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HIGH STRENGTH NIOBIUM-BASE ALLOYS

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This invention is directed to high strength niobium-base alloys particularly intended for service at elevated temperatures.

The trend toward high operating temperatures in jet engines, missiles, gas turbines, and other heat engines has accelerated interest in the development of high temperature structural materials. At present, the primary obstacle to improved performance in many power generation and propulsion systems is the unavailability of materials with sufficient high temperature strength. There is also a continuing need for high temperature alloys for the construction of chemical reactors, oil refining equipment and the like. Much effort has been expended in this field to obtain a material having a combination of high temperature strength and corrosion resistance, and adequate ductility at room temperatures so that they are reasonably workable and usable at room temperature.

At the present time, molybdenum-base alloys are the only materials commercially available with strength properties comparable to the niobium-base alloys described in this application. However, these molybdenum-base alloys have much poorer oxidation resistance than pure nobium, have approximately 25% higher density, and are quite difficult to fabricate.

In accordance with the present invention the niobium-base alloys offer much promise in this field of high temperature alloys. While pure niobium has a high melting point (2468° C.), an intermediate density (8.56 gms./cc.), and a low ductile-brittle transition temperature, it does not possess entirely adequate high temperature properties.

It is, accordingly, an object of this invention to provide niobium-base alloys having substantial ductility at room temperature, and high temperature strength, the alloys including predetermined amounts of at least one of the elements vanadium, molybdenum, zirconium, and hafnium.

It is another object of this invention to provide niobium-base alloys having substantial ductility at room temperature and high temperature strength in which predetermined amounts of the elements vanadium and molybdenum are present, and also incorporating zirconium in predetermined amounts.

A further object of this invention is to provide niobium-base alloys having substantial ductility at room temperature and high temperature strength including, in predetermined amounts, the elements vanadium and molybdenum.

It is also an object of this invention to provide alloys having good ductility at room temperature and high elevated temperature strength including in predetermined amounts, the elements niobium and hafnium.

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

In accordance with the invention, niobium-base alloys having high strength at elevated temperatures along with a low ductile-brittle transition temperature are composed essentially of from 0.5% to a total of 40% of at least one element selected from the group consisting of vanadium, molybdenum, hafnium, and zirconium, the zirconium being present in the alloy along with at least

one of the other elements of the group, and the balance being niobium. The molybdenum present will not exceed 20% by weight. Highly useful binary, ternary, and quaternary niobium-base alloys may be prepared. In some cases, a part of the molybdenum in the ternary and higher component niobium-base alloys may be replaced by tungsten.

Certain of the alloys of this invention comprise, by weight, from 0.5% to 20% vanadium, from 0.5% to 20% molybdenum, from 0.1% to 5% zirconium, and the balance essentially niobium with small amounts of impurities. Within this broad range, there is a range of alloys which has been found to be useful which comprises, by weight, from 4% to 6% vanadium from 4% to 6% molybdenum, from 0.75% to 1.25% zirconium, and the balance essentially niobium with small amounts of impurities.

An additional alloy of this invention comprises, by weight, from 0.5% to 20% vanadium, from 0.5% to 20% molybdenum, and the balance essentially nobium with small amounts of impurities. Within this broad range there is a range of useful alloys comprising from 4% to 6% vanadium, from 4% to 6% molybdenum, and the balance niobium.

Another ternary alloy of this invention comprises, by weight, from 3% to 15% molybdenum, from 3% to 15% hafnium, and the balance essentially niobium with small amounts of impurities.

A binary alloy of this invention comprises from 5% to 40% vanadium, and the balance essentially niobium with small amounts of impurities.

Another useful alloy of this invention comprises from 1% to 40% hafnium, and the balance essentially niobium.

The operating temperature range which is of particular interest for the above alloys is from 1800° F. to 2400° F.

The alloys of this invention were prepared employing essentially conventional non-consumable arc melting techniques. The melting was conducted under a protective atmosphere of argon. In the following Table I properties of several of the alloys, together with their nominal compositions, are set forth:

TABLE I

PROPERTIES OF Nb-BASE ALLOYS

Alloy	Composition, Wt. percent	Test Temp., ° F.	0.2% Yield Str. (p.s.i.)	Ultimate Str. (p.s.i.)	Percent Elon.	Percent Reduction in Area
A	Nb-5V-5Mo	RT	77,200	95,000	28.7	36.6
		2,000	37,300	40,100	43.5	54.2
B	Nb-5V-5Mo-1Zr	2,000	50,500	53,500	5.0	6.2
C [1]	Nb-5Mo-5Hf	RT	100,100	113,200	16.6	18.2
		2,000	34,240	43,350	4.9	11.6
D	Nb-5V(4.86)	RT	74,400	86,150	27.3	72.3
		2,000	33,500	36,900	37.4	
E	Nb-10V(10.50)	RT	101,200	118,800	22.2	49.2
		2,000	39,000	42,500	19.8	12.9
F	Nb-20V	RT	110,100	136,800	25.3	48.9
		2,000	52,500	54,000	2.4	1.6
G	Nb-10Hf	RT	36,750	54,850	20.2	57.2
		2,000	18,200	30,000	16.5	
H	Nb-20Hf	RT	50,700	66,300	22.3	72.4
		2,000	27,900	37,300	30.9	44.0

[1] Tested in air.
( ) Indicates analysis.

While all of the alloys listed in the above table have relatively good high temperature strength, particularly striking is the important improvement in this property displayed by the zirconium-containing Alloy B, which also retains substantial ductility.

To further indicate the improvement over pure niobium realized in the alloys of this invention, certain prop-

erties of pure niobium are presented in Table II for purposes of comparison.

Table II

PROPERTIES OF PURE NIOBIUM

Composition, Wt. percent	Test Temp. ° F.	0.2% Yield Str. (p.s.i.)	Ultimate Str. (p.s.i.)	Percent Elon.	Percent Reduction in Area
Pure Nb	RT	36,000	48,410	48.0	63.5
	2,000	8,100	10,100	34.0	100

The data presented in Tables I and II were obtained from fully recrystallized material, and all high temperature testing (except as noted) was performed in vacuum.

As can be seen from Tables I and II, the alloy A has over 4 times the strength of pure niobium at 2000° F. in addition to satisfactory ductility. Alloy B, which includes 1% zirconium, has even better high temperature strength. The other alloys of Table I have at least twice the high temperature strength of pure niobium.

In the alloys of this invention vanadium is a most potent strengthener and also improves oxidation resistance. Molybdenum is a strengthener though somewhat less effective than vanadium, and it, too. improves oxidation resistance. Zirconium and hafnium function primarily as strengtheners.

The oxidation resistance of Alloy A was determined and compared with oxixdation data obtained under the same test condition as on pure niobium. These data are set forth in Table III below:

Table III

OXIDATION DATA

Composition (Wt. percent)	Temp. (° F.)	Time (hrs.)	Wt. gain mg./cm.²
Nb	2,000	2	75.9
Nb-5V-5Mo	2,000	2	23.2

As the table indicates, the Alloy A has significantly better oxidation resistance than pure niobium.

The density of the alloys of this invention is somewhat less than that of pure niobium. Therefore, on a strength-weight basis, the alloys of this invention, and particularly those disclosed in Table I, are highly attractive for applications where weight is a factor. Further, an improvement of the order of 10% in strength can be accomplished by strain hardening the alloys of this invention.

The niobium-base alloys of this invention may be prepared by standard arc melting techniques, and electron beam melting, and ingots of the alloys may be hot worked by conventional methods such as forging, extrusion, rolling, and swaging. In melting, an inert protective atmosphere, such as the indicated argon, or vacuum, should be employed. The niobium employed in the alloys of this invention will contain the normal impurities carbon, oxygen, nitrogen, tantalum, silicon, iron, and titanium in a total amount of about 1% or less.

Thus, there have been disclosed niobium-base alloys having an exceedingly useful combination of properties with substantial ductility at room temperature and very attractive high temperature strength properties.

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

I claim as my invention:

1. A niobium-base alloy suitable for use at elevated temperatures consisting of, by weight, from 4% to 6% vanadium, from 4% to 6% molybdenum, from 0.75% to 1.25% zirconium, and the balance essentially niobium with small amounts of incidental impurities.

2. A high-strength alloy for use at elevated temperatures consisting of, by weight, from 0.5% to 20% vanadium, from 0.5% to 20% molybdenum, and the balance essentially niobium with small amounts of impurities.

3. A high-strength alloy for use at elevated temperatures consisting of, by weight, from 4% to 6% vanadium, from 4% to 6% molybdenum, and the balance essentially niobium with small amounts of impurities.

4. A high-strength alloy for use at elevated temperatures consisting of, by weight, from 3% to 15% molybdenum, from 3% to 15% hafnium, and the balance essentially niobium with small amounts of incidental impurities.

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