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[54] **HIGH STRENGTH TITANIUM ALLOYS**

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[21] Appl. No.: **245,177**

[52] **U.S. Cl.** **75/175.5**

[51] **Int. Cl.** **C22c 15/00**

[58] **Field of Search** ..... 75/175.5; 148/32, 133, 148/12.7, 11.5 F

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Attorney, Agent, or Firm—Webb, Burden, Robinson & Webb

[57] **ABSTRACT**

A titanium base alloy comprising 6.3 – 11.0 percent vanadium, 1.75 – 3.3 percent aluminum, 0.75 – 2.25 percent iron, up to 2.25 percent chromium, up to 1.25 percent cobalt, up to 2.25 percent tin, up to 2.25 percent zirconium, up to 0.2 percent oxygen, balance titanium; the total of aluminum plus one half zirconium being between 2.25 percent and 3.25 percent, the ratio of iron to aluminum being no greater than about 1:1 and the maximum of iron plus cobalt being 2.25 percent.

3 Claims, No Drawings

HIGH STRENGTH TITANIUM ALLOYS

This invention relates to high strength titanium base alloys and more particularly to titanium base alloys including vanadium, aluminum and iron as essential constituents with other elements included optionally. Various elements are included in the alloy in specified relationships which are set forth hereinafter.

Articles made from alloys within the composition range of our invention are deep hardenable and have high room temperature strength, good ductility, good notch strength and fracture toughness. The articles are age hardenable and heat treatable to high strength in thick sections. Additionally, the parts have good resistance to plane strain fracture.

In modern technology it is important to combine high strength with good ductility and good fracture toughness. For example, a metal which is not resistant to plane strain fracture may fail under stress due to the presence of a finite crack which is so small that it cannot be seen even in the presence of a dye penetrant. In order to obtain a high strength article, the alloy must have sufficient fracture toughness to prevent failure in the presence of microscopic flaws. The alloys of our invention have this capability.

It is known in the art that the addition of beta stabilizers to a titanium base alloy results in good response to heat treatment and imparts high strength to the alloy. Additionally, it is known that the heat treatability and depth of hardening of an alloy increase in proportion to the amount of retained beta phase after quenching the alloy to room temperature. While the alloys of our invention follow these basic principles, it should be understood that we have discovered novel alloying combinations as discussed hereinafter. We have further discovered that direct aging of hot worked articles made from the novel alloys of our invention provides high ductility at ultimate strength to density ratios exceeding 1,100,000 inches. Our alloys have good fracture toughness even after solution treating in the alpha-beta field followed by aging.

The base composition of our novel alloy consists essentially of 6.3 – 11% V, 1.75 – 3.3% Al, 0.75 – 2.25% Fe, balance titanium with a maximum oxygen content of 0.2 percent. The total amount of oxygen plus other incidental impurities should not exceed 0.35 percent. The iron to aluminum ratio in the alloy should not exceed about 1:1. Our alloy may optionally include up to 2.25 percent chromium, up to 1.25 percent cobalt, up to 2.25 percent tin and up to 2.25 percent zirconium. When zirconium is present in the alloy, the total of aluminum plus one half the zirconium will be between 2.25 percent and 3.25 percent. When cobalt is present in the alloy, the percent of cobalt plus the percent of iron should not exceed 2.25 percent since the cobalt replaces an equivalent amount of iron in the composition. Additionally, when chromium is included in the alloy, it should generally replace an equal amount of vanadium.

Table I shows a number of nominal titanium base alloy compositions, both within and outside the range of our invention, together with heat treatments and the results of metallurgical tests performed on these alloys.

TABLE I

TENSILE AND PLANE STRAIN TOUGHNESS PROPERTIES, TENSILE PROPERTIES TRANSVERSE, K_{IC} DATA FOR CRACK PROPAGATING IN DIRECTION OF ROLLING

Heat	Composition V	Fe	Al	Other	Heat Treatment[1]	UTS Ksi	YS Ksi	Lo El[3] %	El[4] %	K_{IC} Ksi/$\sqrt{in.}$
4505[2]	10	2	3		As Rolled+1000F-4Hr-AC	186	181	20	9	51.6
do.	do.	do.	do.		1425F-1/4Hr-AC+1000F-4Hr-AC	194	187	15	3	49.7
4543	10	2	3		As Rolled+950F-4Hr-AC	181	170	30	10	50.1
do.	do.	do.	do.		1400F-1/2Hr-AC+950F-8Hr-AC	179	171	20	8	52.3
do.	do.	do.	do.		1400F-1/2Hr-AC+1000F-2Hr-AC	178	170	25	9	55.3
4550	10	3	2		As Rolled+950F-8Hr-AC	180	176	30	10	32.6
do.	do.	do.	do.		1400F-1/2Hr-AC+1000F-1Hr-AC	198	194	10	4	31.3
4551	10	2	2		1400F-1/2Hr-AC+1000F-1Hr-AC	184	175	10	2	45.3
4552	10	3	3		1400F-1/2Hr-AC+1100F-1Hr-AC	164	159	25	14	67.6
4554	10	2	3	1Zr	As Rolled+950F-8Hr-AC	191	185	30	12	37.2
do.	do.	do.	do.	do.	1400F-1/2Hr-AC+1050F-1Hr-AC	180	172	20	8	44.2
4555	10	2	3	.1Zr	1400F-1/2Hr-AC+950F-4Hr-AC	194	184	20	7	43.0
4556	10	1	3	1Co	1400F-1/2Hr-AC+900F-8Hr-AC	198	190	20	6	38.8
4557	10	1	3	1Co-.1Zr	1400F-1/2Hr-AC+900F-8Hr-AC	200	191	20	8	40.1
4506[2]	7	2	2	2Cr-2Sn-2Zr	As Rolled+1100F-2Hr-AC	187	186	10	6	57.6
do.	do.	do.	do.	do. do. do.	1375F-1/2Hr-AC+1050F-2Hr-AC	187	179	10	7	58.4

(1) As rolled from 1400F.
(2) 0.275" Plate finish rolled at 1450F, all others, 0.325" plate finish rolled at 1400F.

A comparison of the data in Table I shows that Heat 4506 has the highest combination of yield strength and fracture toughness as indicated by K_{IC}. The alloy of Heat 4506 is based upon a substitution of 2%Cr for 3%V and 2%Sn +2%Zr for 1%Al. These substitutions strengthen both the alpha and beta phases in the alloy without substantially changing the ratio of the phases. This permits higher aging temperatures for a given desired strength level. The substitutions are also beneficial to fracture toughness.

As stated earlier, good fracture toughness is achieved by maintaining the iron to aluminum ratio below about 1:1 and by maintaining the aluminum plus one half the zirconium in the range of 2.25 percent to 3.25 percent. This can be seen by comparing the results of Heat 4550, wherein the iron to aluminum ratio is 3:2, and the results of Heats 4505 and 4543, wherein the iron to aluminum ratio is 2:3. Results of Heats 4543, 4555 and 4554 illustrate the effects of aluminum plus one half zirconium. These composition limitations may be seen

more clearly in Table II. In Table II the linear least squares analysis trend line values for K_{IC} for various heats were calculated and are compared with observed K_{IC} values. This data shows that an increase of the iron to aluminum ratio above 1:1 reduces the K_{IC} below expected values by at least 5 Ksi $\sqrt{in.}$ as does allowing the total of aluminum plus one half the zirconium to be outside the range of 2.25 percent to 3.25 percent.

It will also be seen from Table II that substitution of one cobalt for 1 percent iron as well as the addition of 0.1 percent zirconium results in an alloy having observed results close to the trend line.

TABLE II

PLANE STRAIN TOUGHNESS VALUES OBSERVED AND TREND LINE

Composition				K_{IC}-KSI $\sqrt{in.}$	
V	Fe	Al	Other	Observed	Trend Line(1)
10	2	3		49.7	41.9
				52.3	54.2
				55.3	54.9
10	2	2		45.3	51.1
10	3	2		31.3	36.5
10	3	3		67.6	63.4
10	2	3	1Zr	44.2	53.4
10	2	3	.1Zr	43.0	44.2
10	1	3	1Co	38.8	39.6
10	1	3	1Co-.1Zr	40.1	38.8
7	2	2	2Cr-2Sn-2Zr	58.4	48.0

(1) Calculated from linear least squares of solution treat plus age data given in Table I: K_{IC} = 185.42 – 0.7676 YS

As stated, the best K_{IC} performance is obtained by substituting 2 percent chromium for 3 percent vanadium and 2 percent tin plus 2 percent zirconium for 1 percent aluminum in the basic Ti-10V-2Fe-3Al alloy. The preferred compositions of our novel alloy are the basic Ti-10V-2Fe-3Al alloy and Ti-7V-2Cr-2Fe-2Al-2Sn-2Zr. In both of these alloys, the preferred maximum oxygen content is 0.11 percent although oxygen may be present up to 0.2 percent. The total of oxygen and the other interstitials, carbon and nitrogen, may be present up to 0.35 percent.

In many applications the ability of a metal product to retain high strength in the presence of a machined notch is important. Table III shows the results of tests on ½ inch round bars finish rolled from 1,400°F and then subjected to high stress in the presence of machined notches. The alloys of our invention which exhibit good toughness as shown by the K_{IC} values also have high notch strength. The notch tensile strength of the preferred Ti-7V-2Cr-2Fe-2Al-2Sn-2Zr is higher than the yield strength even when the yield strength is in excess of 200 Ksi. Additionally, Table III shows the effect of thermomechanical processing history on the properties of alloys within the scope of our invention. The effect is particularly evident from a consideration of the reduction of area values. Values of about 50 percent are typical when the alloys are rolled from 1,400°F and then aged directly to a yield strength within the range of 160 – 180 Ksi.

It is also shown in Table III that, when finished rolled from 1,400°F, the basic Ti-10V-2Fe-3Al alloy is flexible with regard to subsequent heat treatment. This is an important commercial feature of our alloy since microstructure control is not always possible throughout heavy sections in industrial practice. For this reason, if solutionizing should occur in one portion of a large section of our alloy before the rest of that section is finished forged, the properties will still be uniform after aging. Known high strength commercial titanium base alloys do not include this feature.

TABLE III

TENSILE AND NOTCH TENSILE PROPERTIES OF 1/2" ROUND

Heat	Composition V	Fe	Al	Other	Heat Treatment	UTS Ksi	YS Ksi	RA %	EL %	NTS(1) Ksi
4550	10	3	2	—	As Rolled+950F-4Hr-AC	185	181	56	11	237
do.	do.	do.	do.	—	As Rolled+1000F-2Hr-AC	179	176	57	17	236
do.	do.	do.	do.	—	As Rolled+1050F-1Hr-AC	162	160	56	17	234
do.	do.	do.	do.	—	1400F-1/2Hr-AC+950F-4Hr-AC	202	194	15	9	—
do.	do.	do.	do.	—	1400F-1/2Hr-AC+1000F-2Hr-AC	186	177	29	6	229
do.	do.	do.	do.	—	1400F-1/2Hr-AC+1050F-1Hr-AC	164	158	40	14	221
4551	10	2	2	—	As Rolled+950F-4Hr-AC	154	153	60	19	238
do.	do.	do.	do.	—	1400F-1/2Hr-AC+950F-4Hr-AC	192	186	9	3	160
4552	10	3	3	—	As Rolled+950F-8Hr-AC	179	179	41	15	255
do.	do.	do.	do.	—	As Rolled+1000F-4Hr-AC	172	172	56	18	244
do.	do.	do.	do.	—	As Rolled+1050F-2Hr-AC	174	172	52	14	243
do.	do.	do.	do.	—	1400F-1/2Hr-AC+950F-8Hr-AC	212	210	6	4	133
do.	do.	do.	do.	—	1400F-1/2Hr-AC+1000F-4Hr-AC	210	205	8	2	150
do.	do.	do.	do.	—	1400F-1/2Hr-AC+1050F-2Hr-AC	196	192	13	5	190
4553	10	2	3	—	As Rolled+950F-8Hr-AC	179	176	55	16	242
do.	do.	do.	do.	—	As Rolled+1000F-4Hr-AC	173	170	57	17	241
do.	do.	do.	do.	—	As Rolled+1050F-2Hr-AC	166	164	55	18	248
do.	do.	do.	do.	—	1400F-1/2Hr-AC+950F-8Hr-AC	177	170	55	17	211
do.	do.	do.	do.	—	1400F-1/2Hr-AC+1000F-4Hr-AC	183	173	40	15	228
do.	do.	do.	do.	—	1400F-1/2Hr-AC+1050F-2Hr-AC	174	167	46	14	219
4554	10	2	3	1Zr	As Rolled+950F-4Hr-AC	185	182	51	19	234
do.	do.	do.	do.	do.	As Rolled+1000F-2Hr-AC	179	175	44	15	237
do.	do.	do.	do.	do.	As Rolled+1050F-1Hr-AC	171	168	45	16	226
do.	do.	do.	do.	do.	1400F-1/2Hr-AC+950F-4Hr-AC	200	189	17	8	161
do.	do.	do.	do.	do.	1400F-1/2Hr-AC+1000F-2Hr-AC	191	183	17	7	186
do.	do.	do.	do.	do.	1400F-1/2Hr-AC+1050F-1Hr-AC	192	184	25	12	196
4555	10	2	3	.1Zr	As Rolled+950F-4Hr-AC	177	174	58	19	242
do.	do.	do.	do.	do.	As Rolled+1000F-2Hr-AC	166	164	60	19	240
do.	do.	do.	do.	do.	As Rolled+1050F-1Hr-AC	162	161	60	21	233
do.	do.	do.	do.	do.	1400F-1/2Hr-AC+950F-4Hr-AC	188	179	31	11	228
do.	do.	do.	do.	do.	1400F-1/2Hr-AC+1000F-2Hr-AC	176	169	52	16	214
do.	do.	do.	do.	do.	1400F-1/2Hr-AC+1050F-1Hr-AC	175	169	51	16	225
4556	10	1	3	1Co	As Rolled+950F-8Hr-AC	170	169	61	20	234
do.	do.	do.	do.	do.	As Rolled+1000F-4Hr-AC	163	163	65	22	236
do.	do.	do.	do.	do.	As Rolled+1050F-2Hr-AC	158	156	61	17	232

TABLE III – Continued

TENSILE AND NOTCH TENSILE PROPERTIES OF 1/2" ROUND

Heat	Composition V	Fe	Al	Other	Heat Treatment	UTS Ksi	YS Ksi	RA %	EL %	NTS(1) Ksi
do	do.	do.	do.	do.	1400F-1/2Hr-AC+950F-8Hr-AC	176	171	56	17	230
do	do.	do.	do.	do.	1400F-1/2Hr-AC+1000F-4Hr-AC	173	167	49	16	229
do	do.	do.	do.	do.	1400F-1/2Hr-AC+1050F-2Hr-AC	170	164	58	21	234
4557	10	1	3	1Co-.1Zr	As Rolled+950F-8Hr-AC	170	169	54	17	240
do.	do.	do.	do.	do. do.	As Rolled+1000F-4Hr-AC	167	167	59	20	235
do.	do.	do.	do.	do. do.	As Rolled+1050F-2Hr-AC	159	158	63	20	235
do.	do.	do.	do.	do. do.	1400F-1/2Hr-AC+950F-8Hr-AC	179	176	42	14	238
do.	do.	do.	do.	do. do.	1400F-1/2Hr-AC+1000F-4Hr-AC	175	172	32	13	232
do.	do.	do.	do.	do. do.	1400F-1/2Hr-AC+1050F-2Hr-AC	166	163	56	18	222
4505(2)	10	2	3	—	As Rolled+1000F-2Hr-AC	184	180	51	16	248
do.	do.	do.	do.	—	As Rolled+1000F-4Hr-AC	177	174	54	16	248
do.	do.	do.	do.	—	1450F-1/4Hr-AC+1000F-2Hr-AC	192	183	20	9	218
do.	do.	do.	do.	—	1450F-1/4Hr-AC+1000F-4Hr-AC	188	183	25	10	214
4506(2)	7	2	2	2Cr-2Sn-2Zr	As Rolled+1000F-4Hr-AC	208	204	27	12	248
do.	do.	do.	do.	do. do. do.	As Rolled+1000F-8Hr-AC	208	205	32	13	232
do.	do.	do.	do.	do. do. do.	1450F-1/4Hr-AC+1000F-4Hr-AC	216	211	7	5	215
do.	do.	do.	do.	do. do. do.	1450F-1/4Hr-AC+1000F-8Hr-AC	210	200	9	5	219

(1) Notch acuity factor K_t=8.
(2) Finish rolled above beta transus, all others finished rolled below beta transus.

The alloys of our invention may be made by the conventional industrial technique of compacting sponge blended with the basic or master alloy, melting and remelting the blend in a vacuum or in an inert gas atmosphere followed by forming operations such as forging, rolling, drawing, etc. into the desired semi-finished product. The semi-finished product is then heat treated as necessary to enable finishing and material application. It will be found that the alloys of our invention are useful in the manufacture of aerospace vehicles and in other environments which require a high strength to density ratio.

While we have shown and described preferred embodiments of our invention, it should be understood that our invention may otherwise be embodied within the scope of the appended claims.

We claim:

1. A titanium base alloy consisting essentially of 6.3 – 11.0 percent vanadium, 1.75 – 3.3 percent aluminum, 0.75 – 2.25 percent iron, up to 2.25 percent chromium, up to 1.25 percent cobalt, up to 2.25 percent tin, up to 2.25 percent zirconium, up to 0.2 percent oxygen, balance titanium, the ratio of iron to aluminum in said alloy being no greater than about 1:1 and the total of the iron and the cobalt being not greater than 2.25 percent, the foregoing quantities being in terms of weight percent.

2. An alloy according to claim **1** consisting of 10 percent vanadium, 2 percent iron and 3 percent aluminum.

3. An alloy according to claim **1** consisting of 7 percent vanadium, 2 percent iron, 2 percent aluminum and including 2 percent chromium, 2 percent tin and 2 percent zirconium, said alloy characterized by a K_{IC} fracture toughness of at least 35 Ksi/ $\sqrt{\text{in.}}$

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,802,877 Dated April 9, 1974

Inventor(s) Warren M. Parris and Harry W. Rosenberg

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In Table I after Footnote (2) insert the following:

--(3) Elongation to fracture of 0.2 inch length that includes the Fracture. --.

--(4) Total elongation over 1 inch gage length. --.

Signed and sealed this 30th day of July 1974.

(SEAL)
Attest:

McCOY M. GIBSON, JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

FORM PO-1050 (10-69)

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* U.S. GOVERNMENT PRINTING OFFICE : 1969 O—366-334.