

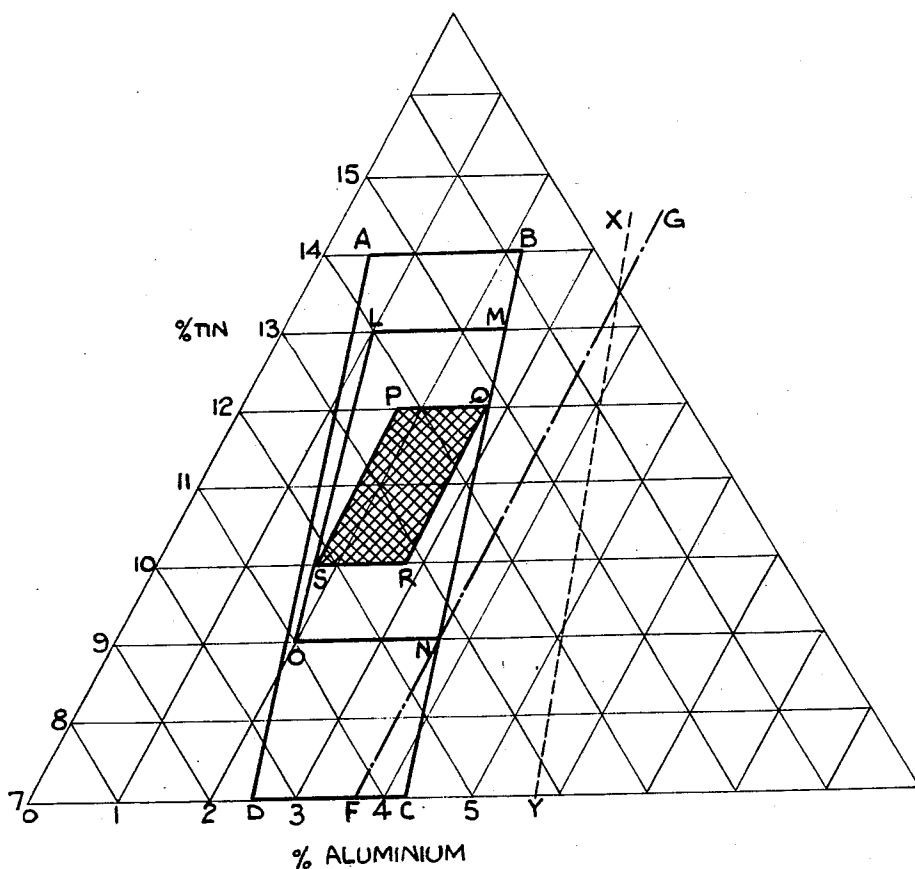
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W. P. FENTIMAN ET AL

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TITANIUM-BASE ALLOYS

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INVENTORS:

William Percival Fentiman,
Peter Harlow Morton,
Stuart Leslie Ames, Jr.
Terence Barclay Marsden,

BY *Cushman, Darby & Cushman*
ATTORNEYS.

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TITANIUM-BASE ALLOYS

William Percival Fentiman and Peter Harlow Morton, Birmingham, England, Stuart Leslie Ames, Natrona Heights, Pa., and Terence Barclay Marsden, Sutton Coldfield, England, assignors to Imperial Chemical Industries Limited, London, England, a corporation of Great Britain

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This invention is concerned with titanium-base alloys which have high temperature creep strength and which do not undergo embrittlement during use at high temperature.

Alloys for use in certain elevated temperature applications where dimensional stability is important, such as gas turbine compressor blades, require to have good creep properties, together with adequate strength and freedom from embrittlement during service. It is desirable that an alloy for use in such applications should possess as many as possible of the following properties: high room temperature ultimate strength and adequate ductility, high strength and low creep rates at temperatures of 400° C. or more, freedom from embrittlement, high tolerance for hydrogen, good forgeability, low density and good oxidation resistance.

In this specification, all components are defined in terms of percent by weight.

Titanium-base alloys have been proposed for such applications since they have moderately low density and good oxidation resistance and certain alloys have good properties at elevated temperatures. One such alloy is that containing 13% tin and 2.75% aluminium which has good creep properties but suffers from the disadvantage that at certain levels of hydrogen content serious embrittlement at service temperatures is encountered which has rendered the alloy unsuitable for use in the above-mentioned applications unless it is vacuum annealed to reduce the hydrogen content. This is an expensive process and obviously adds to the cost of production.

We have found that by modifying the composition of titanium-tin-aluminium alloys good creep resistance without embrittlement at all levels of hydrogen content can be obtained when the alloys have been heat-treated.

An object of the invention is to provide titanium-base alloys having good creep properties.

Another object of the invention is to provide titanium-base alloys with good creep properties which do not undergo embrittlement during use at high temperatures. A further object is a titanium-tin-aluminium alloy having good tolerance for hydrogen, the properties of which can be raised to higher levels by addition elements.

A still further object is a heat-treatment which, with modifications, can be applied to the alloys of the invention to produce creep properties of a high order.

Other objects and advantages of the invention will become apparent from the detailed description thereof.

Titanium-base alloys having good creep properties which are free from embrittlement at elevated temperatures consist essentially of tin and aluminium, the tin

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content and the aluminium content relative to that tin content being in the range 14% tin with 0.5% aluminium, 14% tin with 2.2% aluminium, 7% tin with 4.25% aluminium and 7% tin with 2.5% aluminium and 0-0.5% silicon balance titanium and usual impurities.

A desirable range of composition is that in which the tin and aluminium contents are between the following limits: 13% tin with 1% aluminium, 13% tin with 2.5% aluminium, 9% tin with 2% aluminium, 9% tin with 3.6% aluminium and 0-0.5% silicon. The preferred range of composition is that in which the tin and aluminium contents are between the following limits: 12% tin with 1.75% aluminium, 12% tin with 2.75% aluminium, 10% tin with 2.75% aluminium and 10% tin with 1.75% aluminium and 0-0.5% silicon.

The ranges of composition of tin and aluminium content are illustrated in the accompanying drawing in which:

Point A represents 14% tin, 0.5% aluminium,
Point B represents 14% tin, 2.2% aluminium,
Point C represents 7% tin, 4.25% aluminium,
Point D represents 7% tin, 2.5% aluminium,
Point L represents 13% tin, 1% aluminium,
Point M represents 13% tin, 2.5% aluminium,
Point N represents 9% tin, 3.6% aluminium,
Point O represents 9% tin, 2% aluminium,
Point P represents 12% tin, 1.75% aluminium,
Point Q represents 12% tin, 2.75% aluminium,
Point R represents 10% tin, 2.75% aluminium and
Point S represents 10% tin, 1.75% aluminium.

The usual impurities found in titanium-base alloys include carbon, oxygen, nitrogen, hydrogen and iron and it is desirable that the amounts of such elements should be kept as low as possible.

In the following description relating to various compositions of alloys, in many instances no reference is made to the titanium content, but it is to be understood that the remainder of the composition is titanium and usual impurities.

The line BC of the FIGURE represents the limit of composition of alloys having elongation values of not less than 10% on $4\sqrt{A}$ with a hydrogen content of up to 180 parts per million, determined on specimens heat-treated 30 minutes at 1100° C. air cooled, reheated to 800° C. and furnace cooled. Alloys having compositions on the left of the line BC have at all commercial hydrogen levels been found to be free from embrittlement after heat-treating to produce the best creep properties. On the right of the line, the amount of hydrogen present in the alloy affects the tendency to become embrittled and the further the composition from the line the smaller is the amount of hydrogen that can be tolerated.

This decrease in the tolerable hydrogen content with increasing alloy content is rapid and the line XY represents the limit of composition of alloys having elongation values of not less than 10% when the hydrogen content does not exceed 10 parts per million. It will be seen that the difference in composition between alloys on the limit BC and alloys on the limit XY is small and is equivalent to about 1.5% of aluminium.

Alloys in accordance with the invention are limited to a small area on the left of the line BC and alloy compositions outside this area with a few exceptions do not

have all the beneficial properties possessed by the alloys whose compositions fall within the area. Thus, whilst certain of the alloys outside the area may have, for example, good ductility, they may be rather weak or have poor forgeability or, on the other hand, they may have good tensile strength but rather high creep rate or may suffer embrittlement.

We have found that the best creep properties in the alpha-type ternary titanium-tin-aluminium alloys in accordance with the invention are associated with an acicular type of structure and such a structure may be produced by heat-treatments. The alloys are heated to a temperature in the beta field, cooled and reheated in the upper part of the alpha field, the rate of cooling from the beta field determining the properties. Slow cooling, as by air cooling gives a low creep rate at 500° C. whilst fast cooling as by quenching into water gives a stronger material with a moderately higher creep rate. A heat-treatment which has been found to give satisfactory results is to heat the alloy to a temperature of 1100° C., air cool or quench to room temperature and reheat to 700° C. or 800° C. for a period and air cool in the furnace to room temperature. When air cooled, the alloy is allowed to cool at a natural rate in free air and when furnace cooled the alloy cools at the rate at which the furnace cools when closed and the heating source turned off.

Table I shows the tensile properties of a number of titanium-tin-aluminium alloys outside the range of alloys in accordance with the invention. All the examples contained about 180 parts per million of hydrogen and had been heated to 1100° C. for 30 minutes and air cooled and then reheated to 800° C. for 1 hour and furnace cooled. The elongation of most of the alloys is below 10% which is the minimum acceptable ductility value. Of those alloys which have acceptable elongation figures the majority have lower strength than the alloys of the invention.

In Table II are given the tensile properties of alloys which fall within the range of composition in accordance with the invention and of alloys which are near that range and which have been treated and tested in the same manner as those in Table II. It will be seen that there is a marked fall in ductility of alloys which are on the right of the line BC of the figure, these alloys being outside the range. The strength and ductility of all the alloys falling within the range are good. Creep strength is related to the total content of tin and aluminium and those alloys at the lower end of the range have lower creep strength than those at the upper end. In general, alloys containing less than 8% tin have more limited applications than those containing more than 8% tin but ductility is good, e.g. an alloy containing 7.7% tin and 3.1% aluminium has, after heat-treatment, 15% elongation and 25% reduction in area values.

The area LMNO of the figure represents compositions in which a total plastic strain of about 0.1% or less is produced when creep tested at 400° C. under a stress of 25 tons/sq. in. over a period of 300 hours after quenching from 1100° C. and annealing at 800° C. followed by air cooling. Table III shows the total plastic strain values obtained from alloys which fall within the area. Of the compositions which fall within the area LMNO of the figure, the best combination of properties is found in the alloy containing 11% tin and 2.25% aluminium. This alloy has good creep properties and is free from the occurrence of embrittlement during service. Whilst the creep properties of this alloy are not quite as good as alloys containing higher percentages of tin and aluminium, such as the 13% tin, 2.75% aluminium alloy, the ductility of the 11% tin, 2.75% aluminium during service is a considerable improvement on the

known alloys. The tendency to become embrittled in service can be determined by carrying out tensile tests on heat-treated specimens which have been subjected to creep testing. In such a determination the ductility of the 13% tin, 2.75% aluminium alloy as shown by elongation and reduction in area values fell to about 7% in each case whereas, in the case of the 11% tin, 2.25% aluminium alloy, the elongation and reduction in area values did not fall below 13% and 27% respectively at similar levels of hydrogen content.

For production purposes a suitable range of composition for the 11% tin, 2.25% aluminium alloy is 10.5% to 11.5% tin and 2%–2.5% aluminium.

In the figure the line FG marks the limit of good forgeability at 1000° C. Compositions on the left of the line have good forgeability and such compositions include almost all the alloys of the invention. Alloys on the right of the line are forgeable but rather more care is required than with alloys on the left.

It will be evident from the foregoing consideration of the properties of titanium-tin-aluminium alloys in accordance with the invention that such alloys are an improvement over previously known titanium-tin-aluminium alloys in that, in the alloys of the invention, in particular the 11% tin, 2.25% aluminium alloy, are combined good tensile properties, good creep properties at a temperature of 400° C., freedom from embrittlement, high tolerance for hydrogen, good forgeability, good oxidation resistance and moderate density. It will also be evident that all such properties are not found in all titanium-tin-aluminium alloys but an excellent combination of all or most of these desirable properties is found in the comparatively small range of composition represented by the alloys of the invention.

The creep properties of the ternary alloys can be further improved by the addition of one or more alloying elements. The preferred elements are: zirconium 1–10%, silicon 0.05–0.5% and copper 0.1–2.5%, of which zirconium is an alpha stabiliser and silicon and copper are beta stabilisers which may form metallic compounds in some conditions of heat-treatment. Examples of the improvement in properties are shown in Table IV which summarizes creep tests at 25 tons/sq. in. at 400° C. made on alloys heat-treated 15 mins. at 1100° C. air cooled and 1 hour at 700° C. and furnace cooled. It will be apparent that a reduction of plastic strain results from the inclusion of alloying elements in the ternary alloy.

In those alloys in which the alloying addition is zirconium the 10% addition gives higher room temperature strength and better creep properties at 400° C. than the 5% zirconium alloy. The 5% zirconium alloy gives better creep properties at 500° C. than the 10% zirconium alloy and is also more readily forged. In a comparative test in which the test pieces were heat-treated at 1100° C. and 700° C. as before described and creep tested at 500° C. under a load of 15 tons/sq. in. for 300 hours, the 11% tin, 2¼% aluminium, 5% zirconium alloy had a total plastic strain of 0.049% whilst the 11% tin, 2¼% aluminium, 10% zirconium alloy had a total plastic strain of 0.080%. After creep testing the tensile test figures were: 5% zirconium, U.T.S. 62.2 tons/sq. in., elongation 15%, reduction in area 23%; 10% zirconium, U.T.S. 66 tons/sq. in., elongation 15%, reduction in area 19%. For these reasons the zirconium content of 5% is required for some particular purposes and a zirconium content of about 10% in alloys for other purposes. A desirable range of composition in one case, is therefore, 2½ to 7½ zirconium and a suitable range covering permissible variation of composition on a production scale is 4 to 6% zirconium. In the other case, a desirable range of composition is, therefore, 6 to 10% zirconium and a suitable range covering permissible variation of composition on a production scale is 8 to 10% zirconium. Since zirconium is an alpha stabiliser such alloys are of the alpha type.

The creep properties of alloys in accordance with the invention are to a great extent dependent upon heat-treatment and the effects of various heat-treatments on the 11% tin, 2.25% aluminium, 5% zirconium alloy creep tested at 500° C. under a stress of 15 tons/sq. in. are given in Table V. In order to obtain the best creep properties, the alloy must be heated to a temperature above 950° C. and whilst 975° C. or 1100° C. can be used, preferably the temperature of solution treatment is 1000° C. followed by air cooling and reheating to 700° C. and air cooling. The double heat-treatment involving solution treatment and ageing has the effect of lowering the plastic strain compared with the single heat-treatment.

A comparison of the 11% tin, 2.25% aluminium, 5% zirconium alloy with other well known alloys is made in Table VI in which are given the stress values required to produce 0.1% total plastic strain in 300 hours at various temperatures. Whilst certain of the alloys require higher stress to produce the specified strain at 300° C. and 400° C., the superiority of the alloy in accordance with the invention at higher temperatures is evident.

Silicon may optionally be added to the 11% tin, 2.25% aluminium, 5% zirconium alloy to produce an increase in tensile strength with only a slight fall in ductility.

The most beneficial effect of silicon is in improvement in total plastic strain after heat-treatments involving heating in the beta field at temperatures of 975° C. or more, air cooling and ageing at temperatures in the range 500° C. to 700° C. In one condition of heat-treatment involving heating to 1000° C., air cooling and re-heating to 700° C. and air cooling the total plastic strain is reduced to 0.083% in 300 hours under 20 tons/sq. in. at 500° C., and in another condition of heat-treatment involving heating to 1000° C. air cooling and reheating to 500° C., and air cooling, the total plastic strain under the same test conditions is reduced to 0.070%.

The improvements in the properties of the 11% tin, 2.25% aluminium, 5% zirconium alloy brought about by silicon additions and by heat-treatment are shown in Tables VII, VIII and IX, the 0.2% silicon being the preferred addition. A useful range of composition is 0.05%–0.3% silicon and on a production basis a suitable range for a nominal composition of 0.2% is 0.1%–0.25%.

Copper between 0.1% and 2.5% may be added to the 11% tin, 2.25% aluminium alloy but is not as effective as silicon in improving creep properties.

When added to the 11% tin, 2.25% aluminium, 5% zirconium alloy, the copper additions should preferably be in the upper part of the range, i.e. 1%–2.5%, in order to obtain maximum benefit. Copper and silicon may be added together in the alloys herein described in the amounts specified for single additions without loss of the beneficial properties which result from the addition of either copper or silicon.

Additions of zirconium improve the elevated temperature tensile properties of titanium alloys containing tin and aluminium and the extent of the improvement can be seen in Table X which compares properties of the preferred ternary alloy composition with alloys having the same tin and aluminium contents and containing varying amounts of zirconium and molybdenum and tested at room and at two elevated temperatures. All test-pieces were heat-treated: 15 mins. at 1100° C., air cooled and reheated 1 hour at 700° C. and furnace cooled. An addition of 1% molybdenum produces a similar effect on properties to 5% of zirconium and it will be seen that strength and ductility are very good at both 400° C. and 500° C.

Creep tests on the preferred ternary composition with the addition of zirconium and molybdenum separately and together show that the additions are in general particularly effective at a temperature of 400° C. in reducing total plastic strain whereas at 500° C. there is a greater amount of creep. The results of creep tests on such

alloys is given in Table XI, the heat-treatment being the same as that in Table X.

When, in the fabrication or treatment of alpha-type and alpha plus beta-type alloys, it is necessary to heat them into the beta field, there is in certain cases a loss of ductility particularly when measured by reduction in area and the alloys may have a coarse-grained fracture. Whilst the ductility can be restored by working the alloys in the alpha plus beta field by considerable amounts, serious loss of ductility can be avoided by the addition of boron to the alloy.

Boron can also be used to increase the strength of the alloys without loss of ductility and to reduce the total plastic strain under creep conditions particularly at temperatures around 400° C. Improvements in creep properties and strength resulting from addition of boron are illustrated in the results set out in Table XII in which specimens were heat-treated by air cooling from 1100° C., reheated to 700° C. and furnace cooled. The range over which boron additions are effective in this respect is from 0.005% to 0.5% preferably 0.005% to 0.2%. The actual amount to be added depends upon the particular alloy but additions of the order of 0.025% have been found to be advantageous in many alloys. Alloys of the present invention may, therefore, be modified by the addition of boron within the above-mentioned ranges in order to avoid serious loss of ductility on heating into the beta field. This is of importance in permitting forging to be carried out in the beta field without impairing ductility seriously.

The outstanding creep properties described above depend in the first place on a titanium-tin-aluminium "base" which at all commercial hydrogen contents has good creep properties and is inherently free from embrittlement. The addition elements raise the levels of the properties of the "base" but do not remove the embrittlement characteristics of a "base" which is inherently of low ductility under creep conditions. It is an important feature of the invention that by selecting appropriate compositions an alloy may be produced having the optimum properties for the particular application envisaged having regard to the service temperature and stress involved.

Table I

[Tensile properties of titanium-aluminium-tin alloys containing about 180 p.p.m. hydrogen after heat-treatment]

Al	Sn	U.T.S., t./in. ²	El., per- cent on 4√A	Reduction in area, percent
0	0	32.6	33	35
7.6	0	53.4	7	8
9.0	0	47.2	3	1
2.0	2.5	40.3	24	37
6.2	2.5	62.4	7	5
6.7	2.5	54.3	5	5
8.1	2.5	44.8	2	0
1.0	5.0	38.2	19	33
2.0	4.9	42.7	20	35
3.0	5.1	49.5	15	35
5.0	5.1	55.3	14	35
6.1	5.2	56.1	5	6
6.9	4.5	56.6	5	5
0	7.6	37.7	21	36
1.0	7.4	44.7	14	25
4.0	7.7	64.3	5	5
5.0	7.4	60.2	5	5
5.9	7.2	54.8	5	5
0	10.2	42.7	18	30
3.8	9.9	60.8	7	5
5.0	9.9	37.1	0	0
0	12.3	51.7	8	10
3.0	12.4	60.3	9	16
4.0	12.3	55.2	0	0
2.1	14.8	59.3	8	14
3.0	14.8	53.3	0	0
1.9	17.2	61.8	5	5
1.0	19.8	64.8	4	4
0	21.5	61.8	8	10

Table II

[Tensile properties of titanium-tin-aluminum alloys containing about 180 p.p.m. hydrogen after heat-treatment]

Al	Sn	U.T.S., t./in. ²	El., per cent on $4\sqrt{A}$	Reduction in area, percent
3.1	9.7	61.3	20	43
3.2	9.8	61.3	29	36
3.3	9.8	60.7	11	8
3.6	9.9	61.8	9	10
3.8	9.8	62.3	6	6
4.0	9.8	61.3	6	5
2.5	10.9	60.3	26	36
2.7	11.0	62.8	16	16
2.8	11.0	60.8	24	37
2.0	11.1	60.7	23	32
3.2	11.3	62.3	7	11
3.5	11.3	63.8	9	9
2.0	12.1	60.8	21	33
2.2	12.4	60.8	23	34
2.3	12.5	62.3	21	33
2.6	12.4	62.8	7	10
2.8	12.0	61.8	15	25
3.0	12.4	62.3	5	5
1.5	13.8	59.9	23	30
1.7	13.6	61.3	21	30
1.9	13.5	59.9	24	34
2.2	13.7	61.3	17	32
2.3	13.6	62.9	10	10
2.4	13.5	63.4	6	10
1.0	14.8	58.9	20	33
1.2	14.6	60.7	21	30
1.4	15.0	59.9	24	30
1.5	14.7	60.8	17	23
1.8	14.7	61.8	17	20
2.0	14.7	61.3	14	14

Table III

[Creep properties of Ti-Sn-Al alloys at 400° C. at 25 tons/sq. in. for 300 hours heat treated]

Al	Sn	Total plastic strain, percent
1.0	13	0.106
1.5	13	0.084
2.5	12.5	0.040
1.5	11.5	0.090
2.0	11.5	0.094
3.0	11	0.050
2.0	9	0.107
3.5	9	0.080

Table IV

[Creep properties at 25 tons/sq. in. at 400° C.—Alloys heat-treated 15 mins. at 1100° C., air cooled, reheated 1 hour at 700° C. and furnace cooled]

Composition, percent	Percent total plastic strain in 300 hours	Tensile properties after creep testing		
		U.T.S.	percent el. on $4\sqrt{A}$	percent reduc- tion in Area
11 Sn, 2.25 Al.....	0.438	54.5	13	27
11 Sn, 2.25 Al, 5 Zr.....	0.050	61.4	14	25
11 Sn, 2.25 Al, 10 Zr.....	0.045	65.4	14	15
11 Sn, 2.25 Al, 2 Mo.....	0.054	66.1	10	10
11 Sn, 2.25 Al, 4 Mo.....	0.096	76.4	3	3

Table V

[Creep properties of 11% Sn, 2.25% Al, 5% Zr alloy at 500° C. at 15 tons sq. in. after various heat treatments]

Treatment	Percent total plastic strain in 300 hours	Tensile properties after creep testing		
		U.T.S., t./in. ²	Percent el. on $4\sqrt{A}$	Percent reduction in area
5				
10				
Hot rolled.....	0.698	70.6	13	30
20 mins. at 1,100° C. air cooled.....	0.078	63.7	19	30
20 mins. at 1,100° C. water quenched and 1 hour at 700° C. air cooled.....	0.270	67.7	11	20
15				
20 mins. at 1,100° C. air cooled and 1 hour at 700° C. furnace cooled.....	0.055	61.6	18	26
20 mins. at 1,100° C. air cooled and 1 hour at 700° C. air cooled.....	0.057	60.6	18	22
1 hour at 1,000° C. air cooled.....	0.072	64.7	15	22
20				
1 hour at 1,000° C. air cooled and 1 hour at 700° C. air cooled.....	0.054	64.3	16	32
1 hour at 975° C. air cooled and 1 hour at 700° C. air cooled.....	0.055	63.3	15	30
1 hour at 950° C. air cooled and 1 hour at 700° C. air cooled.....	0.037	63.2	18	27
25				
1 hour at 900° C. air cooled and 1 hour at 700° C. air cooled.....	0.063	65.7	13	28
1 hour at 900° C. air cooled and 1 hour at 700° C. air cooled.....	0.223	64.1	16	25
1 hour at 800° C. air cooled and 1 hour at 700° C. air cooled.....	0.360	66.4	15	30
16 hours at 800° C. air cooled.....	0.234	63.7	19	30
30				
64 hours at 800° C. air cooled.....	0.157	59.4	20	28
	0.153	62.1	23	28

Table VI

[Stress required to produce 0.1% total plastic strain in 300 hours at various temperatures for several alloys—Stress in tons/sq. in.]

° C.	11 Sn, 2.25 Al, 5Zr	2.5 Sn, 5 Al	4 Al, 4 Mn	6 Al, 4 V	7 Al, 3 Mo	4 Al, 4 Mo, 2 Sn, 0.5 Si
40						
300	31.0	23	38	36.8	—	46.5
400	26.9	22	11	9.3	28.5	38.5
450	24.7	—	—	—	—	11.5
500	19.0	8	<1	1.2	4	1
550	8.5	—	—	—	—	—
600	1.0	—	—	—	—	—
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¹ About.

Table VII

[Effect of additions of silicon on creep and tensile properties of 11% Sn, 2¼% Al, 5% Zr—Heat-treatment 8 hours at 800° C., air cooled, creep test 25 tons/in.² at 400° C.]

Composition	Percent total plastic strain in 300 hours	Tensile properties after creep testing		
		U.T.S. t./in. ²	Percent el. on $4\sqrt{A}$	Percent reduction in area
50				
55				
11+2¼+5.....	0.050	58.2	19	44
11+2¼+5+0.1% Si.....	0.092	58.3	19	42
11+2¼+5+0.2% Si.....	0.070	60.3	18	39
11+2¼+5+0.4% Si.....	0.076	65.0	16	34
60				

Table VIII

[Effect of treatment on properties of 11% Sn, 2.25% Al, 5% Zr with and without 0.2% Si, creep tested at 25 tons/in.² at 400° C.]

Composition	Treatment	Percent total plastic strain in 300 hours	Tensile properties after creep testing		
			U.T.S., t./in. ²	Percent el. on $4\sqrt{A}$	Percent reduction in area
11+2¼+5.....	1 hour at 900° C. air cooled.....	0.055	64.3	20	42
11+2¼+5+0.2% Si.....	do.....	0.067	66.8	17	39
11+2¼+5.....	1 hour at 900° C. air cooled and 24 hours at 500° C. air cooled.....	0.043	62.3	20	38
11+2¼+5+0.2% Si.....	do.....	0.048	66.4	16	37

Table IX

[Effect of Si contents of up to 0.4% on creep properties of 11% Sn, 2.25% Al, 5% Zr at 500° C.]

Composition	Treatment	Tons/in. ² stress	Percent total plastic strain in 300 hrs.	Tensile properties after creep testing		
				U. T. S., t./in. ²	Percent el. on $4\sqrt{A}$	Percent reduction in area
11+2¼+5	8 hours at 800° C. air cooled	15	0.112	58.3	18	37
11+2¼+5+0.1% Si	do	15	0.206	60.8	18	38
11+2¼+5+0.2% Si	do	15	0.202	61.8	18	38
11+2¼+5+0.4% Si	do	15	0.300	66.4	13	34
11+2¼+5	1 hour at 1,000° C. air cooled and 1 hour at 700° C. furnace cooled.	20	0.144	60.3	16	27
11+2¼+5+0.1% Si	do	20	0.111	63.3	13	20
11+2¼+5+0.2% Si	do	20	0.083	65.9	11	17
11+2¼+5+0.4% Si	do	20	0.110	67.4	16	30
11+2¼+5	1 hour at 1,000° C. air cooled and 24 hours at 550° C. air cooled.	20	0.136			
11+2¼+5+0.2% Si	do	20	0.080			
11+2¼+5	1 hour at 1,000° C. air cooled and 24 hours at 500° C. air cooled.	20	0.160			
11+2¼+5+0.2% Si	do	20	0.070			

Table X

[Effect of Mo and Zr on elevated temperature tensile properties of Ti, 11% Sn, 2¼% Al heat treated 15 mins. at 1100° C., air cooled, and 1 hour at 700° C., furnace cooled.]

Composition	Test temp., °C.	Limit of proportion- ality, tons/ in. ²	0.05% proof stress tons/ in. ²	U.T.S., t./in. ²	Percent el. on $4\sqrt{A}$	Percent reduction in area
11 Sn plus 2¼ Al	20	44.5	48.7	55.4	12	27
11 Sn plus 2¼ Al plus 1 Mo	20	43.7	48.3	59.5	9	17
11 Sn plus 2¼ Al plus 2 Mo	20	50.0	53.2	61.6	4	6
11 Sn plus 2¼ Al plus 5 Zr	20	49.3	54.9	65.0	16	31
11 Sn plus 2¼ Al plus 10 Zr	20	50.9	54.9	64.4	10	14
11 Sn plus 2¼ Al	400	17.6	21.1	30.9	18	35
11 Sn plus 2¼ Al plus 1 Mo	400	22.3	27.6	40.1	18	53
11 Sn plus 2¼ Al plus 2 Mo	400	27.2	34.4	47.2	14	21
11 Sn plus 2¼ Al plus 5 Zr	400	23.7	27.4	39.7	19	30
11 Sn plus 2¼ Al plus 10 Zr	400	28.8	33.5	47.9	13	26
11 Sn plus 2¼ Al	500	16.5	20.5	28.8	18	31
11 Sn plus 2¼ Al plus 1 Mo	500	21.6	25.9	37.2	21	68
11 Sn plus 2¼ Al plus 2 Mo	500	28.2	32.6	44.5	12	
11 Sn plus 2¼ Al plus 5 Zr	500	21.8	25.4	37.5	19	42
11 Sn plus 2¼ Al plus 10 Zr	500	25.4	29.6	43.7	14	28

Table XI

[Creep properties at 400° C. and 500° C. of Ti, 11% Sn, 2¼% Al containing Mo and Zr, heat treated]

Composition	Test conditions	Percent total plastic strain in 300 hours	0.01% proof stress at test tem- perature	Tensile properties after creep testing		
				U.T.S., t./in. ²	Percent el. on $4\sqrt{A}$	Percent reduction in area
11 Sn plus 2¼ Al plus 5 Zr	35 tons/in. ² at 400° C.	2.196	21.8	60.5	14	15
11 Sn plus 2¼ Al plus 10 Zr	do	0.200	31.2	68.4	10	12
11 Sn plus 2¼ Al plus 2 Mo	do	0.415	30.1	66.5	8	10
11 Sn plus 2¼ Al plus 5 Zr plus ½ Mo	do	0.234	27.7	62.4	12	15
11 Sn plus 2¼ Al plus 5 Zr plus 1 Mo	do	0.096	>35	68.9	9	10
11 Sn plus 2¼ Al plus 5 Zr	15 tons/in. ² at 500° C.	0.049	>15	62.2	15	23
11 Sn plus 2¼ Al plus 10 Zr	do	0.080	>15	66.0	15	19
11 Sn plus 2¼ Al plus 2 Mo	do	0.398	>15	70.0	8	8
11 Sn plus 2¼ Al plus 5 Zr plus ½ Mo	do	0.132	>15	65.9	7	10
11 Sn plus 2¼ Al plus 5 Zr plus 1 Mo	do	0.202	>15	69.9	6	6

Table XII

[Effect of boron on creep and tensile properties of 11% Sn+2½% Al+5% or 10% Zr with and without molybdenum]

Composition percent	Stress	Temp., ° C.	Percent total plastic strain	U.T.S.	Percent el. on $4\sqrt{A}$	Percent reduction in area
11+2½+5 Zr.....	35	400	1.424	62.5	17	27
11+2½+5 Zr plus 0.025 B.....	35	400	0.784	64.4	18	31
11+2½+5 Zr plus 0.05 B.....	35	400	0.674	62.3	18	37
11+2½+5 Zr plus 0.10 B.....	35	400	0.479	63.5	15	35
11+2½+5 Zr plus 0.20 B.....	35	400	0.300	-----	15	32
11+2½+10 Zr.....	35	400	0.265	64.2	15	20
11+2½+10 Zr plus 0.025 B.....	35	400	0.242	66.4	15	15
11+2½+10 Zr plus 0.05 B.....	35	400	0.215	68.5	14	24
11+2½+10 Zr plus 0.10 B.....	35	400	0.186	70.4	15	30
11+2½+10 Zr plus 0.20 B.....	35	400	0.160	72.0	16	25
11+2½+5 Zr plus 0.5 Mo.....	15	500	0.132	65.9	7	10
11+2½+5 Zr plus 0.5 Mo plus 0.2 B.....	15	500	0.139	68.6	16	31
11+2½+5 Zr plus 1.0 Mo.....	35	400	0.096	68.4	10	12
11+2½+5 Zr plus 1.0 Mo plus 0.025 B.....	35	400	0.093	69.3	13	23

NOTE.—All specimens heat-treated 1 hour at 1,100° C. air cooled and 1 hour at 700° C. furnace cooled.

We claim:

1. Titanium-base alloys having low creep rates at high temperature and high tolerance for hydrogen consisting essentially of tin and aluminum in the area defined by straight lines connecting the following four compositions in the ternary constitutional diagram of the titanium-tin-aluminum system: 14% tin, 0.5% aluminum; 14% tin, 2.2% aluminum; 7% tin, 4.25% aluminum; 7% tin, 2.5% aluminum; 0.05%–0.5% silicon, 1%–10% zirconium, 0.005%–0.5% boron, balance titanium and usual impurities, said percentages being by weight.

2. A titanium-base alloy having low creep rates at high temperature and high tolerance for hydrogen consisting essentially of, by weight, 10.5%–11.5% tin, 2.0%–2.5% aluminum, 8%–10% zirconium, 0.1%–0.25% silicon, balance titanium and usual impurities.

3. An alloy consisting essentially of, by weight, 11% tin, 2.25% aluminum, 5% zirconium, 0.2% silicon, balance titanium and usual impurities, having an acicular type structure, less than 0.1% total plastic strain in 300

hours under a load of 25 tons per square inch at 400° C. and elongation of not less than 10% when exposed to hydrogen at a concentration greater than 10 parts per million.

4. A titanium-base alloy consisting essentially of by weight 10.5%–11.5% tin, 2.0%–2.5% aluminum, 4%–6% zirconium, 0.1%–0.25% silicon, balance titanium and usual impurities, having an acicular type structure, less than 0.1% total plastic strain in 300 hours under a load of 25 tons per square inch at 400° C. and an elongation of not less than 10% when exposed to hydrogen having a concentration greater than 10 parts per million.

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