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TITANIUM BASE ALLOYS

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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 and tin, 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 our copending applications S. N. 285,076, filed April 29, 1952, now Patent No. 2,669,513, issued February 16, 1954, and S. N. 294,262 and 294,263, both filed June 18, 1952, and S. N. 344,686, filed March 25, 1953, each now abandoned.

The tin content may be present over a broad range of about 0.5 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 alloy aforesaid, there may advantageously be added up to about 17% in aggregate of one or more of the 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%. For a tin content below about 5%, and particularly 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 adequate 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, 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.

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, cadmium, 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-ismorphism.

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 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 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 base alloys for the alpha promoters depends on the amount of tin present, the less tin present the greater the amount of alpha-promoters that can be added, and vice versa. Aluminum may be added to a maximum content of 8%, and antimony may be added to a maximum content of 17%. The proportioning of aluminum and antimony contents in relation to the tin content 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 beryllium 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 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 ductility, with a moderate degree of resistance to atmospheric contamination.

Since the Ti—Sn 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 ternary 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 ternary 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, now abandoned.

Antimony is a particularly valuable addition to the titanium-tin base metal as it imparts about the same strengthening effect as equivalent additions of tin. As the tin content increases, the tolerance for antimony decreases and vice versa with respect to retention of adequate ductility, in accordance with the following tabulation:

TABLE A

Percent tin:	Percent antimony max.
1	17
5	15
10	10
17.5	5
23	0.5

A somewhat similar relationship applies as between the tin content and the permissible range of aluminum addi-

tions consistent with retention of adequate ductility, as follows:

TABLE B

Percent tin:	Percent aluminum max.
0.25	8
1	6
5	5
10	4.5
15	4
20	3
23	1

Antimony has the same strengthening effect on the above titanium-aluminum-tin alloys as equivalent additions of tin and may be substituted therefor in the proportions above set forth in Table A.

Tin is soluble in alpha titanium to the extent of at least 15%, and alloys of titanium with up to 15% tin are all in the alpha phase. As the tin content is increased, the beta transformation temperature rises, and at a temperature of about 930° C., and a tin content of about 19%, a peritectoid reaction occurs. In alloys containing about 20 to 23% tin, two intermediate phases formed at different temperatures have been tentatively identified.

The following Table I gives, for comparative purposes with the further test data presented hereinafter, test results showing the improvement in mechanical properties, resulting from additions of tin over the range of about 1 to 23%, to both "iodide" and "commercial purity" titanium base metal, with and without further controlled additions of one or more of the interstitials, carbon, oxygen and nitrogen:

TABLE I

Ti—Sn *binary alloys*

[Annealed condition.]

Composition, Percent (Balance Titanium)				Tensile Properties: p. s. i. × 1,000		Percent Elongation in 1"	Percent Reduction in Area	Vickers Hardness	Min. Bend T
Sn	C	O	N	0.2% Offset Yield	Ultimate Strength				
IODIDE TITANIUM BASE									
0	----	----	----	27	43	40	61	105	0
2.5	----	----	----	50	69	23	50	217	0.9
5	----	----	----	56	73	26	37	235	1.6
10	----	----	----	85	99	20	36	298	1.5
15	----	----	----	98	110	19	35	320	1.5
20	----	----	----	117	122	12	36	324	1.5
22.5	----	----	----	135	149	11	19	339	4.7
1	0.2	----	----	55	70	28	48	205	0
2.5	0.2	----	----	65	74	29	51	235	0.5
5	0.2	----	----	79	83	29	53	265	0.5
5	0.5	----	----	109	117	24	43	325	1.3
4	1	----	----	123	138	7	13	387	8.6
10	0.2	----	----	97	102	24	60	308	1.0
10	0.5	----	----	130	147	17	51	373	2.1
15	0.2	----	----	122	127	11	32	364	1.6
1	----	0.2	----	64	84	25	38	237	2.0
2.5	----	0.2	----	71	90	24	33	274	2.0
5	----	0.2	----	79	96	23	47	312	1.0
5	----	0.5	----	128	128	1	10	423	7.6
10	----	0.2	----	99	112	16	32	360	1.7
10	----	0.4	----	131	138	1	23	410	6.5
15	----	0.3	----	124	134	20	40	380	2.3
15	----	0.5	----	147	155	11	38	390	3.2
1	----	----	0.2	94	105	14	33	310	2.0
2.5	----	----	0.2	100	109	16	26	332	1.7
5	----	----	0.11	80	97	19	29	296	2.0
5	----	----	0.29	120	123	20	47	348	2.8
10	----	----	0.11	88	100	18	32	297	2.1
10	----	----	0.27	128	134	18	46	354	2.2
15	----	----	0.30	146	154	12	38	397	2.9
COMMERCIAL PURITY TITANIUM BASE									
0	----	----	----	51	76	21	51	201	0.8
1	----	----	----	48	73	21	54	198	0.8
2.5	----	----	----	67	86	14	48	236	1.5
5	----	----	----	71	90	14	42	246	1.5
10	----	----	----	91	110	11	36	296	1.5
15	----	----	----	108	123	10	35	313	2.3
20	----	----	----	123	131	10	39	330	2.2
22.5	----	----	----	139	150	5	19	341	2.2
5	0.17	----	----	96	106	27	61	311	1.8
4	0.4	----	----	113	121	26	60	335	1.8
5	0.96	----	----	121	129	7	11	367	3.0
5	----	0.2	----	109	123	24	53	351	2.5
5	----	0.4	----	137	148	8	10	403	Brittle
5	----	----	0.28	142	149	12	31	388	7.4
5	----	----	0.42	159	164	1	8	415	Brittle
10	0.2	----	----	112	118	26	53	356	1.9
10	0.58	----	----	146	148	11	32	385	4.5
13	0.1	----	----	109	--------	19	45	--------	1.8
10	----	0.2	----	122	131	19	44	358	2.8
10	----	0.4	----	131	138	16	39	386	3.3
10	----	----	0.13	114	124	18	45	337	1.7
16	0.2	----	----	114	139	14	27	337	2.1
16	----	0.2	----	109	137	12	22	341	3.3
16	----	----	0.18	123	149	9	16	331	6.1
19	0.2	----	----	140	158	9	15	357	4.0
19	----	0.2	----	120	140	18	33	339	2.1
19	----	----	0.14	127	151	5	22	357	4.2

From these results it will be observed that additions of tin up to about 23% greatly strengthen the metal while retaining adequate ductility for fabrication purposes, i. e., forging, rolling, etc. For the "iodide" titanium base the yield strength is more than quadrupled from 27,000 to 135,000 p. s. i., while the ultimate strength is more than tripled from 43,000 to 149,000 p. s. i. For any given tin content further strengthening results from controlled additions of one or more of the interstitials. Thus, at the 5% tin level, the addition of 0.5% carbon, approximately doubles the yield and ultimate strength without reducing ductility. Oxygen and nitrogen additions have generally similar effects as shown. In this way the tensile strength of the material may be raised to as much as about 160,000 p. s. i. with retention of adequate ductility as shown, for example, by the 19% tin, 0.2% carbon, commercial purity base analysis.

Considering now the strengthening effects of additions to the titanium-tin base alloys as typified by Table I, of one or more of the alpha promoters, beta promoters, or compound formers above discussed, the following Table II gives test results for additions of one of the more important beta promoters, namely, manganese:

increases ranging up to about 160,000 p. s. i. with additions of manganese up to about 9%, without serious impairment of ductility. In fact, for additions of manganese up to about 6%, the ductility is actually increased as compared to the alloy omitting manganese, while at the same time increasing the ultimate strength up to about 150,000 p. s. i. The effect of interstitial additions to the manganese-containing alloy again enhances the strength without serious effect on ductility as shown by comparison of the 9% tin, 2.5 and 5% Mn analyses.

The following Table III shows the effects of molybdenum additions to the titanium-tin base alloy. Here again, as in the case of manganese, the molybdenum additions greatly increase the strength of the alloy while retaining adequate ductility. For example, with the 10% tin analysis and a 7.5% molybdenum addition, the ultimate strength is increased from 110,000 to 140,000 p. s. i. with no loss in ductility, as shown by comparison with Table I. At the 15% tin level the ultimate strength is increased from 123,000 to 167,000 p. s. i. with no loss in ductility upon the addition of 5% molybdenum. The effect of adding interstitials is shown by comparison of the values for the 9% tin, 2.5% molybdenum analysis

TABLE II

Ti—Sn—Mn *alloys (commercial titanium base)*

[Annealed condition.]

Composition, Percent (Balance Titanium)					Tensile properties: p. s. i.×1,000		Percent Elongation in 1"	Percent Reduction in Area	Vickers Hardness	Min. Bend T
Sn	Mn	C	O	N	0.2% Offset Yield	Ultimate Strength				
9	----	----	----	----	74	89	21	50	276	1.7
9	0.25	----	----	----	72	90	20	48	261	1.6
9	0.5	----	----	----	74	95	24	49	273	1.7
9	0.5	0.25	----	----	113	122	20	55	369	1.5
9	0.5	----	0.2	----	96	117	20	45	364	1.6
9	0.5	----	----	0.11	94	105	20	46	344	1.5
9	2.5	----	----	----	107	118	11	46	336	1.2
9	2.5	0.2	----	----	138	143	19	39	369	1.8
9	2.5	----	0.2	----	135	144	17	39	389	1.8
9	2.5	----	----	0.2	143	150	13	46	397	2.8
9	5	----	----	----	130	140	16	90	353	1.7
9	5	0.2	----	----	153	157	16	37	424	4.7
9	5	----	0.2	----	151	156	14	36	421	4.8
9	5	----	----	0.2	146	153	12	38	426	2.3
9	7.5	----	----	----	120	129	10	11	350	1.6
10	1	----	----	----	110	118	12	44	341	1.6
10	2	----	----	----	121	128	15	48	326	1.7
10	3	----	----	----	132	141	15	51	356	1.4
10	4	----	----	----	129	140	15	39	363	1.6
10	5	----	----	----	135	144	12	25	375	1.4
10	6	----	----	----	144	151	16	38	369	1.4
10	7	----	----	----	143	147	9	35	385	1.2
10	8	----	----	----	151	154	9	27	386	2.9
10	9	----	----	----	154	157	10	29	377	3.7
10	12	----	----	----	171	173	2	Br	404	Br
1	5	----	----	----	97	111	20	49	316	0.8
5	5	----	----	----	116	126	14	41	324	1.6
15	5	----	----	----	160	170	4	15	431	7.0

Comparing the results of the above table with those given in Table I, it will be seen, for example, that for the 10% tin alloy containing no manganese, the ultimate strength is 110,000 p. s. i., as compared to progressive wherein the ultimate strength is increased from 113,000 to the order of 130,000 to 140,000 p. s. i. with no appreciable effect on ductility. The same order of increase occurs at the 9% tin, 5% molybdenum level.

TABLE III

Ti—Sn—Mo *alloys*

[Annealed condition.]

Composition, Percent (Balance Titanium)			Tensile Properties: p. s. i.×1,000		Percent Elongation in 1″	Percent Reduction in Area	Vickers Hardness	Min. Bend T
Sn	Mo	Other	0.2% Offset Yield	Ultimate Strength				
IODIDE TITANIUM BASE								
5	2.5	------	68	91	17	41	223	1.0
10	2.5	------	84	101	13	44	261	2.0
15	2.5	------	120	134	9	22	304	1.6
COMMERCIAL TITANIUM BASE								
1	5	------	101	105	18	64	268	1.0
5	5	------	101	119	18	53	290	1.2
9	0.25	------	78	96	22	52	308	1.6
9	0.5	------	90	105	19	50	300	1.6
9	2.5	------	96	113	16	45	299	1.7
9	5	------	104	116	14	40	313	1.7
9	7.5	------	43	130	10	17	284	1.7
9	10	------	114	134	15	38	302	0.8
9	15	------	121	124	18	38	298	0.8
10	7.5	------	132	140	9	46	314	1.1
10	10	------	135	142	8	26	329	0.2
15	5	------	162	167	7	30	362	1.8
9	0.25	0.25O	113	121	25	59	352	2.3
9	0.25	0.2O	111	128	23	45	378	1.6
9	0.25	0.17N	123	134	19	51	366	2.3
9	0.5	0.25O	104	122	23	57	369	1.5
9	0.5	0.2O	114	131	22	52	364	1.6
9	0.5	0.14N	115	129	19	46	392	2.3
9	2.5	0.2C	120	127	14	45	343	1.4
9	2.5	0.2O	136	142	11	38	375	1.7
9	2.5	0.2N	135	145	14	36	365	1.8
9	5	0.2C	137	140	10	30	366	2.5
9	5	0.2O	133	142	15	33	354	2.5
9	5	0.2N	138	146	9	31	364	3.5
0.5	30	------	140	141	5	17	301	1.0
0.5	30	0.5Al	124	125	5	28	282	0.5

Table IV below shows the effect of chromium additions to the titanium-tin base. The observed improvement is of the same general order of magnitude as for the molybdenum addition and hence requires no detailed comment.

TABLE IV

Ti—Sn—Cr *alloys*

[Annealed Condition.]

Composition, Percent (Balance Titanium)			Tensile Properties: p. s. i.×1,000		Percent Elongation in 1″	Percent Reduction in Area	Vickers Hardness	Min. Bend T
Sn	Cr	Other	0.2% Offset Yield	Ultimate Strength				
IODIDE TITANIUM BASE								
5	2.5	------	78	97	12	31	265	1.6
10	2.5	------	85	98	10	39	241	1.4
15	2.5	------	117	128	7	25	329	1.1
COMMERCIAL TITANIUM BASE								
1	4	------	102	112	19	55	279	0.5
5	4	------	114	123	19	53	311	1.0
5	10	------	132	138	13	45	320	------
9	0.25	------	70	90	27	52	298	1.6
9	0.5	------	81	104	20	46	301	1.7
9	1.25	------	88	101	15	33	301	1.9
9	2.5	------	117	128	16	37	328	1.7
9	5	------	52	120	15	23	299	0.9
9	10	------	129	130	16	31	330	0.9
9	15	------	143	146	14	36	353	1.6
10	2	------	123	130	16	48	328	2.1
10	4	------	131	138	12	49	335	1.8
10	6	------	140	143	10	43	338	0.7
10	8	------	141	148	11	42	336	1.5
10	10	------	144	153	5	8	431	Br
15	4	------	151	156	8	34	386	1.9
9	1.25	0.2C	125	131	17	42	351	1.9
9	2.5	0.2C	133	139	11	52	349	1.7
9	0.25	0.25C	114	121	28	56	369	1.1
9	0.5	0.25C	114	125	27	58	368	1.7
9	1.25	0.2O	124	133	14	40	371	2.5
9	2.5	0.2O	135	145	8	20	380	2.5
9	0.25	0.2O	103	121	27	43	368	2.4
9	0.5	0.2O	112	132	18	45	356	1.6
9	1.25	0.2N	136	147	13	40	386	2.5
9	2.5	0.2N	138	144	13	27	393	1.7
9	0.25	0.2N	109	128	19	34	355	2.5
9	0.5	0.2N	106	128	21	45	362	2.3

Table V shows the effect of adding iron to the titanium-tin base. It will be noted by comparison with Table I that the iron addition tremendously increases the ultimate strength accompanied in general by retention of adequate ductility. With the 15% tin analysis and a titanium base of commercial purity, the addition of 2% iron increases the ultimate strength from 123,000 to 177,000 p. s. i.

with substantially no change in ductility. At the 10% tin level, the ultimate strength is increased from 110,000 to 150,000 p. s. i. with no change in ductility upon the addition of 4% iron. Here again, as in the previous data, the addition of the interstitials enhances the strength properties with no loss in ductility as can be seen by comparison of the 9% tin, 0.5% iron analyses:

TABLE V

Ti–Sn–Fe *alloys*

[Annealed condition.]

Composition, Percent (Balance Titanium)			Tensile Properties: p. s. i.×1,000		Percent Elongation in 1"	Percent Reduction in Area	Vickers Hardness	Min. Bend T
Sn	Fe	Other	0.2% Offset Yield	Ultimate Strength				
IODIDE TITANIUM BASE								
5	2.5	------	60	97	12	17	247	1.0
10	2.5	------	95	119	8	19	293	1.9
15	2.5	------	115	130	6	15	333	3.0
COMMERCIAL TITANIUM BASE								
1	2	------	77	104	16	42	255	1.3
4	5	------	97	124	17	27	------	2.0
5	2	------	120	125	18	38	328	3.6
9	0.25	------	74	95	20	42	278	2.5
9	0.5	------	74	99	18	39	294	2.7
9	1.25	------	96	112	19	46	320	1.6
9	2.5	------	120	132	15	39	349	1.3
9	5	------	------	103	0	0	375	Br
9	7.5	------	------	115	0	0	382	Br
10	1.5	------	108	120	18	40	330	1.8
10	2	------	121	132	9	31	347	1.5
10	3	------	133	147	14	36	359	2.0
10	4	------	137	150	10	37	370	1.5
10	5	------	185	190	5	16	446	Br
10	7.5	------	176	179	8	31	426	6.1
15	2	------	170	177	12	32	411	2.3
9	0.25	0.25C	113	119	25	54	343	2.5
9	0.25	0.2O	106	122	21	38	341	2.3
9	0.25	0.1N	91	109	21	36	304	2.3
9	0.5	0.25C	104	125	24	50	338	1.3
9	0.5	0.2O	105	125	16	40	321	1.8
9	0.5	0.1N	91	105	17	42	306	2.4
9	1.25	0.2C	123	134	17	27	362	1.7
9	1.25	0.2O	110	123	17	42	383	1.9
9	1.25	0.2N	126	142	16	45	380	1.7
9	2.5	0.2C	143	152	18	50	396	1.5
9	2.5	0.2O	139	152	15	41	408	2.3
9	2.5	0.2N	153	164	15	34	404	Br

Table VI below shows the effects of additions of the beta stabilizers vanadium, tungsten, columbium, tantalum, copper, zirconium, cobalt, and nickel to the titanium-tin base.

TABLE VI

Ti—Sn *base plus* V, W, Cb, Ta, Cu, Zr, Co, Ni, Si, Be *alloys*

[Annealed condition.]

Composition, Percent (Balance Titanium)		Tensile Properties: p. s. i.×1,000		Percent Elongation in 1"	Percent Reduction in Area	Vickers Hardness	Min. Bend T
Sn	Other	0.2% Offset Yield	Ultimate Strength				
IODIDE TITANIUM BASE							
10	2.5V	78	97	10	16	276	0.5
10	2.5W	84	106	7	36	258	0.6
10	2.5Cb	54	76	16	47	268	1.1
10	2.5Ta	68	81	12	53	259	1.7
5	1Cu	55	72	19	32	269	3.1
10	1Cu	75	94	15	29	276	2.0
15	1Cu	100	112	9	29	322	2.9
10	1Cu-0.2C	98	108	22	38	340	1.9
10	1Cu-0.2O	94	108	14	37	347	3.4
10	1Cu-0.2N	114	128	11	28	375	6.3
10	2.5Zr	92	110	20	40	270	2.2
10	2.5Zr-0.2C	106	117	18	43	356	2.1
10	2.5Zr-0.2O	99	113	18	42	318	3.7
10	2.5Zr-0.2N	129	136	15	39	369	3.3
10	2.5Co	123	138	1	9	312	5.7
10	2.5Ni	98	121	2	14	327	2.0

TABLE VI—Continued

Ti–Sn *base plus* V, W, Cb, Ta, Cu, Zr, Co, Ni, Si, Be *alloys*—Continued

Composition, Percent (Balance Titanium)		Tensile Properties: p. s. i.×1,000		Percent Elongation in 1″	Percent Reduction in Area	Vickers Hardness	Min. Bend T
Sn	Other	0.2% Offset Yield	Ultimate Strength				
COMMERCIAL PURITY TITANIUM BASE							
10	----------	86	98	18	52	281	2.5
10	1.5V	99	108	17	46	307	2.6
10	3V	125	136	15	41	333	3.7
10	5V	115	129	11	29	304	1.6
10	10V	107	112	7	40	258	0
10	15V	95	102	8	30	243	0.7
0.5	30V	106	109	9	25	254	0
0.5	40V	109	113	13	31	250	0
10	1W	108	114	17	47	333	2.6
10	2.5W	112	123	14	48	339	2.7
10	5W	118	145	15	43	360	2.7
10	10W	129	152	7	13	370	5.0
10	15W	145	174	4	8	363	5.7
0.5	30Cb	72	90	19	28	206	0
10	2.5Cb	92	102	21	51	304	1.8
10	5Cb	116	123	17	51	327	2.6
10	10Cb	120	130	10	39	312	2.6
10	0.5Cu	94	109	20	42	333	1.6
10	1Cu	87	104	16	34	289	2.5
10	2.5Cu	96	106	18	43	325	2.6
10	5Cu	122	131	13	24	342	3.6
0.5	30Ta	66	101	14	36	220	0.2
10	2.5Ta	85	95	20	51	276	1.8
10	5Ta	86	98	21	51	283	1.7
10	10Ta	110	111	14	48	309	2.2
10	1.0Co	90	106	19	39	289	2.7
10	2.5Co	108	125	11	22	317	2.6
10	5Co	111	124	3	7	357	Br
10	1Ni	88	102	18	41	283	1.8
10	2.5Ni	95	111	10	31	294	2.6
10	5Ni	111	131	11	18	327	5.7
0.5	30Zr	115	145	3	3	316	5.8
10	1Zr	78	96	23	52	285	1.6
10	2.5Zr	84	100	19	50	289	1.8
10	5Zr	89	105	18	46	309	2.5
10	10Zr	93	108	19	46	312	5.2
10	0.5Si	100	111	17	45	325	1.5

Table VII below shows the effects of adding a multiplicity of beta promoters to the titanium-tin base:

TABLE VII

Mechanical properties of Ti—Sn *base alpha-beta alloys containing two beta stabilizers*

[Commercial purity titanium base. Annealed condition.]

Composition, Percent (Balance Titanium)	Tensile properties: p.s.i.×1,000		Percent Elongation in 1″	Percent Reduction in Area	VHN	Min. Bend Radius	
	0.2% Offset Yield	Ultimate Strength				L	T
10Sn–1.5Fe	108	120	18	40	330	1.8	3.0
10Sn–3Fe	133	147	14	36	359	2.0	4.8
10Sn–1.5Fe–4.5Mn	145	151	11	32	365	1.7	5.9
10Sn–1.5Fe–2.5Mo	126	139	13	30	343	2.7	5.6
10Sn–1.5Fe–2.5Cr	127	143	11	34	337	2.8	5.2
10Sn–1.5Fe–2.5W	120	131	12	32	334	2.6	5.2
10Sn–1.5Fe–5Cb	129	141	17	32	337	2.6	4.6
10Sn–1.5Fe–5Ta	121	134	14	43	344	2.6	5.2
10Sn–1.5Fe–5V	123	133	15	25	317	0.6	4.2
10Sn–1.5Fe–2Ni	110	120	2	5	317	Br	Br
10Sn–1.5Fe–2Co	130	148	9	20	366	Br	Br
4Sn–3Fe–2Cu	92	118	18	21	--------	1.0	--------
10Sn–1.5Fe–2.5Cu	117	132	11	26	357	2.0	5.0
10Sn–3Fe–7.5Mo	133	136	10	50	303	0	0
3Sn–3Fe–3Cr	100	127	17	23	--------	1.0	--------
4Sn–5Cr–3Fe	127	143	22	37	--------	0.6	--------
10Sn–3Fe–7.5Cr	140	143	14	47	321	0	0
10Sn–4Fe–10Mo	142	[1] 144	10	42	325	0	6.0
10Sn–4Fe–10Cr	172	173	0	8	375	Br	Br
9Sn–2.5Mn	107	118	11	46	336	1.2	1.6
10Sn–5Mn	135	144	12	25	375	1.4	Br
10Sn–2.5Mn–1.5Fe	146	155	11	34	359	2.1	6.8
10Sn–2.5Mn–2.5Mo	141	142	1	12	340	1.8	6.2
10Sn–2.5Mn–2.5Cr	143	148	13	35	364	1.7	5.0
10Sn–2.5Mn–2.5W	140	143	8	45	351	2.6	6.2
10Sn–2.5Mn–5Cb	133	140	12	45	354	1.7	Br
10Sn–2.5Mn–5Ta	135	139	12	45	350	3.7	2.5
10Sn–2.5Mn–5V	145	147	7	27	344	1.5	Br
10Sn–2.5Mn–2Ni	125	137	6	10	346	Br	Br
10Sn–2.5Mn–2Co	147	153	9	34	354	4.1	Br
5Sn–12Mn–1Cu	143	146	10	45	360	--------	--------
10Sn–2.5Mn–2Cu	129	136	7	37	331	1.9	Br
3Sn–3Mn–3Fe	116	141	16	19	--------	1.0	--------
10Sn–4Mn–3Fe	144	150	9	34	332	0	0
10Sn–4Mn–7.5Mo	125	127	16	52	299	0	0
5Sn–6Mn–9Cr	134	135	17	56	327	0.1	--------
5Sn–7.5Mn–7.5Cr	134	135	16	57	351	0.3	--------

TABLE VII—Continued

Mechanical properties of Ti—Sn *base alpha-beta alloys containing two beta stabilizers*—Continued

Composition, Percent (Balance Titanium)	Tensile properties: p. s. i. ×1,000		Percent Elongation in 1"	Percent Reduction in Area	VHN	Min. Bend Radius	
	0.2% Offset Yield	Ultimate Strength				L	T
10Sn-4Mn-7.5Cr	140	143	18	39	320	0	0
10Sn-6Mn-4Fe	146	152	8	25	359	3.0	4.3
10Sn-6Mn-10Mo	141	[1] 142	12	38	319	0.2	0.8
10Sn-4.5Mn	132	142	13	32	370	1.5	4.0
10Sn-7Mn	143	147	9	35	385	1.2	4.6
10Sn-4.5Mn-2.5Mo	147	149	8	25	340	2.3	4.8
10Sn-4.5Mn-2.5Cr	147	153	8	26	350	1.4	5.4
10Sn-4.5Mn-2.5W	137	144	10	33	361	0.4/2.3	4.7
10Sn-4.5Mn-5Cb	135	143	8	21	340	1.5	4.8
10Sn-4.5Mn-5Ta	141	148	8	10	342	1.9	4.6
10Sn-4.5Mn-5V	135	142	13	33	327	1.0	2.3/4.7
10Sn-4.5Mn-2Ni	133	146	2	6	346	Br	Br
10Sn-4.5Mn-2Co	149	157	9	19	387	1.9	6.1
10Sn-4.5Mn-2.5Cu	139	149	10	12	351	1.5	4.8
9Sn-2.5Mo	96	113	16	44	299	1.7	2.5
9Sn-5Mo	104	116	14	40	313	1.7	3.5
10Sn-2.5Mo-2.5Cr	127	138	13	31	333	1.7	6.6
10Sn-2.5Mo-2.5W	122	137	12	29	333	4.1	Br
10Sn-2.5Mo-5Cb	122	132	[2] 2	5	331	3.0	5.0
10Sn-2.5Mo-5Ta	125	134	10	38	334	2.5/4.9	Br
10Sn-2.5Mo-5V	117	122	8	24	297	2.6	7.0
10Sn-2.5Mo-2Ni	104	105	[2] 1	4	317	2.4	7.0
10Sn-2.5Mo-2Co	133	138	3	8	360	1.6/3.2	4.9
10Sn-2.5Mo-2.5Cu	117	124	15	36	330	2.0	2.0
10Sn-7.5Mo-7.5Cr	136	138	15	39	319	0	0.4
10Sn-2.5Cr	120	128	17	50	320	2.0	2.5
10Sn-5Cr	135	140	11	45	336	1.5	3.5
10Sn-2.5Cr-2.5W	123	129	7	27	339	2.5	4.9
10Sn-2.5Cr-5Cb	118	124	12	28	319	2.0	2.5
10Sn-2.5Cr-5Ta	126	134	11	30	317	2.5	4.9/6.8
5Sn-6.5Cr-7.5V	133	142	9	28	----	1.2	----
10Sn-2.5Cr-5V	116	129	12	28	319	0.9	2.6
10Sn-2.5Cr-2Ni	121	139	4	6	335	7.0	Br
10Sn-2.5Cr-2Co	148	156	16	38	387	1.5	4.7
4Sn-6Cr-1.5Cu	140	153	11	23	----	0.9	----
10Sn-2.5Cr-2.5Cu	118	131	13	29	322	1.5	6.5
10Sn-2.5W	112	123	14	48	339	2.7	2.7
10Sn-5W	118	145	15	43	360	2.7	5.3
10Sn-2.5W-5Cb	119	129	16	42	319	2.6	5.0
10Sn-2.5W-5Ta	120	129	15	48	336	2.6/5.0	5.0
10Sn-2.5W-5V	137	140	10	33	319	2.8	6.2
10Sn-2.5W-2Ni	108	124	10	30	325	5.6	5.2
10Sn-2.5W-2Co	124	142	14	36	363	2.4	4.7
10Sn-2.5W-2.5Cu	116	123	11	27	342	5.0	5.0
10Sn-5Cb	116	123	17	51	327	2.6	2.6
10Sn-10Cb	120	130	10	39	312	2.6	5.2
10Sn-5Cb-5Ta	118	129	13	37	329	2.6	5.1
10Sn-5Cb-5V	113	119	11	34	274	2.2	5.1
10Sn-5Cb-2Ni	114	125	10	24	330	2.8	Br
10Sn-5Cb-2Co	130	140	13	41	348	1.5	1.5
10Sn-5Cb-2.5Cu	121	130	16	45	327	2.5/4.9	4.9
10Sn-5Ta	86	98	21	51	283	1.7	1.7
10Sn-10Ta	110	111	14	48	309	2.8	2.2
10Sn-5Ta-5V	112	120	11	38	281	2.3	5.8
10Sn-5Ta-2Ni	91	106	18	37	304	3.4	5.1
10Sn-5Ta-2Co	103	125	7	18	325	Br	Br
10Sn-5Ta-2.5Cu	94	105	16	32	317	2.4	2.8
10Sn-5V	108	118	10	39	289	1.8	2.1
10Sn-10V	107	112	7	40	258	0	1.9
10Sn-5V-2Ni	137	148	6	8	339	4.8	Br
10Sn-5V-2Co	122	134	13	31	319	0.8	4.9/2.4
10Sn-5V-2.5Cu	114	124	6	21	304	1.5	5.6
10Sn-2Ni	93	110	16	35	290	2.0	2.5
10Sn-4Ni	110	130	12	20	320	5.0	5.0
10Sn-2Ni-2Co	97	118	12	27	325	4.9	Br
10Sn-2Ni-2.5Cu	107	124	13	27	342	4.0	Br
10Sn-2Co	105	120	14	30	305	2.5	3.0
10Sn-4Co	110	125	5	10	350	5.0	5.0
10Sn-2Co-2.5Cu	114	136	5	8	339	Br	Br
10Sn-2.5Cu	96	106	18	43	325	2.6	2.6
10Sn-5Cu	122	131	13	24	342	3.6	3.6
10Sn-2.67Mn-2Fe-5Mo	135	136	7	42	312	0.2	2.6
10Sn-2.67Mn-2Fe-5Cr	138	141	9	35	315	4.0	0
10Sn-2.67Mn-5Mo-5Cr	131	131	15	48	310	0	0
10Sn-2Fe-5Mo-5Cr	135	135	16	47	312	0	0.2
10Sn-2Mn-1.5Fe-3.75Cr-3.75Mo	132	134	14	44	310	0	0/5.8
5Sn-7.5Mn-7.5Cr-0.2C	144	146	14	30	357	5.2	----
5Sn-8Mn-4Cr-4Mo	121	138	19	52	357	0.2	----
4Sn-5Cr-5V-5Mn	131	137	14	36	----	1.3	----
4Sn-3Cr-2.5Mo-1.5Cu	137	146	13	44	----	1.0	----
4Sn-4Cr-2Fe-2Cu	130	141	19	40	----	0.7	----
4Sn-1Mn-2.5Cr-1Fe-1Cu-2Mo-0.5V	124	138	21	38	----	0.9	----

[1] The tensile strength was reached before the 0.2% offset yield strength.
[2] Defective sample.

From the test results of Tables II to VII, inc., the following general conclusions may be drawn with respect to the effect of single and multiple beta stabilizer additions to the titanium-tin base. The beta isomorphous elements V, Cb, Ta, Mo and Zr alone or in combination with each other, produce alloys having similar properties. These alloys have medium strengths, good ductility, good thermal stability and, as shown below, are generally ductile as welded. The elements Fe, Cr, and Mn which form systems containing sluggish eutectoid reactions, produce aloys which have high strengths, good ductility, fair thermal stability and are generally brittle as welded, except for low alloy contents of such additions. The elements with rapidly transforming eutectoids, Co, Ni, Cu and W, produce alloys which have medium strengths, acceptable tensile ductility with borderline bend ductilities, poor thermal stability, and with the exception of the Ti—10Sn—5W alloy are intrinsically

brittle as welded, except for extremely low additions of such elements. On the other hand, by judicious selection and combination of the beta promoters from one of the groups above mentioned with those of the other groups, multiple beta stabilizer alloys may be produced which combine the good qualities imparted by the elements from the groups selected, while tending to suppress and minimize their undesirable qualities. Thus, for example, the combination of beta isomorphous elements with the sluggish eutectoid elements results in alloys that have improved thermal stability and weld ductility as compared to those made with the sluggish eutectoid elements alone. On the other hand, the test data shows that combinations of beta isomorphous elements with the rapid eutectoid elements do not result in improved thermal stability or weld ductility, and the same is generally true for combinations of sluggish eutectoid with rapid eutectoid elements. Over-all analysis of the test results indicates that for maximum thermal stability and weld ductility, the order of merit of the beta stabilizing elements is as follows: Cb, Mo, Ta, V, Cr, Mn, Fe, W, Cu, Co and Ni.

The following Table VIII shows the effects on mechanical properties of additions of the alpha stabilizer aluminum to the titanium-tin base, both with and without additions of the interstitials, carbon, oxygen and nitrogen:

TABLE VIII

Ti—Sn *base plus* Al *alloys*

[Annealed condition.]

Composition, Percent (Balance Titanium)					Tensile Properties: p. s. i. X1,000		Percent Elongation in 1"	Percent Reduction in Area	Annealed Vickers Hardness	Min. Bend T
Sn	Al	C	O	N	0.2% Offset Yield	Ultimate Strength				
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
1.5	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	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	0.20	---	---	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	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	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
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
13	1	---	---	---	112	122	18	26	345	2.5
13	2	---	---	---	124	124	18	30	363	2.6

TABLE VIII—Continued

Ti—Sn *base plus* Al *alloys*—Continued

Composition, Percent (Balance Titanium)					Tensile Properties: p. s. i.X1,000		Percent Elongation in 1"	Percent Reduction in Area	Annealed Vickers Hardness	Min. Bend T
Sn	Al	C	O	N	0.2% Offset Yield	Ultimate Strength				
COMMERCIAL PURITY TITANIUM BASE—Continued										
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	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	----	0.1	----	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	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	Br
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	4	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
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

[1] Annealed 2 hours at 950° C.; other analyses annealed 2 hours at 850° C.

It will be observed from Table VIII that additions of aluminum to the titanium-tin base within the range of proportions set forth in the above Table B produce tensile strengths ranging upwards of 150,000 p. s. i. without undue embrittlement. Moreover, as applicants have shown in their copending application Serial No. 294,263 above mentioned, the titanium-tin-aluminum series described herein forms an excellent ternary base for further additions of other elements to include alpha and beta promoters, to form quaternary and higher component alloys having excellent tensile and other desirable properties as set forth in said application.

The following Table IX shows the effect on mechanical properties of additions of the alpha stabilizer antimony to the titanium-tin base, with and without additions of the interstitials carbon, oxygen and nitrogen:

TABLE IX

Ti—Sn *base plus* Sb *alloys*

[Annealed condition.]

Composition, percent (Balance Titanium)					Tensile Properties: p. s. i.×1,000		Percent Elongation in 1"	Percent Reduction in Area	Vickers Hardness	Min. Bend T
Sn	Sb	C	O	N	0.2% Offset Yield	Ultimate Strength				
IODIDE TITANIUM BASE										
-----	----	----	----	----	22	37	61	58	88	0
5	1	----	----	----	52	68	23	51	210	1.6
10	1	----	----	----	74	86	16	39	254	2.2
10	1	0.2	----	----	107	110	22	55	335	1.6
10	1	----	0.2	----	93	105	17	36	330	2.3
10	1	----	----	0.2	121	127	12	37	369	1.9
15	1	----	----	----	97	105	14	34	304	3.5
COMMERCIAL PURITY TITANIUM BASE										
2.5	7.5	----	----	----	76	96	16	46	268	2.1
2.5	12.5	----	----	----	109	117	14	42	311	1.9
5	5	----	----	----	74	94	17	46	262	1.5
5	10	----	----	----	100	111	17	44	317	2.5
5	12.5	----	----	----	116	125	9	18	331	2.3
5	15	----	----	----	--------	126	0	0	354	Br
7.5	2.5	----	----	----	81	98	18	43	270	2.2
10	1	----	----	----	79	94	21	48	292	2.3
10	2.5	----	----	----	90	101	18	47	304	1.5
10	5	----	----	----	107	116	17	39	325	1.7
10	7.5	----	----	----	114	120	17	47	333	2.7
10	10	----	----	----	125	133	16	38	342	4.9
10	12.5	----	----	----	--------	114	0	0	348	Br
12.5	2.5	----	----	----	109	118	14	36	313	2.9
15	5	----	----	----	128	135	17	40	333	3.6
15	7.5	----	----	----	145	152	9	26	346	2.3
17.5	5	----	----	----	--------	134	0	6	338	5.2

Thus it will be seen by a comparison of Tables I and IX that antimony has about the same strengthening effect as an equivalent weight of tin and may be substituted therefor without undue embrittlement within the range of proportions set forth in the above Table A.

The following Table X shows the effect on mechanical properties of additions of the alpha stabilizers bismuth, indium, cadmium, silver, thallium, lead and zinc to the titanium-tin base:

TABLE X

Ti—Sn *base plus* In, Bi, Pb, Ag, Cd, Tl *and* Zn *alloys*

[Annealed condition]

Composition, Percent (Balance Titanium)		Tensile Properties: p. s. i.×1,000		Percent Elongation in 1"	Percent Reduction in Area	Vickers Hardness	Min. Bend T
Sn	Other	0.2% Offset Yield	Ultimate Strength				
-----	----------	22	37	61	58	88	0
5	1Bi	50	66	30	44	190	1.2
10	1Bi	76	88	16	40	261	2.1
15	1Bi	95	106	18	40	312	2.2
10	1Bi-0.2C	103	107	18	51	324	1.6
10	1Bi-0.2O	94	106	16	45	338	2.0
10	1Bi-0.2N	117	123	20	41	356	1.7
10	2.5In	75	88	13	43	256	2.1
10	2.5In-0.2C	101	108	20	54	337	2.0
10	2.5In-0.2O	93	108	16	46	322	2.5
10	2.5In-0.2N	109	119	18	44	350	2.8
10	1Cd	55	71	18	54	248	1.5
5	1Ag	53	71	22	43	191	1.3
10	1Ag	59	78	21	39	241	2.1
15	1Ag	91	103	16	46	308	2.3
10	1Ag-0.2C	102	104	19	54	321	2.4
10	1Ag-0.2O	93	105	16	45	322	3.5
10	1Ag-0.2N	133	139	12	45	386	6.3
10	2.5Tl	60	75	22	57	238	1.9
COMMERCIAL PURITY TITANIUM BASE							
----	----------	49	76	24	44	197	1.3
10	1Bi [1]	82	97	20	48	297	1.5
10	2.5Bi [1]	86	99	17	45	297	2.4
10	5Bi [1]	87	101	19	48	312	1.5
0	2.5Bi [1]	50	74	24	49	206	1.1
10	1In	79	94	25	51	283	1.7
10	2.5In	88	101	21	48	297	1.5
10	5In	92	104	17	49	289	1.9
10	10In	102	111	20	45	325	2.7
10	10Cd	79	92	18	41	270	1.8
10	1Ag	80	96	17	48	252	1.7
10	2.5Ag	82	95	18	47	287	1.5
10	5Ag	87	102	19	51	309	1.7
10	10Ag	91	104	18	45	309	2.5
10	10Pb [1]	87	101	23	47	314	2.3
10	10Zn [1]	73	86	22	52	268	1.6

[1] Considerable weight loss occurred during melting.

Table XI below shows the effects of additions of the various compound formers to the titanium-tin base:

TABLE XI

Alloys of Ti—Sn *base plus compound formers*
Si, Be, Ce, B, Te, *etc.*

[Annealed condition.]

Composition, percent (Balance Titanium)		Tensile Properties: p. s. i.×1,000		Percent Elongation in 1"	Percent Reduction in Area	Vickers Hardness	Min. Bend T
Sn	Other	0.2% Offset Yield	Ultimate Strength				
IODIDE TITANIUM BASE							
10	1Ce	57	75	16	34	250	2.0
10	1Te	61	78	17	48	232	2.7
10	2.5Te	72	88	7	26	242	1.1
10	0.5B	54	72	21	38	236	1.8
10	2.5Th	60	75	22	57	238	1.9
10	1Si	80	97	16	38	305	1.6
10	0.2Be	70	90	12	22	273	1.6
COMMERCIAL PURITY TITANIUM BASE							
10	1Ce [1]	80	94	17	39	285	2.4
10	2.5Ce [1]	75	92	15	33	276	3.2
10	0.5Si	100	110	17	45	325	1.5
10	1Si	97	109	17	35	330	5.0
10	2Si	104	108	3	8	333	7.0

[1] Considerable weight loss occurred during melting.

The welding characteristics of the various types of alloys of the present invention, are described, and the weldable alloys thereof, covered by the above-mentioned co-pending joint application of the applicants Jaffee and Ogden herein together with R. A. Happe, Serial No. 305,504, now abandoned. As therein shown, the all-alpha or substantially all-alpha titanium-tin base alloys of the present invention, containing up to about 16% tin, are weldable without serious impairment of ductilities, substantially throughout the entire range of analyses that such alloys are ductile in the cast or wrought condition. The same is shown in said application to be generally true with respect to the beta or mixed alpha-beta titanium-tin alloys obtained by additions of beta-promoters of the beta-isomorphous group, i. e., Mo, V, Cb, Ta and Zr, although certain of the molybdenum-containing analyses may require a post welding heat treatment as described in said application, for offsetting a tendency to become embrittled as a result of welding. As further shown in said application, beta-containing alloys formed by additions of the sluggishly eutectoid beta promoters, Cr, Mn and Fe, are generally productive of brittle welds when present in substantial amounts, i. e., above about 2–3%, although certain of the higher alloy analyses restricted to Cr and/or Mn additions are ductile as welded or can have their ductilities restored by post welding heat treatment as above mentioned, i. e., those containing up to about 7–8% Mn or up to about 18% Cr. The beta alloys formed by additions of Co, Ni, Cu and W having rapidly transforming eutectoids are intrinsically brittle in the welded condition when these additions are present in excess of about 2 to 3%, i. e., their ductilities cannot be restored by post welding heat treatment. The compound formers likewise impart intrinsic brittleness as welded to the titanium-tin base alloy when present in amounts exceeding about 2 to 3%.

Our investigations have established that the alloys in accordance with the invention containing about 10 to 15% tin are wholly contamination resistant at temperatures up to 1050° C. and probably higher regardless of the type of alloy, i. e., whether all-alpha, mixed alpha-beta or all-beta. They have further established that there is a marked or critical reduction in contamination resistance commencing at about 5% tin as compared to that of the same alloy containing no tin. The tin addition produces free scaling alloys in most cases, but this tendency to free scaling appears to be reduced when large quantities of beta stabilizers are present.

The findings above stated are based on the test results set forth in the following Table XII, the data for which was obatined by arc melting 15-gram buttons of each of the compositions indicated in the table, including the tin-free alloy bases. The buttons were forged at 850° C. to about ⅜" square x 1¼" long. Each forged billet was then descaled and sectioned into two samples. One sample was heated in air for four hours at 1050° C. and furnace cooled. The second sample received the same treatment in argon. These samples were furnace cooled to minimize any heat treatment effects that might have occurred with some of the alloys during cooling from the beta field. Weight-change data, scale appearance, thickness after wire brushing off the loose scale, and hardness penetration data were obtained for each specimen, with results as recorded in the table.

TABLE XII

Oxidation test data for Ti—Sn *base alloys containing* Ta, W, Cb, V, Al, Mo, Fe, Cr *or* Mn

Composition, Percent (Balance Titanium)	Condition: 4 Hr. at 1,050° C. in Air and Furnace Cooled			
	Weight Gain, g./dm.²	Metal-Thickness Loss, Mils	Depth of Contamination, Mils	Increase in VHN 5 Mils Below Surface
100Ti	3.5	10	60	240
5Sn	15.5	18	40	60
10Sn	13.5	19	Nil	Nil
15Sn	11.9	18	Nil	Nil
5Ta	2.00	Nil	80	350
5Sn-5Ta	6.49	Nil	55	200
10Sn-5Ta	16.09	21	30	60
15Sn-5Ta	19.41	28	Nil	Nil
2.5W	3.52	1	80	220
5Sn-2.5W	23.80	36	40	60
10Sn-2.5W	20.60	29	30	30
15Sn-2.5W	12.27	11	Nil	Nil
5Cb	1.66	Nil	70	230
5Sn-5Cb	5.19	Nil	40	150
10Sn-5Cb	14.30	20	Nil	Nil
15Sn-5Cb	18.67	26	Nil	Nil
5V	5.18	2	85	300
5Sn-5V	12.38	15	35	50
10Sn-5V	14.88	18	Nil	Nil
15Sn-5V	18.70	35	Nil	Nil
2Al	5.5	4	80	200
5Sn-2Al	7.4	Nil	30	120
10Sn-2Al	10.3	16	Nil	Nil
15Sn-2Al	5.6	12	Nil	Nil
2.5Mo	2.8	2	80	280
5Sn-2.5Mo	5.0	22	40	50
10Sn-2.5Mo	20.9	32	10	50
15Sn-2.5Mo	20.9	30	20	40
15Mo	3.8	4	20	80
5Sn-15Mo	12.7	21	15	50
10Sn-15Mo	12.4	22	Nil	Nil
15Sn-15Mo	15.5	21	20	50
2.5Fe	3.8	3	120	280
5Sn-2.5Fe	12.0	16	25	80
10Sn-2.5Fe	10.7	18	50	30
15Sn-2.5Fe	8.5	14	Nil	20
7.5Fe	3.7	2	80	250
5Sn-7.5Fe	6.6	9	35	50
10Sn-7.5Fe	9.4	14	Nil	Nil
15Sn-7.5Fe	7.5	6	Nil	90
2.5Cr	4.6	0.5	60	280
5Sn-2.5Cr	9.9	7	80	140
10Sn-2.5Cr	6.6	10	Nil	Nil
15Sn-2.5Cr	12.8	24	Nil	Nil
10Cr	3.5	0.5	40	300
5Sn-10Cr	3.5	0.5	Nil	Nil
10Sn-10Cr	4.8	8	Nil	Nil
15Sn-10Cr	3.1	6	Nil	Nil
2.5Mn	3.0	2	80	300
5Sn-2.5Mn	12.1	18	5	100
10Sn-2.5Mn	14.9	21	Nil	20
15Sn-2.5Mn	12.8	20	Nil	Nil
7.5Mn	3.7	2	80	250
5Sn-7.5Mn	6.6	9	40	50
10Sn-7.5Mn	9.4	14	Nil	Nil
15Sn-7.5Mn	7.5	6	Nil	Nil

As above stated, the majority of the specimens were found to be free scaling, but this was not so of the Ti—5Sn—2Al alloy. This alloy had a very adherent scale which could not be removed by wire brushing.

Since the binary Ti—5Sn alloy is free scaling, it is quite evident that the aluminum present in the above-mentioned alloy is responsible for the adherent scale obtained. Also the Ti(5—15)Sn—10Cr alloys had rather adherent scales with little loss in metal by oxidation and no noticeable contamination as measured by hardness. The Ti—10Cr control alloy had a similar scale, but the underlying metal was highly contaminated. Thus, when 10% chromium is present, tin appears to afford the contamination resistance without the free scaling characteristics, thus indicating utility of these alloys at elevated temperatures.

Our investigations have further shown that the

Ti—(5—15)Sn—10Cr

alloy, with and without additions of up to 5% of one or more of iron, molybdenum and manganese, have excellent elevated temperature hardnesses combined with contamination resistance at temperatures as high as 800° to 900° F., and good hardness at temperatures up to 1100° to 1200° F. This is shown by the test results submitted in Table XIII.

Referring to the above data, a comparison of the hardness values of the binary Ti—Sn alloys with the binary Ti—Cr alloys shows that it is the chromium or beta addition which promotes the higher hardness at temperatures up to 800° to 900° F. As further shown by the above data, the combination of tin and chromium provides an added hardening increment, due to the tin, which is maintained at elevated temperatures. As further shown, the substitution of manganese, iron and molybdenum for part of the chromium, has varied effects. Iron additions result in higher hardnesses, which prevail at temperatures up to about 1200° F. Manganese additions do not change the hardness of the Ti—Sn—Cr alloy, while molybdenum additions produce some decrease in hardness which prevails at all temperatures referred to. On the basis of hardness alone, the Ti—5Sn—10Cr—5Fe alloy is best. However, on the basis of strong and ductile room temperature properties as well as elevated temperature contamination resistance and hardness, the Ti—Sn—Cr—(Mo, Mn) alloys are of best all-around utility.

The room temperature properties of these alloys are given in Table XIV.

The alloys of the invention may be made by melt casting in a cold mold, employing an electric arc in an inert atmosphere, or may be produced in other ways in which the alloy is rendered molten before casting.

Where the alloys are to be used in the form of sheets, the minimum bend ductilities may range as high as 20T, and where they are to be used in massive form, as in forgings, the percent tensile elongation may range as low as 1 or 2%. Minimum bend ductility T is defined as the minimum radius to which a specimen can be bent through an angle of 75° without fracture, expressed as a multiple of the specimen thickness.

TABLE XIII

Hot hardness values of Ti—Sn-*base alloys for elevated temperature service*

[As hot rolled and annealed.]

Composition, percent (Balance Titanium)	80° F.	250° F.	500° F.	750° F.	1,000° F.	1,250° F.	1,500° F.	80° F.[1]
100Ti	219	195	141	116	72	33		233
5Sn[2]	240	221	163	133	107	60	23	287
10Sn[2]	270	235	189	152	132	71	27	292
10Cr	306	276		223	123	32	18	476
15Cr	297	235	269	247	160	51	27	357
5Sn-10Cr	355	294	261	235	144	42	24	359
10Sn-10Cr	326	313	275	254	180	55	26	339
5Sn-15Cr	360	327	279	265	179	58	32	377
5Sn-10Cr-5Fe	389	353	322	315	244	92	37	409
5Sn-10Cr-5Mo	315	290	246	240	190	75	33	346
5Sn-10Cr-5Mn	324	314	286	271	186	68	31	376
8Mn	377	340	269	235	106	46		

[1] Hardness at room temperature after being heated to 1500° F.
[2] Annealed 2 hours at 850° C. prior to testing; other analyses annealed at 700° C.

TABLE XIV

Mechanical properties of Ti—Sn—Cr-*base alloys for elevated temperature service*

[These alloys were 980° C. forged, hot rolled at 1,400° F. to 0.080 inch, descaled, hot rolled at 1,300° F. to 0.040 inch, held 15 minutes at 1,300° F., furnace cooled to 1,100° F., and air cooled to room temperature.]

Composition, Percent (Balance Titanium)	Tensile Properties: p. s. i.×1,000		Percent Elongation in 1"	Percent Reduction in Area	Vickers Hardness	Minimum Bend Radius, T	
	0.2% Offset Yield	Ultimate Strength				L	T
10Cr	126	134	10	46	300	0	1.5
5Sn-10Cr	132	138	13	45	320	0.9	5.5
10Sn-10Cr	145	151	2	7	372		
5Sn-10Cr-5Fe	165	166	2	6	373	Br	Br
5Sn-10Cr-5Mo	134	139	11	46	314	0.9	1.8
5Sn-10Cr-5Mn	149	155	7	15	352	Br	Br

It will be observed from the data in the tables above set forth that the alloys of the invention have ultimate tensile strengths at least 10% in excess of the unalloyed titanium base metal, and in the vast majority of instances, ultimate strengths at least 30 to 50% in excess of the unalloyed titanium base metal.

In the appended claims, by the expression "beta promoters" is meant elements of the group molybdenum, vanadium, columbium, tantalum, zirconium, manganese, chromium, iron, tungsten, nickel, cobalt and copper; by the expression "alpha promoters" is meant elements of the group antimony, silver, cadmium, zinc, thallium, bismuth and lead; by the expression "compound formers" is meant elements of the group cerium, boron, arsenic, sulfur, tellurium, silicon and beryllium.

What is claimed is:

1. A titanium base alloy consisting essentially of about: 0.5–23% tin, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, and 0.5–49% of at least one beta promoter, said alloy having a tensile elongation of at least 2% and a tensile strength at least 10% in excess of that of the corresponding titanium-tin binary alloy.

2. A titanium base alloy consisting essentially of about: 0.5–23% tin, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, 0.5–20% of at least one alpha promoter and 0.5–49% of at least one beta promoter, said alloy having a tensile elongation of at least 2% and a tensile strength at least 10% in excess of that of the corresponding titanium-tin binary alloy.

3. A titanium base alloy consisting essentially of about: 0.5–23% tin, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, and 0.1–3% of at least one compound former selected from the group consisting of cerium, boron, arsenic, sulfur, tellurium, silicon and beryllium, said alloy having a tensile elongation of at least 2% and a tensile strength at least 10% in excess of that of the corresponding titanium-tin binary alloy.

4. A titanium base alloy consisting essentially of about: 0.5–23% tin, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, 0.5–20% of at least one alpha promoter, 0.5–49% of at least one beta promoter and 0.1–3% of at least one compound former selected from the group consisting of cerium, boron, arsenic, sulfur, tellurium, silicon and beryllium, said alloy having a tensile elongation of at least 2% and a tensile strength at least 10% in excess of that of the corresponding titanium-tin binary alloy.

5. An alloy consisting of about: 0.5–23% tin, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, and at least one element selected from the group consisting of 0.5–49% of beta promoters, 0.5–20% of alpha promoters and 0.1–3% of compound formers selected from the group consisting of cerium, boron, arsenic, sulfur, tellurium, silicon and beryllium, balance titanium.

6. An alloy consisting of about: 0.5–23% tin, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, and 0.5–49% of at least one beta promoter, balance titanium.

7. An alloy consisting of about: 0.5–23% tin, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, and 0.5–20% of at least one alpha promoter, and 0.5–49% of at least one beta promoter, balance titanium.

8. An alloy consisting of about: 0.5–23% tin, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, and 0.1–3% of at least one compound former selected from the group consisting of cerium, boron, arsenic, sulfur, tellurium, silicon and beryllium, balance titanium.

9. A titanium base alloy consisting essentially of about: 0.5–23% tin, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, and 0.5–49% of at least one beta isomorphous promoter selected from the group consisting of molybdenum, vanadium, columbium, tantalum and zirconium, said alloy having a tensile elongation of at least 2% and a tensile strength at least 10% in excess of that of the corresponding titanium-tin binary alloy.

10. A titanium base alloy consisting essentially of about: 0.5–23% tin, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen and 0.5–5% of at least one rapidly eutectoid beta promoter selected from the group consisting of cobalt, nickel and copper, said alloy having a tensile elongation of at least 2% and a tensile strength at least 10% in excess of that of the corresponding titanium-tin binary alloy.

11. A titanium base alloy consisting essentially of about: 5–15% tin, 10% chromium and up to 5% of metal of the group iron, molybdenum and manganese, characterized in being highly resistant to atmospheric contamination at temperatures up to about 2000° F. and in undergoing no substantial reduction in hardness at temperatures up to about 800° F.

12. A titanium base alloy consisting essentially of about: 0.5–23% tin, up to 1% carbon, up to 0.5% oxygen, up to 0.4% nitrogen, 0.5–20% of at least one sluggishly eutectoid beta-promoter selected from the group consisting of chromium, tungsten, manganese and iron, but not to exceed 10% manganese and 7% iron, said alloy having a tensile elongation of at least 2%, and a tensile strength at least 10% in excess of that of the corresponding binary alloy.

References Cited in the file of this patent

UNITED STATES PATENTS

2,596,489	Jaffee et al.	May 13, 1952
2,614,041	Finlay et al.	Oct. 14, 1952
2,622,023	Frazier	Dec. 16, 1952
2,661,286	Swazy	Dec. 1, 1953
2,668,109	Croft	Feb. 2, 1954
2,669,513	Jaffee	Feb. 16, 1954
2,669,514	Finlay	Feb. 16, 1954
2,700,607	Methe	Jan. 25, 1955