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TITANIUM BASE ALLOYS CONTAINING ALUMINUM, MANGANESE, AND MOLYBDENUM

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This invention relates to titanium-base alloys and in particular to titanium-base alloys containing aluminum and beta stabilizers.

Heretofore, titanium-base binary alloys containing aluminum in excess of six percent have been prepared in limited quantity since considerable difficulty has been experienced in their fabrication. The most notable difficulty experienced thus far has been edge cracking during cold working operations. These difficulties have been attributed to the inherent toughness and low ductility of the binary titanium-aluminum alloys. What little ductility these alloys possess is substantially reduced when the binary titanium-aluminum alloys are heated to a temperature over 1700° F. either for the purpose of fabrication or heat treatment.

Since aluminum has the effect of raising the alpha to alpha+beta transus temperature, the alloy system of aluminum and titanium is quite desirable from the standpoint of elevated temperature service, especially in the range from 800° F. to 1200° F. While the alloys of the titanium-aluminum system have the requisite high temperature stability, they do not possess sufficient ductility when the aluminum content is greater than six percent to permit them to be commercially fabricated.

An object of this invention is to provide a titanium-base alloy having a relatively high aluminum content and having small but critical amounts of manganese and molybdenum.

Another object of this invention is to provide a titanium-base alloy having a substantial amount of aluminum and small but critical percentages of manganese and molybdenum, the alloy being characterized by retaining substantial ductility after being heated to a temperature of 1700° F.

A further object of this invention is to provide a titanium-base alloy having aluminum, manganese, and molybdenum contained therein, the alloy having a microstructure consisting of the beta phase in a matrix of the alpha phase with the alpha phase being predominant, said alloy having good ductility after having been forged in a temperature range from 1750° F. to 2000° F.

Another object of this invention is to provide a titanium-base alloy having aluminum and small but critical amounts of manganese and molybdenum contained therein, the alloy being characterized by substantially retaining its mechanical properties after prolonged heating at elevated temperatures.

These and other objects of this invention will become apparent to those skilled in the art when read in conjunction with the following description.

In accordance with this invention, the alloys of this invention are composed of aluminum in the range from 6.0% to 8.0%, and small but critical amounts of two beta stabilizers consisting of manganese and molybdenum. Each of the beta stabilizers present in the alloy is preferably maintained within the range from 0.85% to 1.15%. The balance of these alloys is composed of titanium with incidental impurities such as not more than 0.20% oxygen, not more than 0.15% nitrogen and not more than 0.10% carbon. In all cases these impurities are preferably maintained at a minimum.

Reference is made to the alloys of this invention as set forth in Table I illustrating the general range, the optimum range, and a specific alloy identified as K 1044.

Table I

Element	General Range	Optimum Range	K 1044
	Percent	*Percent*	*Percent*
Al	6.0 -8.0	6.0-7.25	6.0
Mn	0.85-1.15	1.00	0.90
Mo	0.85-1.15	1.00	0.96

In all cases the balance of the alloys of Table I is titanium with incidental impurities.

The alloys of this invention can be prepared in any well-known manner, for example, by the tungsten arc melting or the consumable arc melting processes. In order to introduce a specific amount of the alloying elements into the titanium-base and thereby obtain the titanium-base alloy of the desired chemical composition, the alloying additions may be made in the form of either virgin metals, aluminum master alloys or a combination of both. However, the manner of addition will depend upon the type of melting employed; viz., tungsten arc melting or consumable arc melting.

When tungsten arc melting is employed, the alloying elements are blended with the titanium sponge and the blended mixture is introduced into the molten pool of metal that is formed by the passage of electrical energy between the tungsten electrode and the metal charge, thus creating an arc and thereby melting the metal. On the other hand, if a consumable electrode is employed in arc melting the alloys, the alloying components are preferably added as a part of the consumable electrode per se.

Since aluminum has the effect of raising the alpha to alpha+beta transus temperature and the alpha+beta to beta transus temperature in a titanium-base alloy, the temperature range over which the alpha phase exists is much broader where aluminum is a component of the alloy. However, since the alpha phase has a "close-packed hexagonal" crystallographic lattice configuration, it exhibits low ductility in comparison to the "body-centered cubic" structure of the beta phase. To overcome the low ductility of the "close-packed hexagonal" lattice structure of the alpha phase, small but critical amounts of beta stabilizers which form a "body-centered cubic" crystallographic lattice of the beta phase and which exhibits considerable ductility, are added to the binary titanium-aluminum alloy to increase the overall ductility of these alloys. At the same time, however, the beta stabilizers do not prove detrimental to the alpha stability at elevated temperatures. In so doing, the toughness exhibited by the alpha phase will remain, but the alloys will have sufficient ductility to be fabricated economically.

It has been found also that a small but critical percentage of each beta stabilizer has a more desired effect than larger percentages of either one. For example, it has been found that the effect of about one percent manganese and one percent molybdenum has a greater beneficial effect, for the purpose of these alloys, than two percent of either manganese or molybdenum. While the reason for accomplishing this effect is not clear, it is believed that each element has a multiplying effect on the overall alloy rather than an additive effect.

In order to fabricate the alloys of this invention such as the alloy idenitfied as K 1044 in Table I, it may be forged from a temperature in the range between 1750° F. and 2000° F. The step of forging is performed on the cast ingot to break-up the "as-cast" structure. After forging, the ingot may be rolled in a conventional manner as will hereinafter be described.

The forged alloys are preferably preheated to a temperature of 1400° F. where they are held for a period of 2 hours, or until such time as the ingot has soaked to a

uniform temperature of 1400° F. Of course, as is well known, the time to soak to a uniform temperature will vary with the bulk of the metal employed. After the ingot has attained a uniform temperature of 1400° F., the temperature is raised to 1650° F. where it is held for a period of about ½ hour to develop a substantially uniform temperature, and thereafter the forged alloy is hot rolled to the desired size in any conventional rolling mill.

As an example of the heating and rolling procedure employed in the fabrication of alloys of this invention, alloy K 1044, hereinbefore referred to, was processed in the following manner. This alloy, an eleven pound ingot, was forged at 1750° F. to a 2.25" x 2.25" billet after which it was allowed to cool in the air. The billet was then preheated to a temperature of 1400° F., where it was held for a period of 2 hours, after which time it was heated to 1650° F., held at this temperature for about ½ hour, and thereafter hot rolled to a ⅝" round bar.

Reference may be had to the alloys K 1044 and K 803 in Table II for the purpose of comparing room temperature tensile properties. Alloy K 1044 was referred to in Table I, while alloy K 803 is a binary titanium-aluminum alloy containing eight percent aluminum.

Table II

Alloy	Heat Treatment (Air Cooled)	Code	T. S., p. s. i.	T. Y. S., p. s. i.	El., percent	R. A., percent	R_c
K 1044	As Rolled	FHC	187,500	179,500	15.0	32.2	44.4
	1 hr. @ 1,700° F	FHH	157,000	145,500	20.0	50.5	40.2
	1 hr. @ 1,500° F., W. Q	FHG	155,000	149,000	21.0	40.5	40.0
	24 hrs. @ 1200° F						
	2 hrs. @ 1,450° F	FHI	155,500	147,000	21.0	45.8	41.5
	24 hrs. @ 1,200° F	FHE	156,000	148,800	20.0	42.2	40.2
K 803	As Forged	DOQ	140,500	134,000	4.0	7.1	32.3
	1 hr. @ 1,700° F	DOK	131,500	128,500	4.0	13.9	32.0
	1 hr. @ 1,500° F	DOJ	134,500	133,700	3.0	4.1	29.8
	2 hrs. @ 1,200° F	DOG	147,500	143,000	5.0	6.3	32.0
	24 hrs. @ 1,200° F	DOH	144,300	144,300	----------	4.7	34.0

It is quite evident from the inspection of Table II that the addition of the two beta stabilizers produce an alloy of superior characteristics. For example, the tensile strength of the alloy K 1044 is far superior to that of the binary alloy K 803. The elongation and especially the reduction of area tests prove the superiority of alloy K 1044 over and above K 803. This is most apparent when comparing the two alloys having the same heat treatment; viz., one hour at 1700° F. and twenty-four hours at 1200° F.

In addition to the possession of very desirable room temperature properties, these alloys are quite stable even after heat tretament at elevated temperatures for prolonged periods of time. Reference may be had to Table III illustrating the stability of alloy K 1044 after prolonged heat treatments.

Table III

Heat Treatment	T. S., p. s. i.	T. Y. S., p. s. i.	El. percent	R. A., percent
½ hr. @ 1,700° F	156,500	147,500	22.0	34.0
½ hr. @ 1,700° F+ 500 hrs. @ 700° F	163,000	145,000	19.0	26.7
½ hr. @ 1,700° F.+500 hrs. @ 800° F	163,000	139,000	19.0	39.9
½ hr. @ 1,700° F.+250 hrs. @ 900° F	163,000	159,000	20.0	36.7
½ hr. @ 1,700° F.+250 hrs. @ 1,000° F	158,500	152,500	20.0	45.8

By comparing the results recorded in Table III with those recorded in Table II it may be observed that the alloys of the invention are quite stable. There is very little change in tensile strength and practically no change in the percentage elongation. These alloys thus indicate that they possess desirable properties for use at elevated temperatures. It is also significant to observe that while these alloys have been heated to a temperature of 1700° F. and thereafter subjected to prolonged heat treatments at elevated temperatures, the alloys of this invention possess good ductility as opposed to the binary titanium-aluminum alloys.

I claim:

1. An alloy consisting of, from about 6.0% to about 8.0% aluminum, about 0.85% to 1.15% manganese, about 0.85% to 1.15% molybdenum, and the balance titanium with incidental impurities.

2. An alloy consisting of, from about 6.0% to about 7.25% aluminum, about 1.0% manganese, about 1% molybdenum, and the balance titanium with incidental impurities.

3. An alloy consisting of, about 6.0% aluminum, about 1.0% manganese, about 1.0% molybdenum, and the balance titanium with incidental impurities.

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