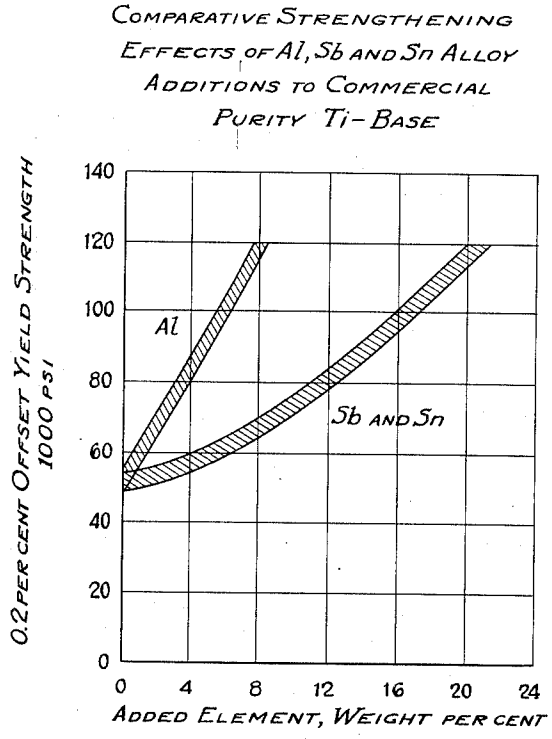
Jan. 29, 1957 R. I. JAFFEE ET AL 2,779,677

TI-SN-AL ALLOYS WITH ALPHA, BETA AND COMPOUND FORMERS

Filed Dec. 28, 1953



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United States Patent Office 2,779,677 Patented Jan. 29, 1957

2,779,677

Ti-Sn-Al ALLOYS WITH ALPHA, BETA AND COMPOUND FORMERS

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Application December 28, 1953, Serial No. 400,744

14 Claims. (Cl. 75—175.5)

This invention pertains to improvements in titanium base alloys, and provides a series of alloys of high strength and ductility, and, as to certain analyses, also of high contamination resistance and high strength at elevated temperatures, and containing as essential constituents titanium, tin and aluminum, together with one or more additional metals selected from the groups comprising alpha promoters, beta promoters and compound formers as enumerated below.

This application is a continuation-in-part of applicants' prior applications Serial Nos. 151,314, filed March 22, 1950, now abandoned; 209,905, filed February 7, 1951, now abandoned; 253,564, filed October 27, 1951, now abandoned; 213,681 to 213,687, inc., all filed March 2, 1951, now abandoned; 285,076, filed April 29, 1952, now Patent No. 2,669,513, granted Feb. 16, 1954; and 294,263, filed June 18, 1952, now abandoned.

The aluminum content may be present over a broad range of about 0.25 to 8% and preferably about 1 to 8%.

The tin content may be present over a broad range of about 1 to 23%, with a preferred lower limit of about 2.5%, as adjudged from the standpoint of good room temperature mechanical properties, and a preferred lower limit of about 5% as regards the imparting of high contamination resistance at elevated temperatures. To the titanium-tin-aluminum alloy aforesaid, there may advantageously be added up to about 20% in aggregate of one or more of the other alpha promoters, up to about 50% in aggregate of one or more of certain of the beta promoters, and up to about 2 or 3% in aggregate of the compound formers, all as set forth more in detail hereinafter. For further enhancing the mechanical properties, the alloys of the invention may contain controlled amounts of the interstitials, carbon, oxygen and nitrogen. For certain analyses, as set forth below, carbon may be present up to about 1%, oxygen up to about 0.5% and nitrogen up to about 0.4%. When the total tin and aluminum content is below about 5%, and particularly when below about 2.5%, substantial additions of one or more of the interstitials carbon, oxygen and nitrogen or of metal of the alpha and/or beta promoter groups, is required for imparting high tensile properties for commercial applications, as elaborated upon below.

As above stated, the alloys of the invention are in general characterized by excellent room temperature mechanical properties, possessing high tensile strength as compared to the unalloyed titanium base metal or as compared to the corresponding binary titanium-tin and titanium-aluminum alloys, combined with adequate ductility for both hot and cold forming operations, i. e., forging, rolling, drawing, extruding, etc. For tin contents up to about 16%, they may likewise, in general, be welded without appreciable loss of ductility in the welded as compared to the non-welded portions. This is particularly true as regards those alloys having an all-alpha microstructure, and also as to certain of those having a beta-

containing microstructure, as explained more in detail below.

For imparting a high degree of contamination resistance, i. e., resistance against penetration by atmospheric gases, particularly oxygen and nitrogen, at elevated temperatures up to about 1100° C., the alloys should contain upwards of about 5% tin, although lesser amounts down to about 2% tin, are materially beneficial in this respect. Tin alloyed with titanium base metal appears to be unique in imparting this contamination resistance, and its effect is quite critical with respect to the degree of contamination resistance imparted commencing at a minimum of about 5% tin.

These contamination resistant alloys are also characterized by free scaling properties resulting from exposure to elevated temperatures up to about 1100° C. and to atmospheric, oxidizing, or alternately oxidizing and reducing conditions. That is to say, the scale formed is easily brushed off or flakes off during hot forming operations, such as forging or rolling.

Test results in support of the above are given in a copending joint application of the present applicants Jaffee and Ogden and W. L. Finlay, Serial No. 341,796, filed March 11, 1953, now Patent No. 2,669,514.

As is known, the metal titanium in the pure state, is capable of existing in either of two allotropic forms. Below a temperature of about 885° C. or 1625° F., it assumes a close-packed hexagonal structure known as the alpha phase, while at this temperature and above, it assumes a body-centered cubic structure known as the beta phase.

Certain substitutional alloying additions to the titanium base metal, among which may be mentioned aluminum, tin, antimony, indium, silver, bismuth, lead, cadium, zinc, and thallium as well as the interstitials carbon, oxygen and nitrogen may be termed alpha stabilizers or alpha promoters. The term alpha stabilizer includes those elements which raise the transformation range sharply, such as aluminum, oxygen, and nitrogen. Also alpha stabilizers include elements such as carbon, which have a relatively small solubility in alpha titanium, but which raise the transformation temperature for that amount which is in solution. Alpha stabilizers also include those elements such as tin, antimony, indium, and silver which have relatively large solubilities, of about the same magnitude, in both the alpha and beta phases and which have little effect on the transformation temperature range, neither raising nor lowering it markedly. A common characteristic of all alpha stabilizers, as we are considering them here, is that little or no hardening occurs in the thermal processing. The resulting alloys are, at room temperature, always all alpha in structure regardless of the heat treatment, including quenching or aging. Actually little is known concerning the specific effects of bismuth, lead, cadmium, zinc, and thallium on the transformation range. These alloying elements produce alloys which fit the criteria given, namely, that they form all-alpha alloys, which do not retain any substantial content of beta phase nor harden appreciably on quenching from the beta field. Hence these elements appear properly classified as alpha promoters, and will be so treated in this application.

Other substitutional alloying elements, when added in progressively increasing quantities, stabilize the beta phase at progressively lower temperatures, until a mixed alpha-beta or stable all-beta microstructure is obtained at normal or atmospheric temperatures, or the beta phase undergoes a eutectoid reaction, depending on the character and amount of the beta stabilizers added as discussed below.

Speaking in broadest terms, the beta stabilizers are Mo, V, Cb, Ta, Zr, Mn, Cr, Fe, W, Ni, Co and Cu. Silicon and beryllium may also be considered as beta stabilizing elements, but their solubilities in titanium are

relatively so slight and the tendency of the beta phase stabilized by these elements to decompose into eutectoid products so great, that it is equally proper to consider them as compound-forming elements. Within this broad category, however, only certain of the elements mentioned are suitable for producing mixed-phase, alpha-beta alloys, or all-beta alloys. These are the elements which have beta-isomorphous diagrams, or which have beta-eutectoid diagrams such that the decomposition of the beta phase into eutectoid is so sluggish that the alloys behave like those in a beta-isomorphous system. The beta stabilizing elements of this type are Mo, V, Cb, Ta, Mn, Fe and Cr. Tungsten is a borderline element as between the sluggishly decomposing and rapidly decomposing types and hence may be classified either way. Within this limited group only Mo, V, Cb and Ta are beta-isomorphous. They form the most thermally stable beta-containing alloys, as a result of their beta-isomorphism.

Zirconium is a beta promoter or stabilizer in the sense that the lowest temperature at which alloys thereof with titanium are entirely beta, becomes progressively lower with increasing amounts of zirconium, until a composition is reached at which this so-called beta transus temperature starts to increase again with further additions of zirconium. While zirconium thus lowers the transformation temperature of titanium, the alloys eventually revert to the alpha phase at lower temperatures unless other beta promoters are present. Zirconium is isomorphous with titanium both in the alpha and beta fields. As a result, it is proper to consider zirconium together with vanadium, molybdenum, columbium and tantalum as all being beta-isomorphous with titanium.

The use of copper alone as an alloying addition to titanium, does not fit into the above-mentioned grouping of beta-isomorphous and sluggishly decomposing eutectoid beta promoters, because the beta phase stabilized by copper always decomposes rather rapidly into pro-eutectoid and eutectoid products, and the same is generally true with respect to cobalt, nickel silicon and beryllium, above listed under the broad category of beta stabilizers. Copper, however, is a useful addition when present as a minor alloying element, for example, up to a few percent, in alloys containing larger amounts of other beta-stabilizing elements, within the narrow group of elements last mentioned above since, in these low concentrations and in the presence of such other beta-stabilizing elements, the tendency of the beta phase stabilized in part by copper to decompose into eutectoid products is minimized or entirely eliminated.

The tolerance of the ductile Ti-Sn-Al base alloys of the invention with respect to additions of the various beta promoters above mentioned, varies considerably for the individual elements of this group, being greatest with respect to those which form beta-isomorphous systems with titanium, and least for those which decompose most readily into eutectoid decomposition products. Thus, the Ti-Sn-Al base alloys may be strengthened without undue embrittlement by additions of up to about 50% in aggregate of elements composing the beta-isomorphous group, viz., molybdenum, vanadium, columbium, tantalum and zirconium, since these elements are soluble in all proportions in beta titanium. Of the sluggishly decomposing elements, the base alloy will tolerate additions of up to about 20% of either or both chromium and tungsten, up to about 10% manganese, and up to about 7% iron. Metal of the group cobalt, nickel and copper may be added up to a total of about 5%. For additions of all of the above-mentioned beta promoters, the lower effective limit is about 0.5% and preferably about 1%.

The tolerance of the ductile Ti-Sn-Al base alloys for the other alpha promoters depends on the amount of tin and aluminum present, the less tin and aluminum present, the greater the amount of other alpha promoters that can be added, and vice versa. Antimony may be added

to a maximum content of 18%. The preferred proportioning of the antimony content in relation to the tin and aluminum contents are given below. Indium may be added up to a maximum content of 15%. Silver may be added up to about 20%. Cadmium, zinc, thallium, bismuth and lead may be added up to 15% each, added to the charge in melting. The lower effective limit for the alpha promoters is about 0.5% and preferably about 1%.

The elements Ce, B, As, S, Te and P are strictly compound forming elements. They do not have appreciable solubilities in either the alpha or beta phases, but form intermetallic compounds with titanium. The beta promoters silicon and baryllium are likewise best grouped as compound forming elements, in view of their above-mentioned low solubilities in titanium and the tendency of the beta phase stabilized by these elements to decompose rapidly into eutectoid products. The Ti-Sn-Al base alloys of the invention will tolerate only relatively small amounts of these compound forming elements, i. e., up to a total of about 2 or 3% maximum, the lower effective limit being about 0.1 or 0.2%.

Substantially pure and ductile metallic titanium may be produced at considerable expense by the so-called "iodide" process described in U. S. Patent 1,671,213 to Van Arkel; while ductile titanium of commercial purity is produced more cheaply by the magnesium reduction of titanium tetrachloride by the process described in U. S. Patent 2,205,854 to Kroll. Both procedures, particularly the latter, result in some contamination of the titanium metal with one or more of the interstitials, carbon, oxygen and nitrogen. But since, as noted above, these are all alpha promoting or stabilizing elements, the resultant somewhat contaminated titanium metal obtained, has at room temperatures a single phase, all-alpha microstructure.

The all-alpha, all-beta and mixed alpha-beta alloys of titanium have their respective advantages and disadvantages. Generally speaking, the alpha alloys provide good all-around performance, having good weldability, and being strong and resistant to oxidation, both cold and hot, but are somewhat inferior as to ductility. The all-beta alloys, on the other hand, have excellent bendability and ductility, are strong both hot and cold, but are somewhat vulnerable to atmospheric contamination, particularly at elevated temperatures. The mixed alpha-beta alloys provide a compromise performance as between all-alpha and all-beta alloys, being strong when cold and warm, but weak hot, while possessing good bendability and ductibility, with a moderate degree of resistance to atmospheric contamination.

Since the Ti-Sn-Al base alloys have, as above noted, an all-alpha microstructure, they may be readily welded in tin contents up to about 16%, with no appreciable impairment of ductility in the welded as compared to the non-welded portions. They also form an excellent base alloy for the quaternary and higher component alloys of the invention, that may be also welded without appreciable loss of ductility in the welded as compared to the non-welded portions. This is particularly true as regards the above-mentioned alpha-promoter additions to the base alloy. Also, in general, the quaternary and higher component alloys made by additions of the beta-isomorphous elements above designated, are weldable without appreciable impairment of ductility. It may furthermore be stated that in general the alpha-beta alloys according to the invention can be produced to have ductile welded portions if suitable post-welding heat treatments are applied as described in the co-pending application of Robert I. Jaffee, Horace R. Ogden and Ralph A. Happe, Serial No. 305,504, filed August 20, 1952 bearing common ownership.

In the ductile Ti-Sn-Al base alloys of the invention, the following Table A shows the preferred maximum aluminum content for any given tin content throughout the range above specified for these elements:

TABLE A

Percent Tin	Percent Aluminum Max.
0.25	8
1	6
5	5
10	4.5
15	4
20	3
23	1

Thus, for best results, as the tin content increases, the aluminum content should be decreased in the above proportions and vice versa.

Antimony is a particularly valuable addition to the Ti-Sn-Al base alloys of the invention, as it imparts thereto about the same strengthening effect as equivalent additions of tin or aluminum. This is shown by the following Table I presenting test data on room temperature mechanical properties which establish the upper limits for various combinations of antimony, tin and aluminum in titanium base alloys:

Table I.—Mechanical properties of Ti-Sb-Sn and Ti-Sb-Sn-Al alloys

(COMMERCIAL PURITY Ti-BASE)

[These alloys were 980° C. forged, 850° C. rolled and annealed two hours at 850° C.]

Composition, Percent (Balance Titanium)	Tensile Properties: p. s. i.X1,000				Vickers Hardness	MBR, T	
	0.2 Percent Offset Yield	Ultimate Strength	Percent Elongation in 1"	Percent Reduction in Area		L	T
5Sb	58	77	22	47	227	1.5	1.6
5Sb-5Sn	74	94	17	46	262	1.5	4.7
5Sb-10Sn	100	111	17	44	317	2.5	3.2
5Sb-15Sn	129	131	15	46	330	2.0	3.7
5Sb-17.5Sn	----------	134	0	6	338	----------	5.2
5Sb-20Sn	(1)	(1)	(1)	(1)	(1)	(1)	(1)
10Sb	77	91	19	46	267	2.5	2.5
10Sb-5Sn	100	111	17	44	317	2.5	3.2
10Sb-10Sn	125	133	16	38	320	4.9	4.9
10Sb-12.5Sn	----------	108	0	0	330	Br	7.0
10Sb-15Sn	(1)	(1)	(1)	(1)	(1)	(1)	(1)
10Sb-17.5Sn	(1)	(1)	(1)	(1)	(1)	(1)	(1)
15Sb	99	111	15	43	304	2.5	3.3
15Sb-5Sn	----------	126	0	6	354	Br	Br
15Sb-7.5Sn	(1)	(1)	(1)	(1)	(1)	(1)	(1)
10Sb	77	91	19	46	267	1.5	1.6
7.5Sb-2.5Sn	76	96	16	46	268	2.3	3.1
5Sb-5Sn	74	94	17	46	262	1.5	4.7
2.5Sb-7.5Sn	81	98	18	43	270	2.2	3.2
10Sn	77	92	20	46	278	1.7	2.1
15Sb	99	111	15	43	304	2.5	2.5
12.5Sb-2.5Sn	109	117	14	42	311	1.9	3.7
10Sb-5Sn	100	111	17	44	317	2.5	3.2
5Sb-10Sn	107	116	17	39	325	1.7	3.5
2.5Sb-12.5Sn	109	118	14	36	313	2.9	5.5
15Sn	107	117	16	45	348	1.8	2.7
10Sb-2.5Al	123	125	13	38	351	2.4	3.3
7.5Sb-2.5Sn-2.5Al	110	115	15	48	339	2.6	3.4
5Sb-5Sn-2.5Al	114	118	13	44	343	2.8	3.6/5.2
2.5Sb-7.5Sn-2.5Al	110	117	15	40	345	2.6	2.5
10Sn-2.5Al	113	119	20	43	345	2.5	3.2
10Sb-2.5Al-0.2C	143	146	16	47	393	2.0	2.8/Br
7.5Sb-2.5Sn-2.5Al-0.2C	136	137	8	24	402	2.8	2.7/5.3
5Sb-5Sn-2.5Al-0.2C	154	157	5	18	400	6.2	Br
2.5Sb-7.5Sn-2.5Al-0.2C	144	146	5	21	390	3.0	5.2
10Sn-2.5Al-0.2C	140	141	6	29	395	5.5	Br
5Al-2.5Sb	110	117	15	42	352	2.8	2.7/5.3
5Al-2Sb-0.5Sn	103	109	15	43	351	2.8	3.7
5Al-1.5Sb-1Sn	106	113	15	37	346	2.1	8.6
5Al-1Sb-1.5Sn	103	112	17	46	343	2.9	7.6
5Al-0.5Sb-2Sn	100	111	14	43	348	2.8	2.7
5Al-2.5Sn	101	110	17	47	344	2.9	2.7
5Al-2.5Sb-0.2C	128	134	7	21	389	2.8	7.6
5Al-2Sb-0.5Sn-0.2C	(1)	(1)	(1)	(1)	(1)	(1)	(1)
5Al-1.5Sb-1Sn-0.2C	132	135	17	42	394	2.8	3.5
5Al-1Sb-1.5Sn-0.2C	131	135	17	48	396	2.8	2.8/5.5
5Al-0.5Sb-2Sn-0.2C	130	134	7	28	391	2.8	2.8/5.5
5Al-2.5Sn-0.2C	134	135	9	25	400	2.8	6.8

[1] Could not be fabricated.

The data of the above Table I establishes that antimony and tin are equivalent in strengthening effect when

substituted one or the other on a weight percentage basis, i. e., percent for percent. This data also establishes that 1% aluminum is roughly equivalent to 3% of tin or antimony in strengthening effect.

This equivalency is also shown by the accompanying drawing giving the 0.2% offset yield strengths for the Ti-Al, Ti-Sn and Ti-Sb binary alloys for varying percentages of the alloying additions.

For additions of antimony to the Ti-Sn-Al alloys of the invention, the following Table B shows the preferred maximum antimony content for given aluminum and tin contents:

TABLE B

Percent Aluminum	Percent Tin	Percent Antimony Max.
0.25	5	13
1	5	11
2	5	9
3	5	7.5
4	5	6
5	5	5

For alloys of the invention containing tin approximating its lower limit, the following Table C shows the

maximum permissible antimony content for any given aluminum content:

TABLE C

Percent Aluminum	Percent Antimony Max.
0.25	18.0
1.0	16.0
2.0	14.0
3.0	12.5
4.0	11.0
5.0	10.0

Conversely, if the aluminum content approximates its lower limit, the following Table D shows the maximum permissible antimony content for any given tin content:

TABLE D

Percent Tin	Percent Antimony Max.
0	18
1	17
5	15
10	10
17.5	5
23	0.5

The following Table II gives the mechanical properties of representative Ti-Sn-Al alloys of the invention both without and with various additions of the interstitials carbon, ogygen and nitrogen. The properties are for these alloys as hot rolled to thin gauge, i. e., about 0.04 inch and thereafter annealed in argon for two hours at 850° C., unless otherwise noted.

Table II.—Mechanical properties of Ti-Sn-Al *alloys with and without additions of* C, O *and* N

Composition, Percent (Balance Titanium)					Tensile Properties: p. s. i.×1,000				Annealed Hardness, Vickers	Min. Bend T
Sn	Al	C	O	N	0.2% Offset Yield	Ultimate Strength	Percent Elongation in 1"	Percent Reduction in Area		
(IODIDE TITANIUM BASE)										
--	--	--	--	--	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
1.6	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	Br
2	5	--	--	0.25	--------	134	1	10	421	Br
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	Br
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	Br
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	--	0.2	--	115	123	15	34	376	2.2
10	2	--	--	0.2	135	142	16	30	408	2.1
15	2	--	--	--	107	109	7	26	328	1.7
(COMMERCIAL PURITY TITANIUM BASE)										
--	--	--	--	--	49	76	24	44	197	1.3
1	4	--	--	--	87	98	20	47	--------	1.7
1	5	--	--	--	106	116	16	38	374	2.7
2	4	--	--	--	90	100	22	49	--------	1.7
2	5	--	--	--	114	122	18	39	380	2.5
2.5	5	--	--	--	106	114	16	41	353	1.7
3	4	--	--	--	97	106	17	46	--------	2.5
3	5	--	--	--	108	114	18	40	357	3.3
3	10	--	--	--	110	--------	18	35	--------	2.5
4	4	--	--	--	108	116	21	44	--------	2.5
5	1	--	--	--	74	87	27	44	268	1.8
5	2	--	--	--	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
6	3	--	--	--	105	116	15	38	331	2.8
6	4	--	--	--	115	123	19	42	344	3.4

Table II.—Mechanical properties of Ti-Sn-Al *alloys with and without additions of* C, O *and* N—Continued

Composition, Percent (Balance Titanium)					Tensile Properties: p. s. i.×1,000				Annealed Hardness, Vickers	Min. Bend T
Sn	Al	C	O	N	0.2% Offset Yield	Ultimate Strength	Percent Elongation in 1"	Percent Reduction in Area		
(COMMERCIAL PURITY TITANIUM BASE)—Continued										
6	5	--	--	--	120	121	12	32	373	3.5
7	4	--	--	--	113	118	14	44	350	3.5
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	--	--	--	137	137	13	30	388	3.0
10	1	--	--	--	95	104	16	48	299	3.0
10	2	--	--	--	115	122	13	45	336	4.3
10	3	--	--	--	126	131	16	43	376	3.2
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	Br
13	5	--	--	--	--------	163	1	10	422	Br
[1] 16	1	--	--	--	97	131	16	21	314	1.8
[1] 16	2	--	--	--	133	145	19	30	344	2.4
[1] 16	3	--	--	--	152	164	10	19	384	Br
[1] 16	4	--	--	--	--------	148	1	5	387	Br
[1] 19	1	--	--	--	126	147	14	29	329	1.2
[1] 19	2	--	--	--	135	151	7	8	342	2.3
[1] 19	3	--	--	--	140	154	4	9	372	Br
1	4	0.1	--	--	101	107	19	51	--------	1.7
1	4	0.2	--	--	119	120	20	52	--------	1.7
1	4	--	0.1	--	100	109	17	44	--------	2.4
1	4	--	0.2	--	115	123	19	42	--------	3.4
1	4	--	--	0.1	122	128	18	30	--------	2.3
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	4.4
1	5	--	0.2	--	129	136	21	36	431	5.1
1	5	--	--	0.1	129	135	14	35	384	3.5
2	4	0.1	--	--	104	111	19	48	--------	1.6
2	4	0.2	--	--	122	124	22	52	--------	1.7
2	4	--	0.1	--	108	117	22	49	--------	1.7
2	4	--	0.2	--	113	121	18	47	--------	3.5
2	4	--	--	0.1	115	122	16	43	--------	2.3
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	Br
3	4	0.1	--	--	119	123	20	48	--------	1.7
3	4	0.2	--	--	125	127	23	49	--------	1.7
3	4	--	0.1	--	112	120	17	43	--------	2.6
3	4	--	0.2	--	116	124	19	45	--------	3.2
3	4	--	--	0.1	125	130	18	42	--------	4.8
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	5	15	429	Br
4	4	0.1	--	--	117	121	19	51	--------	2.5
4	4	0.2	--	--	133	133	15	50	--------	1.7
4	4	--	0.1	--	119	126	15	40	--------	2.5
4	4	--	0.2	--	132	147	21	38	--------	4.6
4	4	--	--	0.1	106	109	2	6	--------	3.0
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	Br
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	Br
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	Br
9	3	--	0.2	--	130	134	17	28	401	3.3
9	3	--	--	0.20	148	152	9	14	--------	Br

[1] Annealed 2 hours at 950° C.

Table II.—Mechanical properties of Ti-Sn-Al *alloys with and without additions of* C, O *and* N—Continued

Composition, Percent (Balance Titanium)					Tensile Properties: p. s. i. X1,000				Annealed Hardness, Vickers	Min. Bend T
Sn	Al	C	O	N	0.2% Offset Yield	Ultimate Strength	Percent Elongation in 1"	Percent Reduction in Area		
(COMMERCIAL PURITY TITANIUM BASE)—Continued										
10	3	0.4	--	--	165	165	8	24	433	Br
10	3	0.6	--	--	(2)	(2)	(2)	(2)	455	Br
10	3	0.8	--	--	(2)	(2)	(2)	(2)	478	Br
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	Br
13	3	--	0.2	--	156	159	5	13	420	Br
13	3	--	--	0.22	--------	166	0	4	331	Br
10	2.5	0.2	--	--	140	141	6	29	395	5.5
10	3	0.2	--	--	136	146	15	40	383	2.8

[2] Very brittle.

It is thus apparent that the ternary alloys of titanium with aluminum and tin, with or without additions of the 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.

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 additions of one or more of the various other metals above mentioned.

For example, the following Table III shows the effect on mechanical properties of additions of the various alpha promoters:

Table III

(Ti-Sn-Al BASE PLUS ALPHA PROMOTERS)

Composition, Percent (Balance Titanium)				Tensile Properties: p. s. i. X 1,000				VHN	Min. Bend T
Sn	Al	Other	C, O, N	0.2% Offset Yield	Ultimate Strength	Percent Elongation in 1"	Percent Reduction in Area		
(IODIDE TITANIUM BASE)									
		Sb							
2.5	5	0.5	0.25 C	150	157	14	23	390	4.1
2.5	5	1.0	0.25 C	137	138	17	26	403	2.1
2.5	5	1.5	0.25 C	143	144	5	11	418	Br
2.5	5	2.5	0.25 C	142	143	3	9	392	Br
2.5	5	5	0.25 C	--------	134	1	5	409	Br
		Bi							
2.5	5	0.5	0.25 C	131	133	15	28	403	4.1
2.5	5	1	0.25 C	132	133	23	36	387	2.3
2.5	5	1.5	0.25 C	141	143	3	10	415	Br
		Ag							
2.5	5	0.5	0.25 C	130	132	22	45	382	1.6
2.5	5	1	0.25 C	132	133	20	45	383	2.3
(COMMERCIAL PURITY TITANIUM BASE)									
		Sb							
2.5	2.5	7.5	--------	110	115	15	48	339	2.6
5	2.5	5	--------	114	118	13	44	343	2.8
7.5	2.5	2.5	--------	110	117	15	40	345	2.6
2.5	2.5	7.5	0.2 C	136	137	8	24	402	2.5
5	2.5	5	0.2 C	154	157	5	18	400	6.2
7.5	2.5	2.5	0.2 C	144	146	5	21	390	3.0
0.5	5	2	--------	103	109	15	43	351	2.8
1	5	1.5	--------	106	113	15	37	346	2.1
1.5	5	1	--------	103	112	17	46	343	2.9
2	5	0.5	--------	100	111	14	43	348	2.8
0.5	5	2	0.2 C	(1)	(1)	(1)	(1)	(1)	(1)
1	5	1.5	0.2 C	132	135	17	42	394	2.8
1.5	5	1	0.2 C	131	135	17	48	396	2.8
2	5	0.5	0.2 C	130	134	7	28	391	2.8

[1] Cracked during forging.

The effect on mechanical properties of adding the various beta promoters is shown by the following Table IV:

Table IV

(Ti-Sn-Al BASE PLUS BETA PROMOTERS)

Composition, Percent (Balance Titanium)				Tensile Properties: p. s. i. × 1,000				VHN	Min. Bend T
Sn	Al	Other	C, O, N	0.2% Offset Yield	Ultimate Strength	Percent Elongation in 1"	Percent Reduction in Area		
(IODIDE TITANIUM BASE)									
		Mn							
2.5	5	0.5	0.25 O	133	133	11	21	411	3.4
2.5	5	1	0.25 O	136	138	13	16	423	4.0
2.5	5	1.5	0.25 O	151	152	2	2	438	Br
		Be							
2.5	5	0.1	0.25 O	133	133	22	32	396	4.0
2.5	5	0.25	0.25 O	137	139	10	19	409	3.8
		Cu							
2.5	5	0.5	0.25 O	144	156	12	21	404	4.1
2.5	5	1	0.25 O	133	133	11	32	407	2.5
2.5	5	1.5	0.25 O	134	134	10	24	424	3.6
		Zr							
2.5	5	0.5	0.25 O	129	132	19	36	377	2.3
2.5	5	1	0.25 O	137	138	21	41	391	4.5
(COMMERCIAL PURITY TITANIUM BASE)									
		Mn							
5	2	4	--------	116	126	12	45	443	2.5
5	2	5	--------	140	145	5	26	389	4.5
10	1	0.5	--------	107	114	13	48	318	2.6
10	1	1	--------	111	118	11	42	326	3.6
10	1	1.5	--------	120	127	14	42	335	2.9
10	1	2	--------	128	134	11	41	335	2.8
10	1	3	--------	138	145	11	35	383	2.0
10	2	0.5	--------	108	118	12	41	338	6.6
10	2	1	--------	139	143	11	40	359	3.2/6.2
10	2	1.5	--------	138	143	12	37	361	3.7
10	2	2	--------	153	158	8	32	372	3.5/6.0
10	2	3	--------	164	164	14	47	404	2.2
10	2	4	--------	146	154	11	38	382	1.5
10	3	0.5	--------	147	150	9	25	327	7.2
10	3	1	--------	143	149	13	34	333	4.0
10	3	1.5	--------	150	154	11	22	339	Br
10	3	2	--------	168	172	7	22	360	6.7/Br
10	3	3	--------	179	181	10	34	414	2.5
10	1	5	--------	149	156	10	41	411	1.5
10	2	5	--------	162	167	7	13	412	1.8
10	3	5	--------	181	187	2	8	457	6.2
10	1	7	--------	154	164	8	33	416	2.5
10	2	7	--------	184	186	5	12	443	6.5
10	3	0.1	--------	116	126	16	45	352	4.4
10	3	0.3	--------	112	119	12	46	342	4.4
10	3	0.5	--------	122	132	14	41	344	4.3
		Mo							
5	2	5	--------	124	130	12	43	338	2.0
10	2	5	--------	142	150	13	24	350	2.6
15	2	5	--------	192	195	1	4	402	Br
10	1	2.5	--------	130	136	14	46	355	1.5
10	2	2.5	--------	142	150	13	41	358	2.6
10	3	2.5	--------	173	178	8	35	397	5.0
10	4	2.5	--------	--------	177	1	2	435	4.8
10	1	5	--------	134	140	11	32	329	2.2
		Mo							
10	2	5	--------	138	153	13	24	350	2.1
10	3	5	--------	171	174	4	19	378	2.0
10	4	5	--------	--------	113	1	2	431	Br
10	1	10	--------	130	135	9	38	320	0
10	2	10	--------	148	154	9	25	332	1.7
10	3	10	--------	174	180	3	12	387	5.3
10	4	10	--------	--------	161	1	3	416	Br
10	1	0.5	--------	125	130	11	46	----	2.8/5.7
10	1	1	--------	131	136	15	42	----	3.7/5.5
10	1	1.5	--------	131	136	12	45	----	2.8
10	1	2	--------	132	139	8	39	----	2.8
10	2	0.5	--------	149	154	9	36	----	Br
10	2	1	--------	147	153	14	42	----	Br
10	2	1.5	--------	155	160	7	29	----	Br
10	2	2	--------	156	161	9	32	----	5.0/Br
10	3	0.5	--------	161	163	7	35	----	5.5/Br
10	3	1	--------	165	169	3	14	----	Br
10	3	1.5	--------	167	169	3	19	----	Br
10	3	2	--------	176	176	5	16	----	Br
0.5	0.5	30	--------	124	125	5	28	282	0.4
		Cr							
5	2	4	--------	142	147	15	34	363	2.1
10	2	4	--------	155	164	10	30	366	2.5
15	2	4	--------	192	202	1	3	419	Br
10	1	2	--------	135	141	14	45	346	1.8
10	2	2	--------	147	153	13	44	360	2.5
10	3	2	--------	179	182	10	28	385	2.0
10	4	2	--------	193	198	4	5	415	5.3
10	1	4	--------	138	147	13	35	360	1.7
10	2	4	--------	155	164	10	30	366	1.9
10	3	4	--------	180	185	9	26	407	2.7
10	4	4	--------	200	204	1	2	447	Br
10	1	8	--------	137	147	13	28	343	0.8
10	2	8	--------	159	167	9	25	378	3.7

Table IV.—Continued

Composition, Percent (Balance Titanium)				Tensile Properties: p. s. i. × 1,000				VHN	Min. Bend T
Sn	Al	Other	C, O, N	0.2% Offset Yield	Ultimate Strength	Percent Elongation in 1"	Percent Reduction in Area		
(COMMERCIAL PURITY TITANIUM BASE)—Continued									
10	3	8		(1)	(1)	(1)	(1)	(1)	(1)
10	4	8		(1)	(1)	(1)	(1)	(1)	(1)
10	1	0.5		124	129	17	40	----	2.9
10	1	1		131	136	12	42	----	2.9
10	1	1.5		135	140	14	16	----	3.4
10	2	0.5		115	123	15	43	----	3.4
10	2	1		131	137	10	36	----	4.8
10	2	1.5		139	146	8	23	----	5.7
10	3	0.5		122	129	13	35	----	5.3
10	3	1		143	149	7	24	----	5.2/Br
10	3	1.5		141	149	8	21	----	5.5/Br
		Fe							
10	1	0.5		103	116	21	45	331	2.7
10	1	1		118	136	15	34	356	2.4
10	1	1.5		122	136	16	37	365	2.8
10	1	2		150	161	14	31	357	2.3
10	2	0.5		118	132	16	41	363	2.8
10	2	1		127	144	14	32	371	2.6
10	2	1.5		136	147	14	37	388	4.0
10	2	2		159	165	11	36	400	5.1
10	3	0.5		143	151	16	41	389	7.9
10	3	1		142	152	10	36	400	2.8
10	3	1.5		169	177	5	12	395	2.9
10	3	2		159	167	9	13	404	2.8
10	4	2		189	193	7	14	441	5.1
10	1	4		162	173	9	30	402	2.3
10	2	4		--------	185	1	5	433	6.8
10	3	4		177	177	1	5	447	6.7
10	4	4		--------	63	0	0	468	8.0
5	2	2		124	135	15	38	351	1.6
15	2	2		(2)	(2)	(2)	(2)	(2)	(2)
10	3	0.1		111	120	13	44	327	4.4
10	3	0.3		111	122	15	44	337	4.4
10	3	0.5		112	125	15	45	343	4.4
		V							
10	1	1.5		118	127	17	30	358	4.1
10	1	3		133	139	14	25	358	4.4
10	1	5		136	146	12	18	364	2.5
10	2	1.5		118	126	12	24	372	4.9
10	2	3		156	165	5	20	392	5.6
10	2	5		158	163	15	39	394	4.9
10	3	1.5		133	137	14	32	385	4.7
10	3	3		161	165	14	27	413	5.2
10	3	5		172	177	6	16	391	5.0
0.5	0.5	30		102	107	15	21	235	0.4
		Zr							
0.5	0.5	30		122	148	2	2	308	6.2
		Cb							
0.5	0.5	30		67	88	14	35	206	0.5
		Ta							
0.5	0.5	30		70	103	11	18	216	0

[1] Broke while machining tensile specimens.
[2] Could not be fabricated.

The effect of addition of a multiplicity of beta promoters is shown in the following Table V:

Table V

(Ti-Sn-Al BASE PLUS MULTIPLE BETA PROMOTER ADDITIONS

[Commercial purity titanium base]

Composition, Percent (Balance Titanium)	Tensile Properties: p. s. i. × 1,000				VHN	Min. Bend T
	0.2% Offset Yield	Ultimate Strength	Percent Elongation in 1"	Percent Reduction in Area		
10Sn-2Al-1.5Fe-4.5Mn	165	168	4	9	425	Br
10Sn-2Al-1.5Fe-2.5Mo	163	169	8	25	397	2.8
10Sn-2Al-1.5Fe-2.5Cr	157	165	12	23	387	2.6
10Sn-2Al-4.5Mn-2.5Mo	163	172	10	31	390	2.5
10Sn-2Al-4.5Mn-2.5Cr	159	165	9	27	383	2.8
10Sn-2Al-2.5Mo-2.5Cr	158	171	8	16	397	2.5
3.6Sn-3.2Al-1.6Mo-1.6Cr	128	130	16	50	--------	3.7
4.6Sn-3.3Al-1.8Mo-1.6Cr	136	138	16	45	--------	1.4
3Sn-3Al-2Cr-2V	136	138	11	45	--------	2.9
3Sn-3Al-2Cr-2V	134	149	14	35	--------	2.9

It will be seen from comparison of the data given in the above Tables III–V inc. with that given in Table II, that the addition of one or more metals of the alpha promoting, beta promoting and compound forming groups, to the Ti-Sn-Al base alloy of any given analysis, results in an increase in tensile strength. For certain additions, such for example as bismuth, silver or copper, the enhancement in strength is relatively slight per percent of such alloying addition, i. e., on the order of a few percent. For other additions the enhancement in tensile strength per percent of the alloying addition is relatively great, on the order of 5 to 30% or more, as in the case of such additions as antimony, beryllium, manganese, molybdenum, chromium, iron and vanadium, etc. Moreover as further shown by the test results, the degree to which the base alloy is thus strengthened varies considerably with the amount of tin and/or aluminum present in the base alloy.

Thus, by way of illustration of the points above noted, the comparative data in the tables referred to, shows that the addition of 1% of bismuth, silver or copper to the Ti-2-5Sn-Al-0.25C base alloy, increases the tensile strength from about 130,000 to 133,000 p. s. i., an increase of about 2% per percent of alloying addition. On the other hand the addition of 1.5% Sb to the Ti-1Sn-5Al base increases the tensile strength from 116,000 to 135,000 p. s. i., an increase of about 11% in tensile strength per percent of the antimony addition. Similarly for the Ti-5Sn-2Al base, the tensile strength of which is 92,000 p. s. i., the addition of 4% manganese increases this value to 126,000 p. s. i., the addition of 5% molybdenum increases it to 130,000 p. s. i., and the addition of 4% chromium provides an increase to 147,000 p. s. i. The tensile strength is thus increased by about 8 to 15% per percent of alloy addition for such elements. On the other hand the addition of 1% manganese, molybdenum or chromium to the Ti-10Sn-1Al base increases the tensile strengths about 11% in the case of manganese and about 31% in the case of molybdenum and chromium, namely from 104,000 p. s. i. to 118,000, 136,000 and 136,000 p. s. i., respectively. Generally similar results are obtainable by vanadium additions as shown by the addition of 1.5% vanadium to the Ti-10Sn-1Al base resulting in an increase in tensile strength from 104,000 to 127,000 p. s. i., an increase of about 15% per percent of vanadium addition. Iron likewise has a high strengthening effect as shown by the addition of 2% Fe to this base resulting in an increase in tensile strength from 104,000 to 161,000 p. s. i., an increase of about 28% in tensile strength per percent of iron addition.

The above comparisons are merely illustrative of the fact above stated that additions of other metals from the groups referred to, to the Ti-Sn-Al base in general produce pronounced enhancement of the tensile strength of the resulting alloy. And this is accomplished without any material reduction in the ductility of the alloys as shown by the values for the percent elongation and minimum bend ductilities as tabulated in the various tables referred to. In this latter connection, it should be pointed out that where the alloys are to be used in sheet form, as in foils for airplane wings and the like, the minimum bend ductility may range as high as about 20 T; and where the alloys are to be used in massive form, as in forgings, the tensile elongations may range as low as 1 or 2%.

The alloys of the invention may be made by arc melting in a cold mold furnace in an inert or argon atmosphere or by other procedures.

Tests in the arc welding of alloys in accordance with the invention establish that those which are predominantly alpha in structure and some of those containing beta stabilizers, notably chromium and molybdenum, may be welded without impairment of their annealed strength and ductility characteristics. Thus, arc welded specimens of the Ti-1Sn-3Al alloy were found to have in the weld zone an ultimate strength of 88,000 p. s. i., an elongation of 14%, an area reduction of 48%, a minimum bend T of 1.5 longitudinal and 3.0 transverse. Similarly the Ti-9Sn-3Al alloy had in the weld zone an ultimate strength of 125,000 p. s. i., an elongation of 10%, an area reduction of 38%, a minimum bend T of 2.5 longitudinal and 4.5 transverse. In addition, minimum bend tests made on arc welded specimens of various analyses, establish that, in general, the bend ductility in the weld zone is as good or better than that of the base metal. These conclusions are substantiated by the following test results of Table VI:

Table VI

Composition, Percent (Balance Titanium)			Minimum Bend T (Longitudinal)	
Sn	Al	Other	Welded Sample	Unwelded Sample
--	--	----	0.2	0.2
1	5	----	1.8	2.7
2	5	----	2.7	2.5
3	5	----	1.8	3.3
4	5	----	1.7	5.7
5	--	----	0.2	0.9
5	2	----	1.9	1.7
5	3	----	1.6	1.8
5	5	----	2.5	2.5
10	--	----	1.4	1.4
10	1	----	1.5	1.7
10	2	----	2.0	2.7
9	4	----	4.4	4.6
9	5	----	5.0	3.0
13	--	----	0.9	1.4
13	1	----	2.5	2.3
13	3	----	2.5	2.3
10	1	4Cr	5.3	1.7
10	2	4Cr	7.0	2.5
10	1	5Mo	2.7	2.2
10	2	5Mo	7.1	2.1
10	1	10Mo	0.9	0
10	2	10Mo	4.8	1.7
5	2	5Mo	7.0	2.0
10	1	3Mn	6.0	2.0

In the appended claims: by the expression "other alpha promoters" is meant elements of the group Sb, In, Ag, Bi, Pb, Cd, Zn and Th; by the expression "beta promoters" is meant elements of the group Mo, V, Cb, Ta, Zr, Mn, Cr, Fe, W, Ni, Co and Cu; and by the expression "compound formers" is meant elements of the group Si, Be, Ce, B, As, S, Te and P.

What is claimed is:

1. An alloy consisting essentially of about: 1 to 23% tin, 0.25 to 8% aluminum, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, 0.5 to 20% of at least one other alpha promoter, balance titanium, characterized in having an ultimate strength substantially in excess of that of the corresponding base alloy without such other alpha promoter addition, said alloy also having a minimum bend ductility of not over 20 T.

2. An alloy consisting essentially of about: 1 to 23% tin, 0.25 to 8% aluminum, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, 0.5 to 50% of at least one beta promoter, balance titanium, characterized in having an ultimate strength substantially in excess of the corresponding base alloy without such beta promoter addition, said alloy also having a minimum bend ductility of not over 20 T.

3. An alloy consisting essentially of about: 1 to 23% tin, 0.25 to 8% aluminum, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, 0.5 to 20% of at least one other alpha promoter, 0.5 to 50% of at least one beta promoter, balance titanium, characterized in having an ultimate strength substantially in excess of the corresponding base alloy without such other alpha promoter and beta promoter additions, said alloy also having a minimum bend ductility of not over 20 T.

4. An alloy consisting essentially of about: 1 to 23% tin, 0.25 to 8% aliuminum, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, 0.1 to 3% of at least one compound former, balance titanium, characterized in

having an ultimate strength substantially in excess of that of the corresponding base alloy without such compound former addition, and a minimum bend ductility of not over 20 T.

5. An alloy consisting essentially of about: 1 to 23% tin, 0.25 to 8% aluminum, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, 0.5 to 20% of at least one other alpha promoter, 0.5 to 50% of at least one beta promoter, 0.1 to 3% of at least one compound former, balance titanium, characterized in having an ultimate strength substantially in excess of the corresponding base alloy without such other alpha promoter, beta promoter and compound former additions, said alloy also having a minimum bend ductility of not over 20 T.

6. An alloy consisting of about: 1 to 23% tin, 0.25 to 8% aluminum, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, 0.5 to 20% of at least one other alpha promoter, balance titanium.

7. An alloy consisting of about: 1 to 23% tin, 0.25 to 8% aluminum, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, 0.5 to 50% of at least one beta promoter, balance titanium.

8. An alloy consisting of about: 1 to 23% tin, 0.25 to 8% aluminum, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, 0.5 to 20% of at least one other alpha promoter, 0.5 to 50% of at least one beta promoter, balance titanium.

9. An alloy consisting of about: 1 to 23% tin, 0.25 to 8% aluminum, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, 0.1 to 3% of at least one compound former, balance titanium.

10. An alloy consisting of about: 1 to 23% tin, 0.25 to 8% aluminum, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, 0.5 to 20% of at least one other alpha promoter, 0.5 to 50% of at least one beta promoter, 0.1 to 3% of at least one compound former, balance titanium.

11. An alloy consisting essentially of about: 1 to 23% tin, 0.25 to 8% aluminum, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, 0.5 to 50% of at least one additional element selected from the group consisting of molybdenum, vanadium, columbium, tantalum, zirconium, balance titanium, characterized in having an ultimate strength substantially in excess of that of the corresponding base alloy without such addition, said alloy also having a minimum bend ductility of not over 20 T.

12. An alloy consisting essentially of about: 1 to 23% tin, 0.25 to 8% aluminum, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, 0.5 to 20% of at least one additional element selected from the group consisting of chromium and tungsten, balance titanium, characterized in having an ultimate strength substantially in excess of that of the corresponding base alloy without such addition, said alloy also having a minimum bend ductility of not over 20 T.

13. An alloy consisting essentially of about: 1 to 23% tin, 0.25 to 8% aluminum, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, 0.5 to 10% manganese, balance titanium, characterized in having an ultimate strength substantially in excess of the corresponding base alloy without such manganese addition, said alloy also having a minimum bend ductility of not over 20 T.

14. An alloy consisting essentially of about: 1 to 23% tin, 0.25 to 8% aluminum, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, 0.5 to 7% iron, balance titanium, characterized in having an ultimate strength substantially in excess of the corresponding base alloy without such iron addition, said alloy also having a minimum bend ductility of not over 20 T.

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