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HIGH STRENGTH NIOBIUM BASE ALLOYS

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This invention relates to niobium-base alloys, and par-
ticularly to niobium-base alloys containing titanium, zir-
conium, hafnium, and oxygen.

The trend toward higher operating temperatures in
jet engines, missiles, gas turbines, and other heat engines
has accelerated interest in the development of high tem-
perature structural materials. At present, the primary

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0.02% to 0.2% oxygen, preferably present as zirconia and
hafnia, and the balance being essentially niobium with
small amounts of incidental impurities. A particularly
useful range of alloys of this invention, falling within
the broad range just defined, comprises, by weight, from
0.6% to 2% titanium, from 0.6% to 2.5% zirconium,
from .6% to 6% hafnium, from 0.04% to 0.2% oxygen,
preferably present as zirconia and hafnia, and the bal-
ance essentially niobium with small amounts of incident-
tal impurities.

Several of the alloys of this invention were prepared
by standard non-consumable arc melting techniques in
which a protective atmosphere of argon was employed.
The nominal compositions (with oxygen analysis) of the
alloys prepared, together with certain of their proper-
ties, are presented in Table I which follows:

TABLE I
Properties of Niobium-Base Alloys

Alloy	Composition, Wt. Percent	Test Temp., ° F.	0.2% Yield Str. (p.s.i.)	Ultimate Str. (p.s.i.)	Percent Elonga- tion	Reduc- tion in area (percent)
A-----	Nb-1Ti-1Zr-5Hf (0.149 O ₂).	RT	53,750	76,800	26.4	41.5
	Nb-1Ti-1Zr-5Hf (0.149 O ₂).	2,000	46,500	49,300	25.2	59
B-----	Nb-3Ti-2Zr-2Hf (0.061 O ₂).	RT	64,600	79,500	30.2	57.7
	Nb-3Ti-2Zr-2Hf (0.061 O ₂).	2,000	41,700	41,800	25.2	13
C-----	Nb-1Ti-1Zr-1Hf (0.056 O ₂).	2,000	43,200	44,280	9.9	48.5

obstacle to improved performance in many power gen-
eration and propulsion systems is the unavailability of
materials with sufficient high temperature strength. There
is also a need for improved high temperature alloys in
the construction of chemical reactors, oil refining equip-
ment, and the like. The combination of workability at
reasonable temperatures and strength at elevated tem-
peratures has proved most difficult to achieve and much
effort has been devoted to attaining this end.

At the present time, molybdenum-base alloys are the
only materials commercially available with strength prop-
erties comparable to the niobium-base alloys described
in this application. However, these molybdenum-base
alloys have much poorer oxidation resistance than pure
niobium, they have approximately 25% higher density,
and they are quite difficult to fabricate. Maximum
strength is achieved in the molybdenum-base alloys by
carefully controlling working procedures in order to ob-
tain a strain hardened material. However, if the alloy
is heated to a temperature at which recrystallization
occurs, as in welding, the strength will be drastically re-
duced by a factor of as much as 50%. The ductile-
brittle transition temperature of molybdenum and com-
mercially available molybdenum-base alloys is close to
room temperature, and therefore, cold working is not
practicable.

It is therefore the object of this invention to provide
niobium-base alloys having good ductility at room tem-
perature and high elevated temperature strength, the alloys
including in predetermined amounts, the elements tita-
nium, zirconium, oxygen and hafnium.

Other objects of the invention will, in part, be obvious
and will, in part, appear hereinafter.

Accordingly, this invention is directed to niobium-base
alloys suitable for use in the temperature range 1800°
F. to 2400° F., and having reasonable ductility at room
temperature. More particularly, the alloys of this inven-
tion comprise, by weight, from 0.5% to 10% titanium,
0.5% to 10% zirconium, 0.5% to 10% hafnium, from

The niobium-base alloys listed in Table I do not rely
on strain hardening to achieve high strength. They are
quite ductile at and below room temperature which
makes severe cold forming operations relatively simple.
Hot working may be accomplished by conventional
methods such as extrusion, rolling, forging and swaging.

By way of contrast, certain of the properties of pure
niobium are set forth in the following Table II.

TABLE II
Properties of Pure Niobium

Composition, Wt. percent	Test Temp., ° F.	0.2% Yield Str. (p.s.i.)	Ultimate Str. (p.s.i.)	Per- cent Elonga- tion	Reduc- tion in area (percent)
Pure Nb-----	RT	36,000	48,410	48.0	63.5
Pure Nb-----	2,000	8,100	10,100	34.0	100

The remarkable improvement in properties achieved
at elevated temperatures by the specified alloying addi-
tions to pure niobium, in accordance with this invention,
is readily apparent.

It should be noted that the alloys of this invention in-
clude from .02% to 0.2% oxygen, and that this is an
essential constituent of these alloys. While the function
of the oxygen in these alloys is not fully understood, it is
believed that predetermined amounts of ZrO₂ and HfO₂
and other oxides in finely dispersed condition are formed,
and these oxides tend to confer additional strength upon
the alloy.

In investigating the effect of oxygen in these alloys an
alloy similar to alloy A of Table I was prepared except
that the oxygen content was held to less than 0.04%,
but more than 0.02%, by weight; that is, at the low end
of the broad oxygen range. The nominal composition
of this alloy and certain physical properties are presented
in Table III.

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TABLE III

Composition, Wt. percent	Test Temp., ° F.	0.2% Yield Str. (p.s.i.)	Ultimate Str. (p.s.i.)	Per- cent Elong- ation	Reduc- tion in area (percent)
Nb-1Ti-1Zr-5Hf----	2,000	25,600	30,300	20.3	-----

Comparison of these data with the similar data for alloy A shows that the low-oxygen alloy is characterized by somewhat degraded properties. With lower amounts of oxygen, that is below 0.02%, the properties of the alloy will be lowered even more.

The titanium in these alloys is considered to provide improved oxidation resistance and workability within the ranges set forth. Another preferred range for titanium providing similarly improved properties is from 2.5% to 3.5%. The zirconium and hafnium in the alloys tends to increase or improve their high temperature strength. For some purposes zirconium may be added in the range from 1.5% to 2.5%. Hafnium may be also added in amounts from 1.5% to 2.5% and from 2% to 8%. The niobium employed in the alloys of this invention will have a normal level of impurity content; that is, a total amount of about 1% or less.

The alloys of this invention are superior to the molybdenum-base alloys now commercially available in that they possess greater oxidation resistance at service temperature, they are relatively ductile and workable at room temperature, they have a favorable strength to weight ratio, and their strength is not dependent upon strain hardening.

It will be understood by those skilled in the art that although the present invention has been described in connection with preferred alloys, modifications and varia-

tions may be employed without departing from the underlying spirit and scope of the invention.

We claim as our invention:

1. A high temperature alloy consisting of from 0.5% to 10% titanium, from 0.5% to 10% zirconium, from 0.5% to 10% hafnium, from 0.02% to 0.2% oxygen, and the balance essentially niobium with small amounts of incidental impurities.

2. A high temperature alloy consisting of from 0.6% to 2% titanium, from 0.6% to 2.5% zirconium, from 0.6% to 6% hafnium, from 0.04% to 0.2% oxygen, and the balance essentially niobium with small amounts of incidental impurities.

3. A high temperature alloy consisting of from 0.6% to 2% titanium, from 0.6% to 2.5% zirconium, from 2% to 8% hafnium, from 0.04% to 0.2% oxygen, and the balance essentially niobium with small amounts of incidental impurities.

4. A high temperature alloy consisting of from 2.5% to 3.5% titanium, from 1.5% to 2.5% zirconium, from 1.5% to 2.5% hafnium, from 0.04% to 0.2% oxygen, and the balance essentially niobium with small amounts of impurities.

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