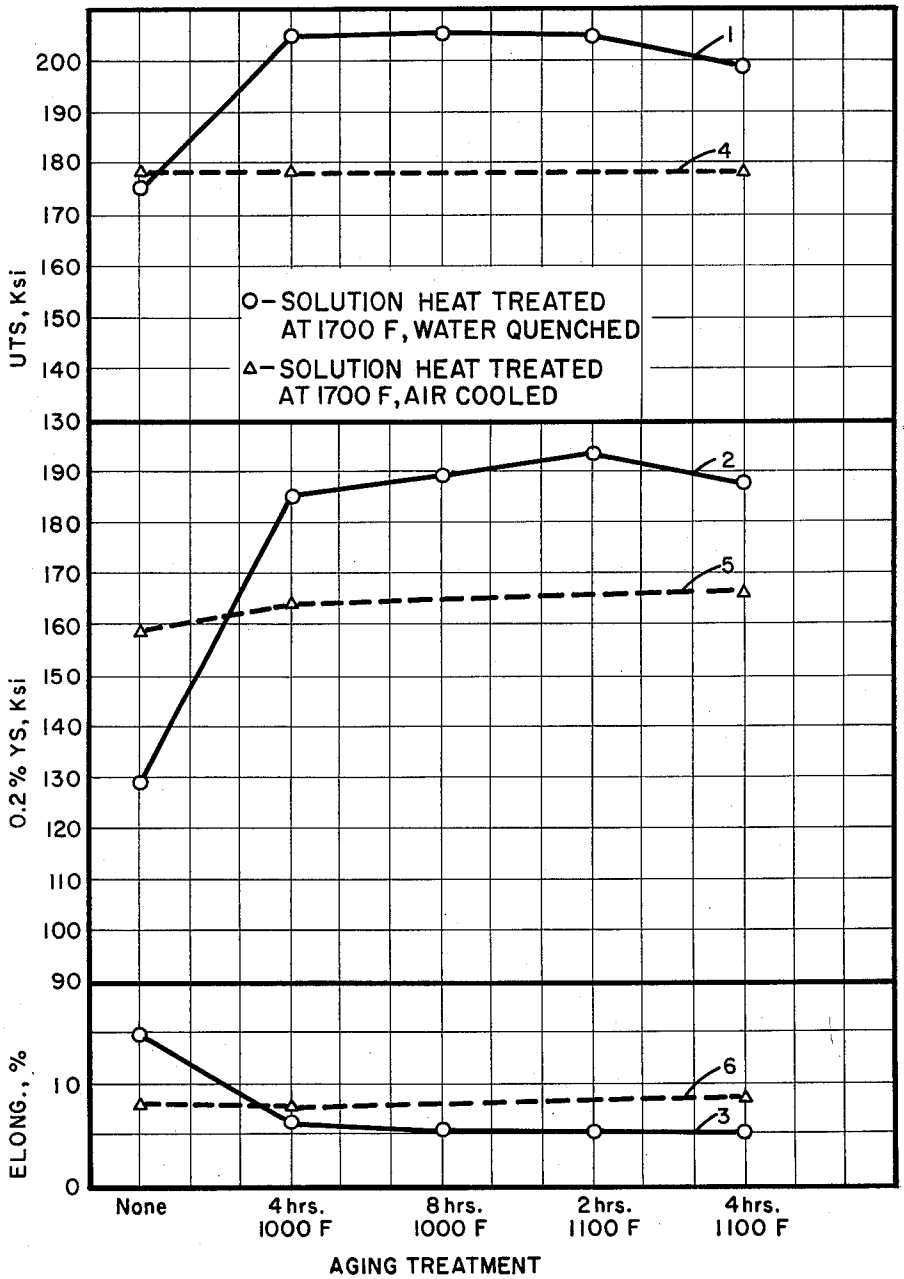
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ALLOY OF TITANIUM

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EFFECT OF HEAT TREATMENT AND AGING ON Ti-5Al-5Zr-5Sn-1Mo-1V ALLOY.

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ALLOY OF TITANIUM

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This invention relates to titanium base alloys and more particularly to a titanium base alloy which is heat treatable to high tensile strength.

The advantages of alpha type titanium base alloys are well known. These include high temperature strength, creep resistance, and weldability. The alpha type alloys, however, being composed of a one phase system, are not appreciably heat treatable. Addition of a substantial proportion of beta stabilizing alloying elements can produce an alpha-beta type alloy which is heat treatable, but the advantages of the alpha type alloy will generally be to a large degree lost in compositions of this type heretofore used or proposed.

It is therefore the principal object of this invention to provide an improved titanium base alloy. Another object of this invention is to provide a highly heat treatable titanium base alloy. A further object of this invention is to provide a heat treatable titanium base alloy but which also possesses in useful measure attributes of an alpha type titanium alloy. Another object of this invention is to provide a heat treatable, titanium base alloy having a substantially flat aging response curve. These and other objects of this invention will be apparent from the following description thereof.

This invention contemplates an alloy consisting essentially of about 5% aluminum, about 5% zirconium, about 5% tin, about 1% vanadium, and about 1% molybdenum with the balance substantially all titanium and incidental impurities. The alloy is characterized by good room temperature properties as well as elevated temperature properties, and is particularly characterized by being heat treatable to a strength level of over 200,000 pounds per square inch while retaining good ductility.

The proportions of the alloying elements employed in the alloy of this invention are critical. The amounts of the alpha stabilizers, aluminum, zirconium, and tin, provide mechanical properties not found in other combinations of these metals. Apparently there is some complexing action which produces the beneficial effects when these three elements are present in about these amounts. While the percentages should be as close to 5% as possible, this precision cannot always be obtained in large scale production, but the percentage of aluminum should lie within the range of 4.5% to 5.5% while some slight additional leeway may be permitted in the amounts of tin and zirconium, these each should be within the range of 4% to 6%.

The amounts of vanadium and molybdenum are also critical and these should each be present in amount about 1%, and should be within the range of 0.7% to 1.3%. More than this will result in loss of ductility and a tendency towards embrittlement, and less will not provide sufficient heat treatment response.

Incidental impurities such as oxygen, nitrogen, carbon, and various metals in impurity amounts, may be present in the alloy of this invention to the extent that they do not materially affect the characteristic properties thereof. Such impurities should total less than about 0.5%, and the oxygen content alone should ordinarily be less than about 0.2%.

The characteristics and unique properties of the alloy of this invention will be apparent from consideration of the data shown in the single FIGURE of the drawing.

The alloy for this work was produced by arc melting the titanium and alloying ingredients. The melted ingot was then forged to sheet bar and rolled to 0.050 inch sheet. Specimen samples were machined from the sheet.

As seen in the figure the alloy is capable of being solution heat treated and aged to strengths of over 200,000 pounds per square inch. The curve identified as **1** shows that after solution heat treating at 1700° F. and water quenching, the alloy has an ultimate tensile strength of 163,000 pounds per square inch, and after a subsequent aging at 1000° F. for four hours, 1000° F. for eight hours or 1100° F. for two hours the ultimate tensile strengths were found to be 204,000; 205,000; and 205,000 pounds per square inch respectively. After an aging treatment of 1100° F. for four hours the strength is only slightly lower at 199,000 pounds per square inch. The curve **2** shows that the yield strength under the same conditions of aging rose from 128,000 pounds per square inch to 185,000; 189,000; 194,000; and 188,000 pounds per square inch respectively.

The percent elongation curve **3** shows value of 15% for the solution treated and water quenched alloy and 6%, 5.5% and 5% for the aged conditions at 1000° F. for 4 hours, 1000° F. for 8 hours and 1100° F. for 4 hours.

Curves **4**, **5**, and **6** show, respectively, the ultimate tensile strength, yield strength and elongation of the alloy after solution heat treatment followed by air cooling, and subsequent aging. It is a unique feature that the alloy of this invention under these conditions shows substantially flat aging curves. In curve **4** the ultimate tensile strength, after solution heat treating and air cooling, is 178,000 pounds per square inch and this value remains the same after aging at 1000° F. for 4 hours, or at 1100° F. for 4 hours. The yield strength curve **5** rises only a few thousand pounds per square inch on aging, while the elongation curve **6** is essentially flat with the values in the solution heat treated and in the aged condition all being between 7.5% and 9%.

The flat aging response characteristic is important when the alloy of this invention is used or fabricated under elevated temperature conditions. After solution heat treating and air cooling it may be re-heated without appreciable change in strength or other mechanical properties, for example, when required for hot forming. In addition, the air cooling step is much easier to accomplish in a small fabricator's shop than a water quench, and does not result in distortion which often accompanies a quenching operation.

Thus, the alloy of this invention possesses a valuable combination of heat treat capabilities. On the one hand, it may be solution treated, quenched and aged to strengths of over 200,000 pounds per square inch for application where extremely high strength is required. On the other hand, it is also useful after solution treating and air cooling, at somewhat lower strength levels, in applications requiring uniformity of properties at normal and elevated temperatures, as in hot forming.

It is of the utmost significance that the properties of the alloy of this invention are obtained with a total beta stabilizer content of only about 2%. At this beta stabilizer level the alloy possesses remarkably high heat treatment capability, yet retaining in good measure characteristics of an all alpha alloy. The following tables show the room temperature properties, elevated temperature properties and weldability (as determined by bend test on a weld) which will be shown by the 5Al-5Zr-5Sn-1Mo-1V alloy compared to an alloy containing 6% aluminum and 4% vanadium and one containing 5% aluminum and 2.5% tin. Both these comparison alloys have enjoyed commercial success, the 6Al-4V alloy be-

ing of the alpha-beta type, heat treatable generally up to about 190,000 pounds per square inch ultimate, and the 5Al-2.5Sn alloy being an alpha type alloy and not heat treatable.

Table 1 below compares the room temperature properties, as annealed, and the superiority of the 5Al-5Zr-5Sn-1Mo-1V alloy in tensile properties will be apparent and it also possesses a degree of weldability indicated by the weld bend test.

TABLE 1

Room Temperature Tensile, Bend and Weld Bend Properties—Annealed

Alloy	U.T.S., p.s.i.	Y.S. (0.2%), p.s.i.	Elong., percent	Weld Bend T
Ti-5Al-5Zr-5Sn-1Mo-1V [a]	156,000	147,000	13	9.5 (4.4 base).
Ti-6Al-4V [b]	130,000	120,000	10	7 (4.5 base).
Ti-5Al-2.5Sn [b]	115,000	110,000	10	2.5–5.0 (4 base).

[a] Ti-5Al-5Zr-5Sn-1Mo-1V annealed 1,450° F.—1 hour air cool.
[b] Ti-6Al-4V, Ti-5Al-2.5Sn commercial material as mill annealed.

Table 2 below compares the 5Al-5Zr-5Sn-1Mo-1V alloy with the 6Al-4V alloy; both in the heat treated and aged condition. The 5Al-5Zr-5Sn-1Mo-1V alloy solution treated and air cooled shows about the same strength as 6Al-4V solution treated and quenched and also shows a degree of weldability not shown by the 6Al-4V alloy. The 5Al-2.5Sn alloy, being of the all alpha type is not heat treatable.

TABLE 2

Room Temperature Tensile, Bend and Weld Bend Properties—Heat Treated

Alloy	U.T.S., p.s.i.	Y.S. (0.2%), p.s.i.	Elong., percent	Weld Bend T
Ti-5Al-5Zr-5Sn-1Mo-1V [a]	179,000	163,000	8	14.5–16.3 (9.1 base).
Ti-6Al-4V [b]	183,000	175,000	4	No successful bends (4.2 base).

[a] Ti-5Al-5Zr-5Sn-1Mo-1V heat treatment 1,700° F.—1/3 hr. AC+1,000° F.—4 hrs. AC.
[b] Ti-6Al-4V heat treatment 1,700° F.—1/2 hr. WQ+900° F.—8 hrs. AC for tensile; 1,700° F.—1/2 hr. WQ+900° F.—16 hrs. AC for weld.

Table 3 below compares elevated temperature strength and creep resistance of these alloys, and it will readily be seen that the 5Al-5Zr-5Sn-1Mo-1V alloy is superior to the 6Al-4V alloy and also superior to the 5Al-2.5Sn alpha alloy.

TABLE 3

Elevated Temperature Tensile and Creep Properties

Alloy	Tensile Properties			Stress for Creep to 1.0% at 850° F. for 150 Hrs., p.s.i.
	Temp., ° F.	U.T.S., p.s.i.	Y.S. (0.2%), p.s.i.	
Ti-5Al-5Zr-5Sn-1Mo-1V [a]	750	152,000	127,000	75,000
	1,000	130,000	89,000	
Ti-6Al-4V [b]	750	100–115,000	85–90,000	50,000
	1,000	80–95,000	60–75,000	
Ti-5Al-2.5Sn	750	77,000	65,000	40,000
	1,000	65,000	55,000	

[a] Ti-5Al-5Zr-5Sn-1Mo-1V round bar heat treated 1,725° F.—1 hr. AC+1,000° F.—2 hrs. AC. Room temperature strength approximately equivalent to 1,700° F.—1/3 hr. AC+1,000° F.—4 hrs. AC for sheet.
[b] Low values for T.S. and Y.S. are for mill annealed condition, high for high strength heat treated.

It will be apparent from the above that neither the 6Al-4V nor the 5Al-2.5Sn alloys possess the high temperature strength or creep resistance of the alloy of this invention. The superiority of the 5Al-5Zr-5Sn-1Mo-1V composition in these respects must also be considered in view of its heat treatability which is also greater than either of these other alloys, and its weldability.

The alloys of this invention may be produced by any convenient method. Advantageously they may be produced by arc melting, employing a consumable electrode of titanium sponge and the alloying elements in proper proportions. Such an electrode is progressively melted into a cooled crucible or mold to form a solid ingot. Such an ingot may be subjected to usual working procedures such as forging and rolling to provide intermediate products such as billet, bar, sheet, strip, and wire which may be further fabricated into shapes, forms, and elements useful in applications where titanium's light weight and strength are advantageous such as aircraft parts.

I claim:

1. An alloy consisting essentially of from 4.5% to 5.5% aluminum, from 4% to 6% zirconium, from 4% to 6% tin, from 0.7% to 1.3% molybdenum, and from 0.7% to 1.3% vanadium with the balance substantially all titanium and incidental impurities, characterized by being weldable and by being heat treatable to a tensile strength of over 200,000 pounds per square inch.

2. An alloy consisting essentially of about 5% aluminum, about 5% zirconium, about 5% tin, about 1% molybdenum and about 1% vanadium with the balance substantially all titanium and incidental impurities, characterized by being weldable and by being heat treatable to a tensile strength of over 200,000 pounds per square inch.

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