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TITANIUM BASE ALLOYS

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This invention relates to titanium base alloys, and is a continuation-in-part of our application Serial No. 548,235, filed November 21, 1955. The alloys concerned are alpha-titanium (hexagonal close-packed structure) an dhave good creep resistance at 400-500° C. and good forgeability.

It is known that alpha-titanium alloys are more likely to be more creep resistant due to their hexagonal close-packed structure than the body centre cubic structure beta alloys. While additions such as aluminum, tin, zirconium, oxygen and nitrogen are known to stabilize the alpha form of titanium, such simple alloys are difficult to manipulate as they are stable alpha in the forging range. Also, the best creep resistance can, so far as we are aware, only be imparted to titanium alloys, as with other alloy systems, when suitable precipitation hardening phases are present.

According to this invention, titanium alloys contain all three of:

(*a*) One or more elements for the strengthening of solid solution of alpha-titanium,

(*b*) One or more beta-forming elements which do not form intermetallic compounds but which make the alloy duplex (i.e. alpha and beta phases) in the forging range, which is usually about 700 to about 1100° C, and

(*c*) One or more elements which form precipitation hardening compounds with titanium.

As stated above, examples of alpha-strengthening or stabilizing agents are aluminum, tin, zirconium, oxygen and nitrogen.

The most readily available beta-forming element which does not form an intermetallic compound is molybdenum, but this may be replaced in whole or in part by one or more of the elements vanadium, niobium and tantalum.

Any of the known elements which form precipitation hardening compounds with titanium may be used. Examples of suitable elements are silicon, chromium, manganese, boron, and beryllium. Iron can be tolerated so long as one of the above elements is present.

The following are suitable ranges for the three essential simultaneous additions to titanium for improved or optimum creep strength and ease of fabrication:

(*a*) *Alpha-strengtheners.*—One or more of:

	Percent
Aluminum (preferred)	2–10
Tin	0–8
Zirconium	0–10
Oxygen	0.02–0.3
Nitrogen	0.02–.02

In this range, oxygen and nitrogen are shown as essential because they are invariably present as impurities, oxygen being usually present between 0.1% to 0.2% and nitrogen about 0.1%. If oxygen-free or nitrogen-free alloys could be prepared they would be regarded as being within the scope of the invention so long as aluminum with or without tin and/or zirconium were present within its or their respective ranges.

(*b*) *Beta-formers.*—One or more of:

	Percent
Molybdenum (preferred)	0–8
Vanadium	0–10
Niobium	0–10
Tantalum	0–10

(*c*) *Precipitation hardening elements.*—One or more of:

	Percent
Silicon (preferred)	0–2
Chromium	0–2
Manganese	0–2
Boron	0–0.5
Beryllium	0–0.5
With or without iron	Up to 1

The remainder consists of titanium and incidental impurities.

Examples of alloys according to the invention are:

Example No.	Composition in weight percent. Balance Ti and impurities												
	Al	Sn	Zr	Mo	V	Nb	Ta	Si	Cr	Mn	B	Fe	Be
F.T. 401	2	4		4				0.5					
T. 44	4			4				0.1	0.2	0.2			
T. 45	4			4				0.2	0.4	0.4			
T. 46	4			4				0.3	0.6	0.6			
T. 47	4			4				0.4	0.8	0.8			
T. 53	4	2		4						0.5			
F.T. 397	4	2		4				0.5	1				
T. 55	4	2		4					2				
F.T. 398	4	2		4				0.5		1			
T. 58	4	2		4						2			
F.T. 407	4		3	4				0.5					
T. 136	4	2	5	4				0.5					
F.T. 403	4		8	4				0.5					
F.T. 404	2		10	4				0.5					
T. 140	4	2		4				0.5			0.1		
F.T. 416	4	2		4				0.5			0.25		
F.T. 417	4	2		4				0.5			0.5		
T. 144	4	2		4				0.5					0.25
T. 191	4	2		4									0.1
F.T. 418	4	2		4				0.5					0.5
T. 102	4	2		4				0.1					
T. 262	4	2		4				0.3					
T. 263	4	2		4				0.4					
T. 51	4	2		4				0.5					
T. 264	4	2		4				0.6					
T. 104	4	2		4				0.75					
T. 52	4	2		4				1					
T. 186	4	2		4				2					
T. 91	6	2			2			0.5					
T. 156	6			4				0.5					

Example No.	Composition in weight percent. Balance Ti and impurities												
	Al	Sn	Zr	Mo	V	Nb	Ta	Si	Cr	Mn	B	Fe	Be
T. 107	6	2	------	4	------	------	------	0.5	------	------	------	------	------
F.T. 408	6	------	1	4	------	------	------	0.5	------	------	------	------	------
T. 295	6	------	5	4	------	------	------	0.5	------	------	------	------	------
T. 292	8	------	------	4	------	------	------	0.5	------	------	------	------	------
T. 291	8	2	------	4	------	------	------	0.5	------	------	------	------	------
F.T. 402	10	8	------	4	------	------	------	1	------	------	------	------	------
F.T. 405	4	1	------	1	------	------	------	0.5	------	------	------	------	------
F.T. 406	4	4	------	1	------	------	------	0.75	------	------	------	------	------
T. 124	4	2	------	6	------	------	------	0.5	------	------	------	------	------
F.T. 409	4	2	------	8	------	------	------	0.5	------	------	------	------	------
T. 106	4	6	------	4	------	------	------	0.5	------	------	------	------	------
T. 138	4	2	------	------	2	------	------	0.5	------	------	------	------	------
T. 181	4	2	------	------	8	------	------	0.5	------	------	------	------	------
F. T. 414	4	2	------	4	------	------	1	0.5	------	------	------	------	------
T. 170	4	2	------	------	------	------	6	0.5	------	------	------	------	------
F. T. 415	4	2	------	1	------	------	10	0.5	------	------	------	------	------
T. 145	4	2	------	------	------	1	------	0.5	------	------	------	------	------
T. 147	4	2	------	------	------	4	------	0.5	------	------	------	------	------
F. T. 412	4	2	------	2	------	7	------	0.5	------	------	------	------	------
F. T. 413	4	2	------	1	------	10	------	0.5	------	------	------	------	------
F. T. 410	4	2	------	1	10	------	------	0.5	------	------	------	------	------
F. T. 411	4	2	------	8	1	------	------	0.5	------	------	------	------	------
T. 158	4	2	------	2	2	------	------	0.5	------	------	------	------	------
T. 183	4	2	------	2	4	------	------	0.5	------	------	------	------	------
F. T. 419	4	2	------	4	------	------	------	0.5	------	------	------	0.1	------
F. T. 399	4	2	------	4	------	------	------	0.5	------	------	------	0.5	------
F. T. 400	4	2	------	5	------	------	------	0.5	------	------	------	1	------

In these examples, oxygen and nitrogen may be present as impurities in the usual amounts as hereinbefore set forth.

Properties of the foregoing examples are as follows:

Example No.	Creep Tests—Percent Strain in 100 hrs. at temp.			U.T.S. tons/in.²	Tensile Tests	
	25 tons/in.² 400° C.	30 tons/in.² 400° C.	15 tons/in.² 500° C.		Elong'n., Percent	Red'n. of Area, Percent
T. 44	0.1	----------	----------	72	11	----------
T. 45	0.089	----------	----------	68	14	----------
T. 46	0.080	----------	----------	72	6	----------
T. 47	0.080	----------	----------	74	8	----------
T. 53	0.089	----------	----------	71	11	----------
T. 136	0.051	----------	0.18	64.5	13	38
T. 140	0.047	----------	0.36	77.2	16.5	42
T. 144	0.082	----------	0.75	82.5	12.4	32
T. 191	----------	0.17	0.735	68	20	22
T. 102	----------	0.175	----------	----------	----------	----------
T. 262	----------	0.104	----------	----------	----------	----------
T. 263	----------	0.086	----------	77	15	33
T. 51	0.076	0.065	----------	83	11	40
T. 264	----------	0.068	----------	79	13.5	36
T. 104	0.072	----------	----------	74.5	12.3	37
T. 52	0.055	0.069	----------	76.2	13.8	37
T. 186	----------	0.112	----------	63.4	5.5	----------
T. 156	----------	0.046	0.365	78.6	15	38
T. 107	----------	0.040	0.37	82.4	10	34
T. 295	----------	0.068	0.34	82.4	12	18
T. 292	----------	0.033	0.28	86.1	14	22
T. 291	----------	0.026	0.238	93	15	20
T. 124	0.062	----------	0.47	92	10	27
T. 106	0.060	----------	----------	75	13.7	----------
T. 138	0.077	----------	0.90	61	15.4	27
T. 181	0.165	----------	1.84	78.6	9.7	20
T. 170	0.140	----------	1.0	61.4	16.2	29
T. 145	0.130	----------	0.36	60	16.9	32
T. 147	0.14	----------	1.05	60.5	16.9	39
T. 158	0.12	----------	1.3	82.6	15.8	39
T. 183	0.11	----------	1.0	81.1	14.1	38

The remaining examples, namely Nos. F.T. 397–419 inclusive, all have a creep strength of more than 20 tons/sq. inch at 400° C. based on a strain criterion of 0.1% total plastic strain in 100 hours.

It will be understood by those skilled in the art that the creep strength of an alloy is inversely related to the percentage strain in a given time under standard conditions of stress and temperature.

For the purposes of comparison, the compositions and properties of four alloys which are not according to the invention in that they contain no precipitation hardening additions, are:

Example No.	Comp'n., Wt. percent (all balance Ti and impurities)	Creep Tests—percent strain in 100 hrs. at T.			U.T.S., t/in.²	Tensile Tests	
		25 t/in.² 400° C.	30 t/in.² 400° C.	15 t/in.² 500° C.		Elong'n., Percent	R. of A., Percent
T. 48	4 Al, 2 Sn, 4 Mo	0.21	0.44	----------	67.8	13.8	49
T. 289	6 Al, 4 Mo	----------	0.26	1.26	70.2	16	38
T. 293	6 Al, 5 Zr, 4 Mo	----------	0.100	0.585	81.6	12.5	38
T. 290	8 Al, 4 Mo	----------	0.128	0.87	80.6	16	34

The heat treatment used for the above tests was air cooling from 900° C., ageing for 24 hours at 500° C., and air cooling.

The heat treatment afforded the alloys for the above tests was similar to that hereinbefore set forth.

Example T. 48 may be compared with the examples ac-

cording to the invention which have 4% Al, 2% Sn and 4% Mo together with precipitation hardening additions with or without additional alpha-strengthener(s) and/or beta-former(s). Examples T. 289 and T. 293 can be compared with the following examples according to the invention: T. 156, T. 107 and T. 295. Example T. 290 can be compared with Examples T. 292 and T. 291 which are according to the invention. It will readily be observed that incorporation of a precipitation hardening addition or additions with or without additional alpha-strengthener(s) and/or beta-former(s) gives rise to markedly improved properties.

Alloys according to the invention may also contain carbon up to 2%, with a preferred upper limit of 1% and a preferred lower limit of 0.1%. It has been found that the room temperature tensile strength of the alloys is improved by the addition of carbon in the above range or preferred range. Any of the examples hereinbefore set forth can therefore contain, in addition to oxygen and/or nitrogen, carbon within the above-stated range or preferred range and serve to improve the room temperature tensile strength of the alloys disclosed. For example, the effect of adding 0.2% carbon to the alloy according to Example T. 51 aforesaid is to improve the tensile properties thereof as follows: ultimate tensile stress 99.2 tons per square inch, elongation 9.9%, and reduction of area 16%.

We claim:

1. A creep resistant titanium alloy consisting of at least one alpha-strengthening element selected from the group consisting of about 4–6% aluminum and about 2% tin, at least one of the beta-forming elements selected from the group consisting of about 4% molybdenum and about 2% vanadium, a precipitation hardening element selected from the group consisting of about 0.1 to 0.5% silicon, and about 0.2 to 2% manganese, and the balance titanium and impurities.

2. A creep resistant titanium alloy consisting essentially of about 4% aluminum, about 2% tin, about 4% molybdenum, about 0.5% silicon, and the balance titanium and impurities.

3. A creep resistant titanium alloy consisting essentially of about 4% aluminum, about 4% molybdenum, one or more of the precipitation hardening elements selected from the group consisting of about 0.1 to 0.5% silicon, and about 0.2 to 0.8% manganese, and the balance titanium and impurities.

4. A creep resistant titanium alloy consisting essentially of about 4% aluminum, about 2% tin, about 4% molybdenum, about 0.5 to 2% manganese, and the balance titanium and impurities.

5. A creep resistant titanium alloy consisting essentially of about 4% aluminum, about 4% molybdenum, about 2% tin, and the balance titanium and impurities.

6. A creep resistant titanium alloy consisting essentially of about 6% aluminum, about 2% tin, about 0.5% silicon, about 2% vanadium, and the balance titanium and impurities.

7. Creep resistant titanium alloys consisting essentially of 2–10% aluminum, 1–8% molybdenum, and 0.1–2% silicon, balance titanium and impurities.

8. Alloys according to claim 7, containing in addition at least one of the alpha-strengthening elements selected from the group consisting of

	Percent
Tin	Up to 8
Zirconium	Up to 10

9. Alloys according to claim 7, containing in addition at least one of the beta-forming elements selected from the group consisting of

	Percent
Vanadium	Up to 10
Niobium	Up to 10
Tantalum	Up to 10

10. Alloys according to claim 7, containing in addition at least one precipitation hardening element selected from the group consisting of

	Percent
Manganese	Up to 2
Boron	Up to 0.5
Beryllium	Up to 0.5

11. Creep resistant titanium alloys consisting of 2–10% aluminum, 1–8% molybdenum, 0.1–2% silicon, up to 1% of iron, and the balance titanium and impurities.

12. Creep resistant titanium alloys consisting of 2–10% aluminum, 1–8% molybdenum, 0.1–2% silicon, at least one of the interstitial elements

	Percent
Oxygen	0.02–0.3
Nitrogen	0.02–0.2
Carbon	0.1– 1

and the balance titanium.

13. A creep resistant titanium alloy consisting essentially of about 4% aluminum, about 2% tin, about 5% zirconium, about 4% molybdenum, about 0.5% silicon, and the balance titanium and impurities.

14. A creep resistant titanium alloy consisting essentially of about 4% aluminum, about 2% tin, about 4% molybdenum, about 0.5% silicon, about 0.1% boron, and the balance titanium and impurities.

15. A creep resistant titanium alloy consisting essentially of about 6% aluminum, about 4% molybdenum, about 0.5% silicon, and the balance titanium and impurities.

16. A creep resistant titanium alloy consisting essentially of about 6% aluminum, about 2% tin, about 4% molybdenum, about 0.5% silicon, and the balance titanium and impurities.

17. A creep resistant titanium alloy consisting essentially of about 6% aluminum, about 5% zirconium, about 4% molybdenum, about 0.5% silicon, and the balance titanium and impurities.

18. A creep resistant titanium alloy consisting essentially of about 8% aluminum, about 4% molybdenum, about 0.5% silicon, and the balance titanium and impurities.

19. A creep resistant titanium alloy consisting essentially of about 8% aluminum, about 2% tin, about 4% molybdenum, about 0.5% silicon, and the balance titanium and impurities.

References Cited in the file of this patent

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