloys of the invention without departing from the spirit and scope thereof.

What is claimed is:

1. A wrought, precipitation-strengthened nickel-base alloy which is substantially free of face-centered cubic structured precipitation such as the conventional gamma prime phase but which possesses an unusual combination of mechanical strength and ductility, especially in the temperature range of about 1000 through about 1200° F. consisting essentially of weight of

	Percent
Chromium	15-22
Molybdenum	3-12
Tantalum	5-10

- with the balance being essentially nickel and residual elements normally found in nickel-base alloys and provided that the iron content must be less than 20%, the cobalt content must be less than 10%, and the carbon content must be less than 0.15% and there is present in the alloy structure an effective strengthening intermetallic precipitate of a coherent, noncubic structure having the general stoichiometry, A<sub>3</sub>M, where M is predominantly tantalum and A is predominantly nickel.

2. An alloy as defined in claim 1 wherein any aluminum and titanium content is well below the interfering precipitation level.

3. An alloy as defined in claim 1 wherein tungsten is substituted on a two-for-one weight basis for part of said molybdenum.

4. An alloy as defined in claim 1 wherein vanadium is substituted on an equal-weight basis for up to half of said tantalum content.

5. An alloy as defined in claim 1 wherein columbium is substituted on an equal weight basis for up to one-fourth of said tantalum content.

#### References Cited

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