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TITANIUM BASE ALLOYS

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This invention relates to titanium base alloys and in particular to titanium base alloy for use at elevated temperatures.

Perhaps one of the most significant characteristics of the metal titanium is its density. However, commercially pure titanium possesses relatively low tensile strengths, viz., between 70,000 to 85,000 p. s. i. depending upon the amount of impurities contained therein. In order to increase the mechanical properties of titanium and reduce the density of the overall product, the element aluminum, has been alloyed therewith. The practical limit of the binary alloy of aluminum and titanium has been determined to be about 7.5% aluminum, since any additions of aluminum beyond 7.5% render the resultant binary alloy commercially unfeasible because of the difficulties encountered in the fabrication of such alloys into useful articles.

It is well-known that aluminum raises the alpha to alpha+beta and the alpha+beta to beta transus temperatures. In so doing, the alpha phase of the titanium-aluminum alloy exists over a broader temperature range, thus presenting a desirable situation for the development of alloys for use at elevated temperatures. But, as was stated hereinbefore, titanium base alloys containing relatively high percentages of aluminum are difficult to fabricate. In addition, these alloys, while possessing little ductility, proved to be quite brittle after heating to a temperature in excess of 1700° F.

In an attempt to rectify this condition, the density of the alloy was sacrificed along with elevated temperature properties of the alloy by the addition of large percentages of beta stabilizers. Hence, these alloys were only suitable for use below the temperature of 800° F. for, when this temperature was exceeded, the strength of the alloy decreased at such a rapid rate that the alloy was no longer useful.

An object of this invention is to provide a titanium base alloy containing a substantial amount of aluminum and small but critical amounts of beta stabilizers.

Another object of this invention is to provide titanium base alloys containing aluminum and small but critical amounts of beta stabilizers, the alloys being characterized by retaining substantial ductility after being heated to a forging temperature.

A further object of this invention is to provide titanium base alloys containing aluminum and beta stabilizers, the alloys being characterized by excellent creep-rupture properties 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 specification.

In accordance with this invention, the alloys of this invention comprise aluminum within the range from about 7.5% to about 10.0% by weight of the alloy, and from about 2.0% to about 3.0% of beta stabilizers selected from the group consisting of chromium, iron, molybdenum and vanadium, each of the stabilizers present in the alloy being in the range from about 0.85% to about

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1.15% by weight of the alloy. While two of the beta stabilizers are satisfactory in most cases, where the aluminum content is near the upper limit of its range, three beta stabilizers are preferred. The balance of the alloy is composed of titanium with not more than 0.20% oxygen, not more than 0.15% nitrogen and not more than 0.10% carbon present in the form of incidental impurities.

Reference may be had to Table I illustrating the general range, the optimum range and two specific alloys of this invention. The two specific alloys within the limits of this invention are identified as K 1026 and K 1030.

Table I

Elements	General Range, percent	Optimum Range, percent	K 1026, percent	K 1030, percent
Al	7.5-10.0	7.5-8.5	7.5	8.0
Fe	0.85-1.15	1.00	1.00	0.9
Cr	0.85-1.15	1.00	1.14	0.85
Mo	0.85-1.15	1.00	1.06	0.85
V	0.85-1.15	1.00		

In each of the alloys identified in Table I, the balance is titanium with incidental impurities.

The alloys of this invention may be prepared in any suitable manner, for example, by the well-known tungsten arc melting or consumable arc melting processes. In order to introduce the alloying components into the titanium base metal that go into the make-up of the alloys of this invention, either virgin metals, aluminum master alloys or the combination of both may be employed. Where tungsten arc melting is employed, the alloying components are blended with the titanium metal after which the blended mixture is introduced into the molten bath formed by the arcing of electrical energy between the tungsten electrode and the metal charge. On the other hand, if consumable electrodes are used, the alloying elements form a part of the consumable electrode per se.

Since aluminum has the effect of raising the alpha to alpha+beta and the alpha+beta to beta transus temperatures, the temperature range over which the alpha phase exists is much broader where aluminum is a component of the alloy. However, the alpha phase has a "close-packed-hexagonal" crystallographic configuration and thus exhibits little ductility. In order to overcome the low ductility of the "close-packed-hexagonal" structure, small but critical amounts of beta stabilizers, which form the "body centered cubic" crystallographic lattice and which also exhibits considerable ductility are employed to greatly increase the overall ductility of these alloys, while at the same time not prove detrimental to the alpha stability and creep-rupture strengths at elevated temperatures. In so doing, the toughness of these alloys will remain while at the same time provide the alloys with sufficient ductility to be fabricated economically.

It has been found that small but critical amounts of at least two of the beta stabilizers have a more desired effect on the alloys of this invention than larger percentages of any one. For example, it has been found that the effect of about one percent molybdenum and about one percent chromium has a greater beneficial effect for the purpose of these alloys than two percent of either molybdenum or chromium. The same applies to the other beta stabilizers used in this invention regardless of whether two or three beta stabilizers are used. While the reasons for accomplishing this effect are not certain, it has been theorized that each element has a multiplying effect on the overall alloy rather than an additive effect.

After the molten metal has solidified to form ingots, the ingots may be processed by an initial step of forging. The ingots of the alloys of this invention are preferably heated to a temperature within the range from about

1750° F. to about 2000° F. and thereafter forged in a conventional manner. The step of forging is employed to break-up the "as-cast" structure of the ingots.

In order to further hot work these tough alloys after forging, the alloys are preferably preheated to a temperature of 1400° F. where they are held for a period of about two hours or until such time that the alloys will attain a uniform temperature of 1400° F. Of course, as is well-known, the time required to attain a uniform temperature will vary with the bulk of the material to be heated. When the uniform temperature is attained, the temperature is then raised to 1650° F. where it is held for about one-half hour or longer depending upon the bulk of the alloy and the alloys are thereafter rolled in any conventional manner.

As an example of the heating and rolling treatments as hereinabove described, the alloy identified as K 1026 in Table I was processed in the following manner: An

thus far encountered has been in excess of 150,000 p. s. i. thus indicating the superiority of this alloy over and above that of the binary titanium-aluminum alloy.

However, the above mentioned properties of these alloys are room temperature properties. It is well-known that the mechanical properties of an alloy will differ at elevated temperatures from the mechanical properties measured at room temperature. In any true engineering application involving use at elevated temperatures, the mechanical properties of the alloy at elevated temperatures, especially creep-rupture strengths, is the usual governing criteria when selecting the proper metal to be utilized.

Reference may be had to Table III illustrating some of the mechanical properties measured at different elevated temperatures. The alloys are identified as K 1026 and K 1030, the compositions of which have been hereinbefore listed in Table I.

Table II

K 1026							K 803						
Heat Treatment (Air Cooled)	Code	T. S., p. s. i.	T. Y. S., p. s. i.	El, per- cent	R. A., per- cent	Rc	Heat Treatment (Air Cooled)	Code	T. S., p. s. i.	T. Y. S., p. s. i.	El, per- cent	R. A., per- cent	Rc
As Rolled	FEY	181,000	171,500	14.0	15.5	44.4	As Forged	DOO	140,500	134,500	4.0	7.1	32.2
1 hr. @ 1,700° F.	FFD	151,000	149,000	20.0	48.3	37.5	1 hr. @ 1,700° F.	DOK	131,500	128,500	4.0	13.9	32.0
1 hr. @ 1,500° F. W. Q.	FFC	155,700	149,000	13.0	22.6	42.9	1 hr. @ 1,500° F.	DOJ	134,500	133,700	3.0	4.1	29.8
24 hrs. @ 1,200° F.	FFE	153,500	151,000	21.0	35.5	41.6	2 hrs. @ 1,200° F.	DQG	147,500	143,000	5.0	6.3	32.0
2 hrs. @ 1,450° F.	FFA	164,000	155,500	10.0	10.2	44.9	24 hrs. @ 1,200° F.	DOH	144,300	144,300	-----	4.7	34.0

eleven pound ingot was forged at 1850° F. to a square size of 2.25" x 2.25". The ingot, after air cooling, was heated to a temperature of 1400° F. where it was held for a period of two hours and thereafter heated to 1650° F. The 2.25" x 2.25" ingot was held at this temperature for one-half hour and thereafter rolled in a conventional rolling mill to a ¾" round bar.

Reference may be had to Table II illustrating the room temperature tensile properties of the alloy K 1026, hereinbefore referred to in Table I and a binary titanium base alloy containing 8% aluminum identified as K 803, the alloys having been treated as indicated.

From the values tabulated in Table III, both the ductility and creep rupture properties of these alloys may be evaluated. It is to be noted that in a total of 500 hours there were no failures recorded while the alloys were subjected to stresses at elevated temperature as indicated. The secondary creep rates are outstanding in exhibiting a very low percentage creep per hour and at the same time retaining good ductility as measured by the bend test. It will also be noted that these alloys were given a 1700° F. heat treatment followed by air cooling. While such a treatment would substantially reduce what little ductility the binary titanium-aluminum alloy possessed, it

Table III

Alloy	Code	Heat Treatment	Stress (p. s. i.)	Temp., °F.	Failure Time (Hrs.)	El, per- cent	R. A., per- cent	Secondary Creep Rate (Percent/ Hr.)	First Stage Creep	Second Stage Creep	Bend, degrees
K 1026	FYS	½ hr. @ 1,700° F., A. C.	85,000	700	1 529¾	Nil	Nil	0.00023	0-30 hr., 0.9%.	30-500 hr., 1.0%.	50-55
	FYT	½ hr. @ 1,700° F., A. C.	60,000	800	1 545½	Nil	Nil	0.0004	0-50 hr., 1.3%.	50-546 hr., 1.5%.	-----
	FYY	½ hr. @ 1,700° F., A. C.	85,000	700	1 506¾	Nil	Nil	0.00045	0-60 hr., 0.6%.	60-500 hr., 0.8%.	40-45
K 1030	FYZ	½ hr. @ 1,700° F., A. C.	60,000	800	1 650	0.1	0.67	0.0002	0-15 hr., 0.8%.	15-501 hr., 0.9%.	30-45
	GYF	½ hr. @ 1,700° F., A. C.	30,000	1,000	1 500	Nil	Nil	0.005	0-22 hr., 0.8%.	Still Running.	-----

¹ Discontinued—did not rupture.

By inspecting Table II, it is apparent that alloy K 1026 is far superior to K 803. The only compositional difference between the two alloys resides in the fact that alloy K 1026 has about 2% of beta stabilizers present in its composition instead of the .5% greater aluminum content of alloy K 803. Using the reduction of area as a criterion of ductility, it may be observed that the 2% beta stabilizers render the alloy quite ductile even after long period of heat treatment at elevated temperatures. It may also be observed that the 2% beta stabilizers, while increasing the ductility, also substantially increases the hardness of the alloy. The lowest tensile strength

did not affect the alloys of this invention in that manner.

Particular notice should be given alloy K 1030, code GYF. This alloy was subjected to a stress of 30,000 p. s. i. at a temperature of 1000° F. While most titanium base alloy containing large percentages of beta stabilizers are not used at a temperature in excess of 800° F., this alloy possesses excellent properties at 1000° F. as evidenced by the fact that it was still running in the test apparatus after 500 hours.

The alloy of this invention combines a number of features that make these alloys outstanding. By making use of the low density of aluminum and alloying it with

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titanium along with small but critical percentages of beta stabilizers, the overall density of the alloy is lowered. The use of aluminum also promotes alpha stability over a broader range of temperatures while the beta stabilizers render the alloy sufficiently ductile to allow economical fabrication of these alloys. These alloys also possess excellent creep-rupture strength at elevated temperatures even after heating in a temperature range which substantially reduces the ductility of the binary titanium-aluminum alloys.

I claim:

1. A titanium base alloy consisting of, from about 7½% to about 10% aluminum, about 2% to about 3% of not less than two nor more than three beta stabilizers selected from a group consisting of chromium, iron, molybdenum, and vanadium, each of the stabilizers present in the alloy being in an amount of about 0.85% to about 1.15%, and the balance being essentially titanium with incidental impurities. 15

2. A titanium base alloy consisting of, from 7½% to 10% aluminum, from 2% to 3% of not less than two nor more than three beta stabilizers selected from the group consisting of chromium, iron, molybdenum, and vanadium, each of the stabilizers present in the alloy being in the amount of about 0.85% to about 1.15%, and the balance titanium with incidental impurities. 20

3. A titanium base alloy consisting of, from 7½% to 8½% aluminum, from 2% to 3% of not less than two nor more than three beta stabilizers selected from a

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group consisting of chromium, iron, molybdenum, vanadium, each of the stabilizers present in the alloy being in an amount of about 1%, and the balance titanium with incidental impurities.

4. A titanium base alloy consisting of, about 8% aluminum, about 1% chromium, about 1% molybdenum, and the balance titanium with incidental impurities. 5

5. A titanium base alloy consisting of, about 8% aluminum, about 1% each of iron, chromium and molybdenum, and the balance titanium with incidental impurities. 10

6. A titanium base alloy consisting of, about 8% aluminum, about 1% chromium, about 1% vanadium, and the balance titanium with incidental impurities.

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