

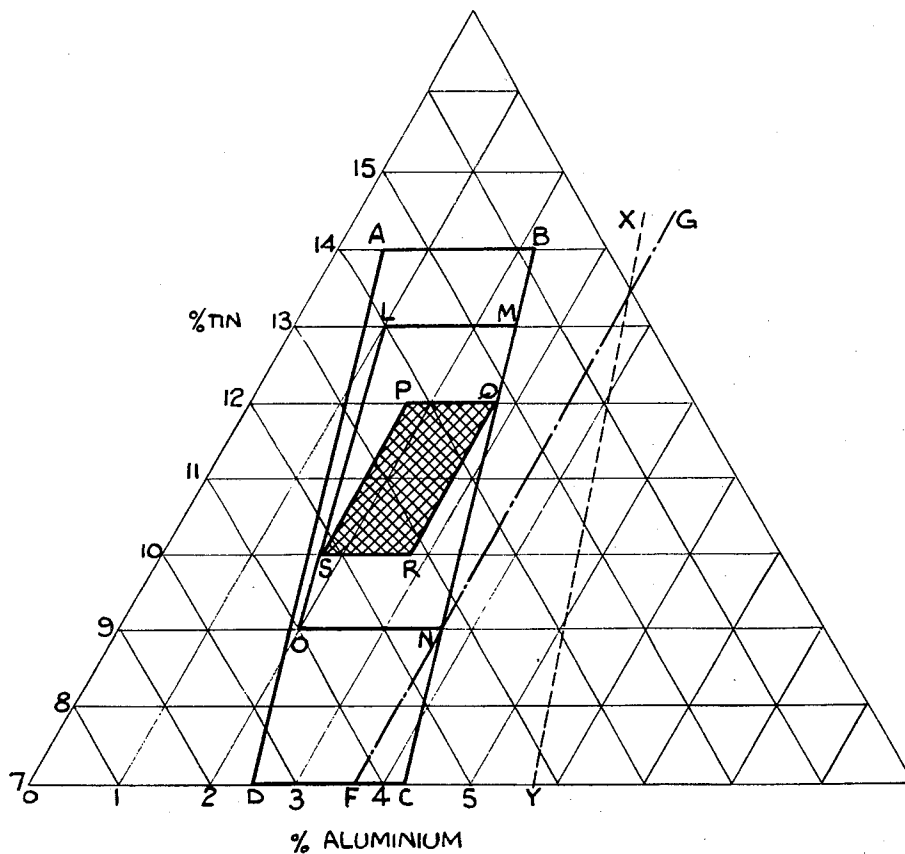
Aug. 14, 1962

W. P. FENTIMAN ETAL

3,049,425

ALLOYS

Filed Nov. 12, 1959



INVENTORS:

William Percival Fentiman,
Stuart Leslie Ames,
Peter Harlow Morton,
Harry Wilfrid Mead,

BY *Cushman, Darby & Cushman*
ATTORNEYS.

1

3,049,425
ALLOYS

William Percival Fentiman, Birmingham, England, Stuart Leslie Ames, Natrona Heights, Pa., and Peter Harlow Morton and Harry Wilfrid Mead, Birmingham, England, assignors to Imperial Chemical Industries Limited, London, England, a corporation of Great Britain
Filed Nov. 12, 1959, Ser. No. 852,493
Claims priority, application Great Britain Nov. 14, 1958
10 Claims. (Cl. 75-175.5)

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.

Throughout this specification the proportions of all components are specified 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 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.

2

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. In the description and tables the expression El. percent on $4\sqrt{A}$ refers to the gauge length of the test piece and means the elongation percent on 4 times the square root of the cross-sectional area.

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 or 800° C. for a period and air cool or 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 of 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 23% 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. inch 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, 2.25% 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 zirconium 1–10%, and molybdenum 0.5–5%, and optionally silicon 0.05–0.5% and copper 0.1–2.5%, of which zirconium is an alpha stabiliser and molybdenum a beta stabiliser and silicon and copper are beta stabilisers which may form metallic compounds in some conditions of heat-treatment.

Excellent creep properties have been obtained from an alloy having a nominal composition of 11% tin, 2.25% aluminium, 5% zirconium, 1% molybdenum and 0.3% silicon as hereinafter described and suitable ranges of composition are: zirconium 2.5%–7.5%, and molybdenum 0.8%–1.2%. On a production scale with suitable melting techniques the range of composition for zirconium may be 4%–6% and for silicon 0.2%–0.5%.

Silicon is an optional addition but is desirable because of its beneficial effect on tensile strength.

Because molybdenum is a beta stabilizing element, alloys of the invention which contain molybdenum are alpha plus beta type alloys.

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 IV, the heat-treatment being 1 hour at 1100° C., air cooled and reheated 1 hour at 700° C. and furnace cooled.

The creep properties of alpha plus beta type alloys in accordance with the invention are associated with certain types of structure. An acicular type of structure produced by solution treatment at 1100° C. and ageing at 700° C. with appropriate cooling rates gives low creep rates and an equiaxed structure, produced at lower temperatures, results in greater ductility but increased creep. Examples of the effects of two types of heat-treatment on structure and on creep properties are given in Table V, the creep tests being carried out at 400° C. under a load of 35 tons/sq. in. for 300 hours.

Further improvements in creep properties of an alpha plus beta type alloy of nominal composition 11% tin, 2.25% aluminium, 5% zirconium, 1% molybdenum may be brought about by the addition of 0.05% to 0.5% of silicon to the alloy. There is a progressive reduction in initial plastic strain up to 0.2% silicon at which composi-

5

tion the initial plastic strain has disappeared. Strength is good and the alloys are free from embrittlement. Between 0.20% and 0.5% silicon, properties do not change appreciably but above 0.5% silicon there is a tendency towards inhomogeneity and embrittlement. The composition, 11% tin, 2.25% aluminium, 5% zirconium, 1% molybdenum, 0.3% silicon is a particularly useful alloy for elevated temperature applications in which the requirements are not greater than 0.1% total plastic strain at 400° C. under a load of 35 tons (78,400 pounds)/sq. in. for 100 hours. The effect of different silicon contents on creep properties as described above is shown in Table VI in which the heat-treatment given to the specimens was 1 hour at 900° C., air cooled, reheated at 500° C. for 24 hours and air cooled. Creep tests were carried out at 400° C. under a load of 35 tons/sq. in. for 300 hours.

The best heat-treatment for the 11% tin, 2.25% aluminium, 5% zirconium, 1% molybdenum, 0.3% silicon alloy is that given to the specimens in Table VI.

The effects of varying the ageing temperature on creep properties of the alloy are given in Table VII in which it will be seen that, for the same creep conditions as in Table VI, increasing the ageing temperature increases the total plastic strain and reduces strength after creep tests, whilst there is also some loss of ductility.

The 11% tin, 2.25% aluminium, 5% zirconium, 1% molybdenum, 0.3% silicon alloy may be heated to temperatures above the beta transus of 950° C. without suffering embrittlement and this is shown in Table VIII, in which the specimens, after heating to various temperatures in the beta field, have been solution treated at 900° C. and aged at 500° C. This particular alloy can be forged in the beta field without fear of subsequent embrittlement and without having to adopt complex forging schedules to avoid embrittlement and this characteristic of the alloy is important in facilitating manufacture of such components as compressor blades and discs for gas turbine engines.

Some typical properties of an alloy in accordance with the invention are compared in Table IX with alloys containing molybdenum only, the alloys being in the solution treated and aged condition as previously described. 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 in 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 X 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 properties and is inherently free from embrittlement. The

6

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. Thus it is now possible to meet a requirement of 0.1% total plastic strain at 400° C. in 100 hours at a load of 78,400 pounds/sq. in. with a titanium-base alloy without embrittlement and this represents a very considerable improvement on titanium-base alloys hitherto known.

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. percent on $4\sqrt{A}$	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-Aluminium Alloys Containing About 180 p.p.m. Hydrogen After Heat-Treatment

Al	Sn	U.T.S., t./in. ²	El. percent 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
3.0	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

7
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	0.060
2.0	9	0.107
3.5	9	0.080

TABLE IV

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 Temperature	Tensile Properties after Creep Testing		
				U.T.S. t./in. ²	Percent El. on 4√A	Percent Reduction Area
11Sn+2¼Al+5Zr.....	35 tons/in. ² at 400° C.	2.196	21.8	60.5	14	15
11Sn+2¼Al+10Zr.....	do.	0.200	31.2	68.4	10	12
11Sn+2¼Al+2Mo.....	do.	0.415	30.1	66.5	8	10
11Sn+2¼Al+5Zr+½Mo.....	do.	0.234	27.7	62.4	12	15
11Sn+2¼Al+5Zr+1Mo.....	do.	0.096	>35	68.9	9	10
11Sn+2¼Al+5Zr.....	15 tons/in. ² at 500° C.	0.049	>15	62.2	15	23
11Sn+2¼Al+10Zr.....	do.	0.080	>15	66.0	15	19
11Sn+2¼Al+2Mo.....	do.	0.398	>15	70.0	8	8
11Sn+2¼Al+5Zr+½Mo.....	do.	0.132	>15	65.9	7	10
11Sn+2¼Al+5Zr+1Mo.....	do.	0.202	>15	69.9	6	6

TABLE V

Effect of Heat-Treatment on Structure and Properties of Ti, 11% Sn, 2¼% Al Containing Mo and Zr

Composition	Heat-Treatment	Type of Structure	Percent Total Plastic Strain at 400° C. under stress of 35 tons/in. ²	Tensile Properties after Creep Testing		
				U.T.S. t./in. ²	Percent El. on 4√A	Percent Reduction in Area
11Sn+2¼Al+5Zr+1Mo.....	½ hour at 1,100° C. air cooled and 1 hour at 700° C. furnace cooled.	Acicular...	0.096	68.9	9	10
	1 hour at 900° C. air cooled and 24 hours at 500° C. air cooled.	Equiaxed...	0.225	67.4	20	42
11Sn+2¼Al+2Mo.....	½ hour at 1,100° C. air cooled and 1 hour at 700° C. furnace cooled.	Acicular...	0.415	66.5	8	10
	1 hour at 900° C. air cooled and 24 hours at 500° C. air cooled.	Equiaxed...	0.913	67.4	18	38
11Sn+2¼Al+4Mo.....	1 hour at 900° C. air cooled and 24 hours at 500° C. air cooled.	Equiaxed...	0.385	80.5	16	30

TABLE VI

Effect of Different Silicon Contents on Creep (35 Tons/in.² at 400° C) of 11% Sn, 2¼% Al, 5% Zr, 1% Mo Heat Treated 1 Hour at 900° C. Air Cooled and 24 Hours at 500° C. Air Cooled

Percent Silicon	Percent Initial Plastic Strain	Percent 300 Creep	Percent Total Plastic Strain	Tensile Properties after Creep Testing		
				U.T.S. t./in. ²	Percent El. on 4√A	Percent Reduction in Area
Nil.....	0.057	0.169	0.225	67.4	20	42
0.05.....	0.039	0.104	0.143	71.9	16	37
0.10.....	0.017	0.094	0.111	72.5	20	45
0.15.....	0.029	0.092	0.121	74.5	15	36
0.20.....	Nil	0.098	0.098	71.4	17	34
0.5.....	Nil	0.093	0.093	71.9	15	30

8
TABLE VII

Effect of Varying Ageing Temperature on Creep (35 Tons/in.² at 400° C.) and Tensile Properties of 11% Sn, 2¼% Al, 5% Zr, 1% Mo, 0.3% Si.

Treatment	Percent Total Plastic Strain in 300 hours	Tensile Properties after creep Testing		
		U.T.S. t./in. ²	Percent El. on 4√A	Percent Reduction in Area
10 1 hour at 900° C. air cooled and 24 hours at 500° C. air cooled.....	0.095	76.6	15	40
1 hour at 900° C. air cooled and 24 hours at 600° C. air cooled.....	0.179	75.5	15	40
15 1 hour at 900° C. air cooled and 24 hours at 700° C. air cooled.....	0.270	968.4	13	28

TABLE VIII

Effect of Heating 11% Sn, 2¼% Al, 5% Zr, 1% Mo, 0.35% Si at Temperatures Above Beta Transus All Specimens Heat-Treated 1 Hour at 900° C. Air Cooled and 24 Hours at 500° C. Air Cooled After Beta Treatment

Beta Treatment 1 hour at	0.1% Proof Stress, tons/in. ²	Tensile Properties after Creep Testing		
		U.T.S. t./in. ²	Percent El. on 4√A	Percent Reduction in Area
65 950° C. air cooled.....	64.5	71.6	15	35
950° C. water quenched.....	61.8	71.3	16	40
1,000° C. air cooled.....	63.9	72.6	19	41
1,000° C. water quenched.....	59.4	69.8	17	31
70 1,040° C. air cooled.....	61.9	71.6	15	27
1,040° C. water quenched.....	58.5	70.5	17	30
1,070° C. air cooled.....	61.9	72.7	11	18
1,070° C. water quenched.....	61.0	73.0	11	12
1,100° C. air cooled.....	64.0	75.3	11	13
1,100° C. water quenched.....	60.0	71.9	3	5
75 1,100° C. water quenched.....	64.8	74.0	4	7

TABLE IX

Typical Properties of Three Alloys Heat-Treated 1 Hour at 900° C. Air Cooled and 24 Hours at 500° C. Air Cooled

Composition	Creep Test Temperature, ° C.	Stress to Produce 0.1% Total Plastic Strain in 300 hrs.	Tensile Properties at Room Temperature			
			0.1% Proof Stress	U.T.S., t./in. ²	Percent El. on 4√A	Percent Reduction in Area
11Sn+2¼Al+5Zr+1Mo+0.3Si.....	Room	-----	64.0	71.0	18	41
	300	44.0	-----	-----	-----	-----
	400	37.0	-----	-----	-----	-----
	450	25.0	-----	-----	-----	-----
	500	13.5	-----	-----	-----	-----
11Sn+2¼Al+4Mo+0.3Si.....	Room	-----	75.0	88.0	10-15	20-45
	300	49.0	-----	-----	-----	-----
	400	35.0	-----	-----	-----	-----
	450	13.5	-----	-----	-----	-----
	500	3.5	-----	-----	-----	-----
11Sn+2¼Al+2Mo+0.3Si.....	Room	-----	63.0	75.0	17	49
	400	35.0	-----	-----	-----	-----
	450	15.0	-----	-----	-----	-----

TABLE X

Effect of Boron on Creep and Tensile Properties of 11% Sn+2¼% Al+5% or 10 Zx With and Without Molybdenum

Composition, Percent	Stress	Temperature, ° C.	Percent Total Plastic Strain	U.T.S. t./in. ²	Percent El. on 4√A	Percent Reduction in Area
11+2¼+5Zr.....	35	400	1.424	62.5	17	27
11+2¼+5Zr+0.025 B.....	35	400	0.784	64.4	18	31
11+2¼+5Zr+0.05 B.....	35	400	0.674	62.3	18	37
11+2¼+5Zr+0.10 B.....	35	400	0.479	63.5	15	35
11+2¼+5Zr+0.20 B.....	35	400	0.300	-----	15	32
11+2¼+10Zr.....	35	400	0.265	64.2	15	20
11+2¼+10Zr+0.25 B.....	35	400	0.242	66.4	15	15
11+2¼+10Zr+0.05 B.....	35	400	0.215	68.5	14	24
11+2¼+10Zr+0.10 B.....	35	400	0.186	70.4	15	30
11+2¼+10Zr+0.20 B.....	35	400	0.160	72.0	16	25
11+2¼+5Zr+0.5 Mo.....	15	500	0.132	65.9	7	10
11+2¼+5Zr+0.5 Mo+0.2 B.....	15	500	0.139	68.6	16	31
11+2¼+5Zr+1.0 Mo.....	35	400	0.096	68.4	10	12
11+2¼+5Zr+1.0 Mo+0.025 B.....	35	400	0.093	69.3	13	23

All specimens heat-treated 1 hour at 1100° C. air cooled and 1 hour at 700° C. furnace cooled.

We claim:

1. Titanium-base alloys consisting essentially of tin and aluminium in the area defined by straight lines connecting the following four compositions in the ternary constitutional diagram of the titanium-tin-aluminium system: 14% tin, 0.5% aluminium; 14% tin, 2.2% aluminium; 7% tin, 4.25% aluminium; 7% tin, 2.5% aluminium, up to 0.5% silicon, 1%-10% zirconium, 1%-5% molybdenum, balance titanium and usual impurities, said percentages being by weight.

2. An alloy as claimed in claim 1 containing in addition 0.1%-2.5% copper by weight.

3. An alloy as claimed in claim 1 having an acicular type structure.

4. Titanium-base alloys consisting essentially of tin and aluminium in the area defined by straight lines connecting the following four compositions in the ternary constitutional diagram of the titanium-tin-aluminium system: 13% tin, 1% aluminium; 13% tin, 2.5% aluminium; 9% tin, 2% aluminium; 9% tin, 3.6% aluminium; up to 0.5% silicon; 2.5%-7.5% zirconium; 0.8%-1.2% molybdenum, balance titanium and usual impurities, said percentages being by weight.

5. Titanium-base alloys consisting essentially of tin and aluminium in the area defined by straight lines connecting the following four compositions in the ternary constitu-

tional diagram of the titanium-tin-aluminium system: 12% tin, 1.75% aluminium; 12% tin, 2.75% aluminium; 10% tin, 2.75% aluminium, 10% tin, 1.75% aluminium; 0.05%-0.3% silicon, 4%-6% zirconium, 0.8%-1.2% molybdenum, balance titanium and usual impurities, said percentages being by weight.

6. Titanium-base alloys consisting essentially of, by weight, 10.5%-11.5% tin, 2.0%-2.5% aluminium, 4%-6% zirconium, 0.8%-1.2% molybdenum, 0.1%-0.5% silicon, balance titanium and usual impurities.

7. An alloy as claimed in claim 6 having an acicular type of structure and a creep strength of not less than 78,400 pounds per square inch at 400° C. based on a criterion of 0.1% creep strain in 100 hours at 400° C.

8. Titanium-base alloys consisting essentially of tin and aluminium in the area defined by straight lines connecting the following four compositions in the ternary constitutional diagram of the titanium-tin-aluminium system: 14% tin, 0.5% aluminium; 14% tin, 2.2% aluminium; 7% tin, 4.25% aluminium; 7% tin, 2.5% aluminium; up to 0.5% silicon 1%-10% zirconium, 1%-5% molybdenum, 0.005%-0.5% boron, balance titanium and usual impurities, said percentages being by weight.

9. An alloy as claimed in claim 8 having an acicular type structure.

11

10. A method of heat treating a titanium-base alloy consisting essentially of, by weight, 10.5%–11.5% tin, 2.0%–2.5% aluminium, 4%–6% zirconium, 0.8%–1.2% molybdenum, 0.1%–0.5% silicon, balance titanium and usual impurities which comprises solution heat treating the alloy at 900° C., air cooling, aging the alloy at 500° C. and air cooling, whereby the creep strength of not less than 78,400 pounds per square inch at 400° C., based on a criterion of 0.1% creep strain in 100 hours at 400° C.

12

References Cited in the file of this patent

UNITED STATES PATENTS

2,669,513	Jaffee et al.	Feb. 16, 1954
2,779,677	Jaffee et al.	Jan. 29, 1957
2,797,996	Jaffee et al.	July 2, 1957
2,867,534	Jaffee et al.	Jan. 6, 1959

FOREIGN PATENTS

219,498	Australia	May 16, 1957
---------	-----------------	--------------