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TITANIUM BASE ALLOYS CONTAINING ALUMINUM AND TIN

Robert I. Jaffee, Worthington, and Horace R. Ogden and Daniel J. Maykuth, Columbus, Ohio, assignors, by mesne assignments, to Rem-Cru Titanium, Inc., Midland, Pa., a corporation of Pennsylvania

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This invention relates to titanium base alloys and particularly to alloys of titanium with aluminum and tin. The invention further contemplates the addition to a titanium-aluminum-tin base of one or more of numerous substitutional ingredients, among which are antimony, beryllium, bismuth, copper, manganese, silver and zirconium.

The use of titanium as a structural material is limited by its relatively low strength and high cost, and it becomes desirable to alloy titanium with such other metals as will increase the strength to acceptable levels and preferably at the same time effect some reduction in the total material cost. Aluminum is a metal well suited to the attainment of these objectives. It is quite plentiful, has a low density, and has a material strengthening effect on titanium. However, the amount of aluminum alone that can be added to titanium is limited by its adverse effect on ductility. Binary alloys of titanium with more than about 5% of aluminum are too brittle for most structural uses; and such binary alloys containing less than about 5% of aluminum do not possess sufficient strength to be of general utility. A further strengthening, as well as an increase in the amount of relatively inexpensive aluminum, is highly desirable.

The present invention, in one of its aspects, comprises the discovery that the addition to titanium-aluminum alloys of a few percent of tin, effects a marked improvement in the properties of titanium-aluminum alloys of a given aluminum content, say 3.5% to 5%, and likewise enables an increase of the aluminum content up to about 7.5% with a material increase in strength, while maintaining adequate ductility.

The invention further contemplates, in its broader aspect, a series of alloys which may be

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regarded as additions of aluminum, with or without other ingredients, to a titanium-tin base. The tin content of such alloys may range from about 1% to 23%, with the aluminum ranging from about 0.25 to 7.5% depending on the tin content, the aluminum being preferably on the low side when the tin is on the high side and vice versa. It has been found that these alloys, particularly those of relatively high tin content, not only have excellent properties when made from substantially pure titanium, but are characterized by a most unusual tolerance for the interstitial ingredients, carbon, oxygen and nitrogen. For example, an alloy of 10% tin, 2% aluminum, 0.2% nitrogen, balance titanium, possesses a rare combination of high strength and good ductility.

For producing ductile titanium-tin-aluminum alloys in accordance with the invention, having good forging and rolling properties, the aluminum content is preferably related to the tin content substantially in accordance with the following proportions:

Table I

Tin Content, Percent	Aluminum Content, Percent
1	0.5–6
5	0.5–5
10	0.5–4.5
15	0.25–4
20	0.25–3
23	0.25–1

The metal used as a base for any of the alloys of the present invention may contain the interstitial contaminants, carbon, oxygen and/or nitrogen, in amounts ranging from 0.02% up to at least the total quantity to be found in good

commercial titanium. Further controlled additions of the interstitials show some distinctive effects. In general, the tolerance for the interstitials, as determined by a ductility requisite to broad and varied utility, is greater than that of most titanium alloys, and this is particularly true of those alloys which contain a relatively small amount of aluminum. For example, in alloys containing not over 5% tin and not over about 2% aluminum, carbon may be added up to about 1% without excessive embrittlement.

However, increasing the metallic alloy constituents diminishes the carbon tolerance. For example, in an alloy containing say 13% tin and 3% aluminum, balance titanium, the bend ductility deteriorates rapidly if the carbon content is increased above about 0.2%. As distinguished from carbon, the tolerance for nitrogen diminishes more slowly from a maximum of about 0.3% for a very low content of aluminum and tin to a value between 0.15% and 0.19% which remains almost constant for a wide range of compositions. Oxygen occupies an intermediate position, the tolerance therefor decreasing at a more constant rate from a maximum of about 0.5%. The permissible oxygen content of an alloy containing 13% tin, 3% aluminum is about 0.2%.

The alloys of this invention may be prepared by melt-casting in an atmosphere of argon, rolling at a suitable temperature, say 850° C. to 980° C., and annealing under conditions which will effect recrystallization but not substantial grain growth or re-solution of carbides. A typical but by no means universal annealing treatment comprises soaking at a temperature of about 850° C. for from 2 to 3½ hours. The rate of cooling after annealing is not material, since in these alloys the titanium, with the exceptions noted later, is all in the alpha phase except for minor amounts which may be combined as titanium-carbide.

The properties of selected alloys of titanium of requisite purity with aluminum and tin, as annealed for 3½ hours at 850° C., unless otherwise noted, are as follows:

Table II

[Iodide titanium-base alloys]

Composition, Percent (Balance Titanium)			Tensile Properties: p. s. i.×1,000				
Al	Sn	C	Annealed V. H. N. Surface	0.2% Offset Yield	Ultimate Strength	Elongation 1", Percent	Bend T
0	0		88	22	37	61	0
5	1		278	67	78	15	.7
5	2.5		312	81	88	14	1.6
5	5		312	90	94	12	1.1
5	2.5	.1	385	129	144	12	1.4
5	2.5	.2	404	130	145	12	1.6
5	2.5	.3	426	149	152	3	[3]
5	2.5	.35	427	140	144	4	[3]
5	1.5	.25	394	140	149	9	4.4
5	2	.25	389	140	151	13	4.2
5	3	.25	390	139	149	13	4.2
5	3.5	.25	399	144	161	11	4.2
5	5	.25	391	144	147	17	2.3
5	7.5	.25	398	[3]	110	0	6.2
[1] 7.5	1		357	103	106	20	2.8
7.5	2.5		324	94	101	16	1.8
7.5	5		357	109	118	14	.7
[1] 7.5	7.5		398	116	116	[3]	[3]
[2] 7.5	2.5	.25	392	136	138	10	2.3
[2] 7.5	2.5	.25	393	132	132	9	6

[1] Annealed 4 hours at 925° C.
[2] Annealed 3½ hours at 850° C. plus 1 hour at 925° C.
[3] Brittle.

In the foregoing table, and those which follow, "bend ductility" is measured as the radius upon which the alloy can be bent without fracture to an angle of 75°, the radius being stated as a multiple of the specimen thickness.

Microscopic examination shows most of these alloys to be of small grain size, probably due to a fine distribution of carbides. Carbon is less soluble in beta titanium than in alpha titanium, hence in a melt containing, say 0.2 carbon, a substantial proportion of the carbon will be present as carbides, which as the melt congeals are frozen in a matrix of beta titanium in a fine dispersion. As recrystallization proceeds without substantial solution of carbides, the numerous carbide particles form nucleation sites for the growth of relatively small alpha grains, and inhibit the growth of large grains. Grain sizes as small as 0.012 mm. and 0.015 mm. have been observed repeatedly, and the average grain size is from about 0.020 mm. to 0.030 mm. Fine grain size and the presence of visible carbide particle stringers are associated with the substantial differences between yield strength and ultimate strength appearing in the above table. This characteristic renders the alloys universally useful, being particularly advantageous for sheet and other forms which are stretched in fabrication.

All of the alloys whose properties are tabulated in Table II above contain a minimum of 5% of aluminum and show embrittlement by a tin content of about 7.5%. A reduction of the aluminum content, say to 2%, greatly increases the tolerance for tin as well as for the interstitials, enabling the use of as much as 23% tin. For example, an alloy containing 10% tin, 2% aluminum, and 0.2% nitrogen, has a 0.2% offset yield strength of 135,000, an ultimate strength of 142 000, with an elongation of 16% and a bend ductility of 2.1 T.

Other alloys containing varying amounts of

aluminum, tin and the interstitials, and their properties as rapidly cooled after annealing in

argon for 2 hours at 850° C., are given in Tables III, IV–A and IV–B below:

Table III

[Iodide-titanium-base alloys]

Composition, Percent (Balance Titanium)				Tensile Properties: p. s. i. × 1,000					
Sn	Al	C	N	0.2% Offset Yield	Ultimate Strength	Elongation to 1"	Percent Reduction in Area	Annealed Hardness, Vickers	Min. Bend T
----	--	--	--	22	37	61	58	88	0
1	1	--	--	30	50	28	55	156	0
1	1	0.25	--	70	79	25	56	251	0.6
1	2	--	--	34	53	29	46	179	1.0
1	2	0.25	--	86	86	21	53	274	0.5
1	3	--	--	50	67	20	48	269	1.5
1	3	0.25	--	95	95	21	52	327	1.0
1	5	--	--	67	102	15	42	278	0.7
1	7.5	--	--	103	106	20	27	357	2.8
1.5	5	0.25	--	140	149	9	19	327	4.4
2	1	--	--	29	50	28	52	154	0
2	1	0.25	--	71	79	27	56	246	0
2	2	--	--	41	60	31	52	238	2.1
2	2	0.25	--	90	90	22	50	273	1.0
2	3	--	--	61	74	19	45	246	1.5
2	3	0.25	--	102	103	19	49	315	1.0
2	5	--	--	81	93	18	46	310	1.3
2	5	0.25	--	140	151	13	24	323	4.2
2	5	--	0.06	96	107	13	42	333	2.2
2	5	--	0.16	126	133	11	24	392	2.1
2	5	--	0.24	------	139	0	10	428	(1)
2	5	--	0.25	------	134	1	10	421	(1)
2.5	5	--	--	81	88	14	43	312	1.6
2.5	5	0.25	--	145	157	---------	15	329	4.2
2.5	7.5	--	--	94	101	16	42	324	1.8
2.5	10	--	--	------	107	---------	---------	408	(1)
3	1	--	--	38	57	27	48	211	1.5
3	1	0.25	--	85	90	19	54	278	1.0
3	2	--	--	48	63	21	49	235	2.1
3	2	0.25	--	96	96	27	55	301	1.0
3	3	--	--	70	82	17	44	258	1.5
3	3	0.25	--	108	109	17	58	329	1.1
3	5	0.25	--	139	149	13	27	343	4.2
3.5	5	0.25	--	144	161	11	28	355	4.2
5	2	--	--	60	75	20	41	250	1.0
5	5	--	--	90	94	12	20	312	1.1
5	5	0.25	--	144	147	17	24	391	2.3
5	7.5	--	--	109	118	14	26	357	0.7
7.5	7.5	--	--	116	116	---------	5	391	(1)
7.5	5	0.25	--	------	110	0	0	398	6.2
10	2	--	--	85	101	13	38	302	2.0
10	2	0.2	--	123	127	20	39	380	1.5
10	2	0.20	--	115	123	15	34	376	2.2
10	2	--	0.2	135	142	16	30	403	2.1
15	2	--	--	107	109	7	26	328	1.7

[1] Brittle.

Table IV–A

[Commercial-Purity Ti-Sn-Al alloys]

Composition, Percent (Balance Titanium)		Tensile Properties: p. s. i. × 1,000					
Sn	Al	0.2% Offset Yield	Ultimate Strength	Elongation to 1"	Percent Reduction in Area	Annealed Hardness, Vickers	Min. Bend T
----	---	49	76	24	44	197	1.3
1	5	106	116	16	38	374	2.7
2	5	114	122	18	39	380	2.5
2.5	5	106	114	16	41	353	1.7
3	5	108	114	18	40	357	3.3
4	5	115	118	16	31	370	5.7
5	1	74	87	27	44	268	1.8
5	1	83	92	21	58	299	1.7
5	3	92	102	15	28	319	2.8
5	3.5	103	121	16	24	356	3.6
5	4	104	122	19	34	360	2.7
5	4.5	117	124	19	49	373	2.2
5	5	120	125	20	47	406	2.5
9	1	86	99	19	42	299	1.7
9	2	99	109	21	46	333	2.7
9	3	110	118	18	33	357	2.5
9	3.5	120	132	19	33	390	2.5
9	4	125	132	21	40	388	4.6
9	4.5	131	131	21	46	421	2.3
9	5.0	137	137	13	30	388	3.0
13	1	112	122	18	26	345	2.5
13	2	124	124	18	30	363	2.6
13	3	135	135	12	25	366	5.1
13	2.5	134	138	20	36	394	2.5
13	4	143	146	12	27	376	4.8
13	4.5	146	149	4	18	389	(1)
13	5	----	163	1	10	422	(1)
16	1	97	131	16	21	314	1.8
16	2	133	145	19	30	344	2.4
16	3	152	164	10	19	384	(1)
16	4	----	148	1	5	387	(1)
19	1	126	147	14	29	329	1.2
19	2	135	151	7	8	342	2.3
19	3	140	154	4	9	372	(1)

[1] Brittle.

Table IV–B

[Commercial-purity Ti-Sn-Al alloys with interstitials]

Composition, percent (Balance Titanium)					Tensile Properties: p. s. i. × 1,000					
Sn	Al	C	O	N	0.2% Offset Yield	Ultimate Strength	Elongation to 1"	Percent Reduction in Area	Annealed Hardness, Vickers	Bend T
1	5	0.1	--	--	128	133	16	38	422	5.4
1	5	0.2	--	--	138	143	14	31	451	6.2
1	5	0.25	--	--	139	144	20	40	444	2.5
1	5	--	0.1	--	120	129	16	39	393	3.4
1	5	--	0.2	--	129	136	21	36	431	5.1
1	5	--	--	0.1	129	135	14	35	384	3.5
2	5	0.2	--	--	136	141	18	35	423	4.7
2	5	--	0.1	--	128	136	12	23	437	2.6
2	5	--	0.2	--	127	133	17	34	423	5.1
2	5	--	--	0.1	127	134	16	31	394	3.7
2.5	5	0.1	--	--	143	147	19	33	438	6.6
2.5	5	0.2	--	--	141	143	22	37	422	6.4
2.5	5	--	0.2	--	137	142	16	39	423	5.2
2.5	5	--	--	0.1	124	131	3	--------	421	5.5
2.5	5	--	--	0.2	151	155	5	15	442	(1)
3	5	0.1	--	--	138	141	19	33	421	4.8
3	5	0.2	--	--	140	144	17	29	421	4.5
3	5	0.25	--	--	142	144	20	35	420	2.7
3	5	--	0.1	--	132	138	16	40	421	5.2
3	5	--	0.2	--	139	143	16	31	424	5.1
3	5	--	--	0.1	122	128	6	12	392	5.6
3	5	--	--	0.2	148	152	6	15	429	(1)
4	5	0.1	--	--	130	134	20	43	405	4.9
4	5	--	0.2	--	136	137	2	15	428	7.0
4	5	--	--	0.1	129	134	12	23	404	5.4
4	5	--	--	0.2	155	156	2	12	454	(1)
5	1	0.2	--	--	105	108	25	50	322	1.2
5	1	--	0.2	--	105	106	19	42	348	3.3
5	1	--	--	0.2	127	135	21	38	373	2.0
5	2	0.2	--	--	118	125	22	49	348	2.4
5	2	--	0.2	--	117	125	24	40	333	2.4
5	2	--	--	0.3	125	132	19	40	376	2.4
5	3	0.2	--	--	125	129	20	46	363	1.9
5	3	--	0.1	--	125	139	16	31	391	4.8
5	3	--	0.2	--	124	132	20	41	390	2.2
5	3	--	0.3	--	131	147	16	31	413	6.6
5	3	--	0.4	--	151	155	6	12	431	(1)
5	3	--	--	0.20	142	146	15	16	417	2.4
9	1	0.2	--	--	118	123	23	48	357	2.4
9	1	--	0.2	--	107	118	9	11	380	2.3
9	1	--	--	0.15	120	128	9	15	373	2.4
9	2	0.2	--	--	132	136	16	38	380	2.3
9	2	--	0.2	--	110	117	5	15	376	2.3
9	2	--	--	0.16	------	143	----	20	390	3.2
9	3	0.1	--	--	131	142	16	39	401	2.4
9	3	0.2	--	--	139	142	16	40	397	3.3
9	3	0.3	--	--	147	156	23	40	418	4.9
9	3	0.4	--	--	161	163	19	32	450	(1)
9	3	--	0.2	--	130	134	17	28	401	3.3
9	3	--	--	0.20	148	152	9	14	--------	(1)
13	1	0.2	--	--	122	148	13	23	390	2.6
13	1	0.26	--	--	139	144	22	43	383	3.1
13	1	--	0.2	--	134	140	15	31	376	3.3
13	1	--	--	0.14	149	151	16	35	413	3.3
13	2	0.2	--	--	143	153	18	20	411	4.7
13	2	--	0.2	--	140	150	4	5	386	3.5
13	2	--	--	0.16	134	154	9	23	387	3.6
13	3	0.2	--	--	164	164	12	13	416	(1)
13	3	--	0.2	--	156	159	5	13	420	(1)
13	3	--	--	0.22	------	166	0	4	331	(1)

[1] Brittle.

It is thus apparent that the ternary alloys of titanium with aluminum and tin, with or without the addition of interstitials, constitute an outstandingly versatile and desirable group, offering a wide range of properties and a composition tolerance for any given set of properties which greatly facilitates their production. Particularly desirable are the alloys containing 9% to 13% tin, 2% to 4% aluminum and about 0.2% carbon or another interstitial or combination of interstitials having a hardening and strengthening effect equivalent to that of 0.2% carbon.

The alloys of this invention, in general, will withstand prolonged aging at temperatures as high as 400° C. without material embrittlement—hence, they are particularly adapted for use under high temperature conditions. Moreover, these titanium-aluminum-tin alloys are susceptible to a variety of useful modifications by the addition of fractions of other metals. For example, some compositions are benefitted by the addition of 0.5% to 5% antimony. Typical alloys and their properties are:

Composition, Percent (Balance Titanium)				Tensile Properties: p. s. i. × 1,000					
Al	Sn	Sb	C	V. H. N. Surface	Proportional limit	0.2% Offset Yield	Ultimate Strength	Elongation in 1"	Bend T
5	2.5	0.5	0.25	390	100	150	157	14	4.1
5	2.5	1.0	0.25	403	130	137	138	17	2.1
5	2.5	1.5	0.25	418	131	143	144	5	(1)
5	2.5	2.5	0.25	392	129	142	143	3	(1)
5	2.5	5	0.25	409	114	--------	134	1	(1)

[1] Brittle.

Beryllium in amounts from 0.1% to 1% is a useful adidtion, particularly for forging and casting alloys. Representative compositions and their properties are the following:

Composition, Percent (Balance Titanium)				Tensile Properties: p. s. i. × 1,000					
Al	Sn	Be	C	V. H. N. Surface	Proportional limit	0.2% Offset Yield	Ultimate Strength	Elongation in 1"	Bend T
5	2.5	0.1	0.25	396	133	133	133	22	4.0
5	2.5	0.25	0.25	409	136	137	139	10	3.8

Bismuth is useful when added in amounts from 0.5% to 5%, as shown by the following:

Intended Composition, Percent (Balance Titanium)				Tensile Properties: p. s. i. × 1,000					
Al	Sn	Bi	C	V. H. N. Surface	Proportional Limit	0.2% Offset Yield	Ultimate Strength	Elongation in 1"	Bend T
5	2.5	0.5	0.25	403	122	131	133	15	4.1
5	2.5	1.0	0.25	387	128	132	133	23	2.3
5	2.5	1.5	0.25	415	127	141	143	3	(1)

[1] Brittle.

Somewhat similar properties are found in titanium-aluminum-tin alloys containing 0.5% to 5% copper. The following are typical:

Composition, Percent (Balance Titanium)				Tensile Properties: p. s. i. × 1,000					
Al	Sn	Cu	C	V. H. N. Surface	Proportional limit	0.2% Offset Yield	Ultimate Strength	Elongation in 1"	Bend T
5	2.5	0.5	0.25	404	100	144	156	12	4.1
5	2.5	1.0	0.25	407	124	133	133	11	2.5
5	2.5	1.5	0.25	424	130	134	134	10	3.6

Manganese is a particularly desirable addition to a titanium-aluminum-tin base, being usable in amounts from 0.25% to as high as 12%. Examples are as follows:

Composition, Percent (Balance Titanium)				Tensile Properties: p. s. i. × 1,000				
Sn	Al	Mn	C	0.2% Offset Yield	Ultimate Strength	Elongation in 1"	Percent Reduction in Area	Bend T
2.5	5	0.5	0.25	133	133	11	21	3.4
2.5	5	1	0.25	136	138	13	16	4.0
2.5	5	1.5	0.25	151	152	2	2	(1)
5	2	5	--	140	145	5	26	4.5
5	1	3	--	138	145	11	35	2.0
10	2	3	--	164	164	14	47	2.2
10	3	3	--	179	181	10	34	2.5
10	1	5	--	149	156	10	41	1.5
10	2	5	--	162	167	7	13	1.8
10	3	5	--	181	185	2	8	6.2
10	1	7	--	154	164	8	33	2.5
10	2	7	--	184	186	5	12	6.5

[1] Brittle.

The properties of selected alloys of titanium, aluminum, tin and silver are as follows, the silver being added up to about 10%:

Composition, Percent (Balance Titanium)				Tensile Properties: p. s. i. × 1,000					
Al	Sn	Ag	C	V. H. N. Surface	Proportional limit	0.2% Offset Yield	Ultimate Strength	Elongation in 1"	Bend T
5	2.5	0.5	0.25	382	105	130	132	22	1.6
5	2.5	1.0	0.25	383	131	132	133	20	2.3

Zirconium is useful in amounts from 0.5% to about 20%, as exemplified by the following:

Composition, Percent (Balance Titanium)				Tensile Properties: p. s. i. × 1,000					
Al	Sn	Zr	C	V. H. N. Surface	Proportional limit	0.2% Offset Yield	Ultimate Strength	Elongation in 1"	Bend T
5	2.5	0.5	0.25	377	126	129	132	19	2.3
5	2.5	1.0	0.25	391	133	137	138	21	4.5

The aforesaid additions of one or more of antimony, beryllium, bismuth, copper, manganese, silver and zirconium are preferably alloyed with a titanium-tin-aluminum base containing about 1 to 5% tin, and 0.25 to 7.5% aluminum, and optimally about 3.5 to 7.5% aluminum. The added elements aforesaid retain the alpha structure of the base alloy with the exception of beryllium, copper and manganese. Beryllium forms intermetallic compounds. Copper and manganese are beta promoting or forming elements, depending on the amount added, in addition to which the beta phase promoted by copper precipitates an intermetallic compound during cooling much more so than the beta phase promoted by manganese.

The above described alloys comprising additions to the Ti-Al-Sn base of antimony, beryllium, bismuth, copper, manganese, silver and zirconium, are described and claimed in our copending applications Serial No. 294,263, filed June 18, 1952, and Serial No. 400,744, filed December 28, 1953, both comprising continuations-in-part of this application.

This application is a continuation-in-part of applicants' previously filed applications, Serial No. 151,314, filed March 22, 1950; Serial No. 209,905, filed February 7, 1951; Serial No. 253,564, filed October 27, 1951; and Serial Nos. 213,681 to 213,687, inc., all filed March 2, 1951. All of the above applications have become abandoned.

What is claimed is:

1. A titanium base alloy containing about: 1–23% tin, 0.25–7.5% aluminum, characterized in being ductile and forgeable and in having a tensile strength at least 10% in excess of the unalloyed titanium base metal.

2. An alloy consisting of about: 1–23% tin, 0.25–7.5% aluminum, up to 1% carbon, up to 0.5% oxygen, up to 0.3% nitrogen, and the balance titanium.

3. A titanium base alloy containing about: 1–23% tin, 0.25–7.5% aluminum, the tin content being related to the aluminum content within said ranges, substantially in conformity with the following tabulation:

Tin, Percent	Aluminum, Percent
1	0.5–6
5	0.5–5
10	0.5–4.5
15	0.25–4
20	0.25–3
23	0.25–1

characterized in being ductile and forgeable and in having a tensile strength at least 10% in excess of the unalloyed titanium base metal.

4. An alloy consisting of about 1–23% tin, 0.25–7.5% aluminum, the aluminum content being related to the tin content within said ranges, substantially in conformity with the following tabulation:

Tin, Percent	Aluminum, Percent
1	0.5–6
5	0.5–5
10	0.5–4.5
15	0.25–4
20	0.25–3
23	0.25–1

said alloy also containing up to 1% carbon, up to 0.5% oxygen, up to 0.3% nitrogen, and the balance titanium.

ROBERT I. JAFFEE.
HORACE R. OGDEN.
DANIEL J. MAYKUTH.

References Cited in the file of this patent

"The Canadian Mining and Metallurgical Bulletin," January 1950, page 27.

"Journal of Metals," March 1950, page 498.