Sept. 29, 1959 S. ABKOWITZ 2,906,654

HEAT TREATED TITANIUM-ALUMINUM-VANADIUM ALLOY

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Fig. 1.

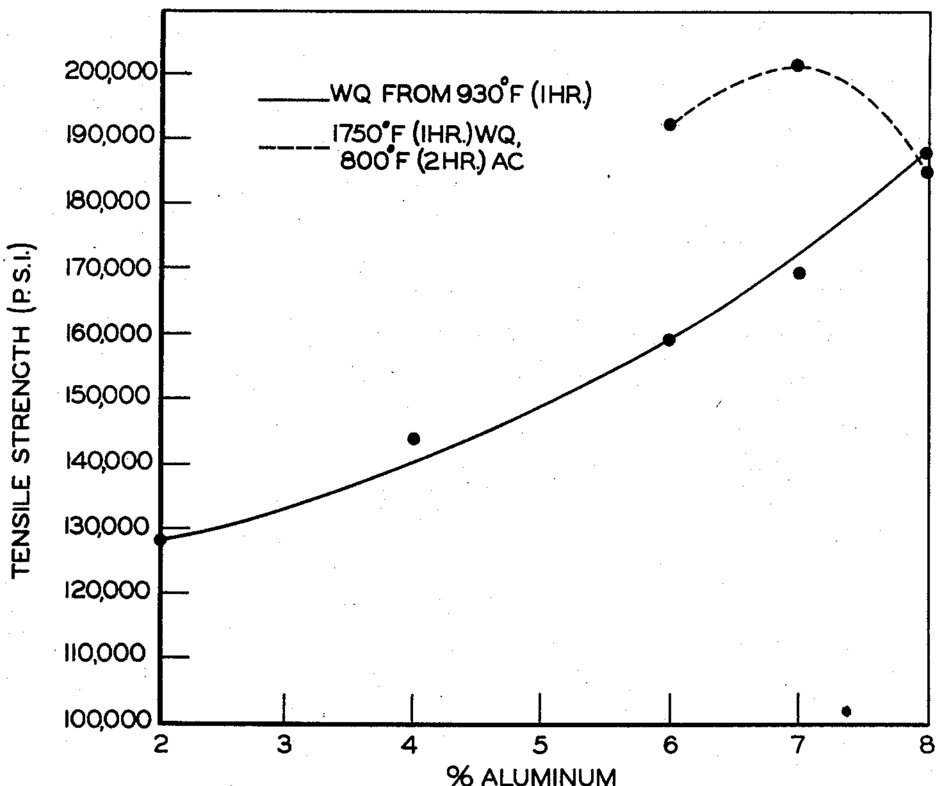
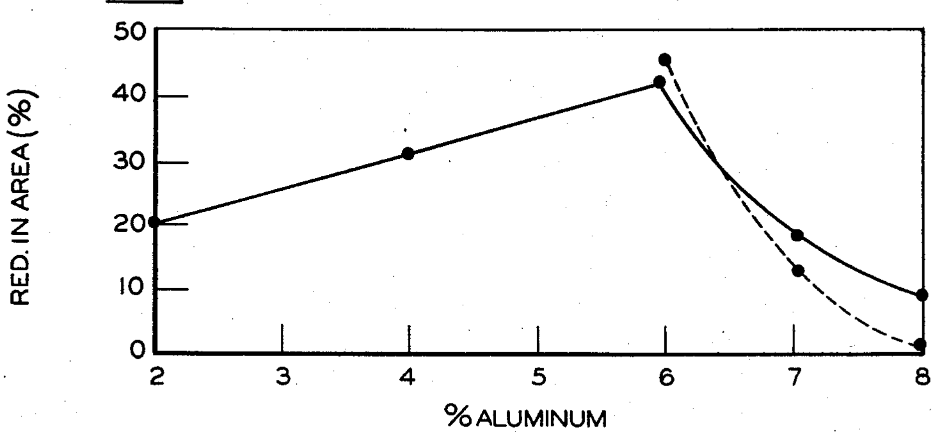


Fig. 2.



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HEAT TREATED TITANIUM-ALUMINUM-VANADIUM ALLOY

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1 Claim. (Cl. 148—32.5)

(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government of the United States for governmental purposes without the payment of any royalty thereon.

This invention relates to titanium base alloys and more particularly to ternary alloys of titanium containing minor proportions of aluminum and vanadium.

Since titanium base alloys offer such desirable properties as lightness of weight and resistance to corrosion, the art is continually striving to utilize these alloys as an effective substitute for high-strength steels. However, it has been found that the addition of the alloying elements heretofore utilized for the purpose of increasing tensile strength in titanium base alloys have invariably decreased the ductility thereof to such extent as to prevent adequate fabrication of structural shapes therefrom. Moreover, these prior art alloying elements also contribute to an appreciable reduction in the resistance to impact or toughness of the resulting alloy thereby seriously limiting the usefulness thereof for such important applications as ordnance materiel.

It is, therefore, an object of this invention to provide ternary alloys consisting of titanium, aluminum and vanadium.

A further object of this invention is to produce high-strength, tough titanium base alloys of aluminum and vanadium characterized by a degree of ductility superior to that found in existing types of commercial alloys.

Yet another object of this invention is to provide a titanium base alloy possessing an optimum combination of tensile strength and ductility superior in either respect to that found in known commercial type alloys.

It is a specific object of this invention to provide a titanium base alloy of aluminum and vanadium wherein the proportions of the alloying elements are particularly selected to yield an optimum combination of tensile strength and ductility together with a useful level of toughness and weldability.

Other advantages and purposes of the present invention will become apparent from the following disclosure thereof, when considered in conjunction with the accompanying drawing wherein:

Fig. 1 is a graph illustrating the effect on tensile strength, in both the annealed and heat treated conditions, of increasing the proportion of aluminum in a Ti—Al—V alloy containing 4% vanadium; and

Fig. 2 is a graph which shows the effect on ductility as measured by the reduction in area of the same additions of aluminum under the same conditions as those of Fig. 1.

According to the present invention, it has been discovered that adding up to 6% aluminum to a binary titanium alloy which includes from 3% to 5% of vanadium produces a substantial increase in tensile strength together with a corresponding increase in both ductility and toughness. At the same time, it has been determined that while any further increase in the percentages of aluminum above 6% produced a corresponding decrease in ductility, the ease of fabrication of the resutling alloy was still substantially greater than that encountered in existing commercial types of titanium base alloys having comparable tensile strengths.

While most titanium base alloys suffer a marked loss in ductility as a result of any increase in those alloying elements which are known to provide high tensile strength, such is not the case in the present invention where the ductility actually increases at a constant rate as indicated in Fig. 2 of the drawing until such time as the total aluminum content exceeds 6%. A further aluminum increase up to 7% will, of course, produce the conventional loss in ductility but even then the reduction in area in the annealed state of the alloy remains at about 17% which is considered satisfactory from the standpoint of ordinary mechanical working. However, when the aluminum content is increased beyond 7%, the ductility of the resulting alloy drops to such an extent that the forming and drawing qualities thereof are below the minimum regarded as essential in many industrial and ordnance applications.

In previous titanium base alloys containing aluminum, the third alloying element ordinarily consists of manganese, chromium, or iron. While these elements do improve the tensile strength of the resulting alloy, they severely decrease the ductility thereof. However, investigation has revealed that unlike the alloying elements of the prior art, vanadium has little adverse effect on ductility, possibly because it, as well as the aluminum, does not appear to form compounds with the titanium. It has been previously established that the percentage of beta stabilizing elements alloyed with titanium has a marked effect on weldability. Consequently, in order to provide maximum tensile strength consistent with good weldability, the vanadium content of the alloys should be limited to 4%. On the other hand, where weldability is not of prime importance, the vanadium content can be increased to 6% in order to attain the maximum tensile strength possible without an undue loss in ductility.

Toughness is another vital factor in those titanium base alloys intended for ordnance use. As is apparent from the table, the preferred alloy provides adequate toughness as indicated by the 11 ft.-lbs obtained in a V-notch Charpy impact test at −40° C. However, where slightly lower tensile strengths are permissible, both the ductility and toughness of the preferred alloy can be increased to much higher levels by the proper heat treatment as indicated in the table.

The titanium base alloys of the present invention may be prepared from either commercial or high purity titanium. However, when the commercial product is employed, the amounts of such contaminants as nitrogen, oxygen, carbon, and hydrogen must be kept to a minimum. For example, neither the oxygen nor carbon should exceed 0.1% while the nitrogen must be kept below 0.07% and the hydrogen below 0.03% in order to limit their embrittling effects on the alloy.

It has been found that the optimum combination of high strength and ductility is obtained when a 6% Al–4% V titanium base alloy is subjected to a solution treatment at a temperature just below the beta transus and is thereafter water-quenched and tempered in the alpha-beta range. Illustrative properties of the preferred alloy composition at various heat treatments are shown in the following table:

TABLE

6% Al–4 V titanium alloy

[20 lb. ingot rolled to ½-inch plate]

MECHANICAL PROPERTIES AFTER VARIOUS HEAT TREATMENTS

Heat treatment	Yield strength, p.s.i., .2%	Ultimate tensile, p.s.i.	BHN	Percent elon.	Percent R.A.	V-notch, Charpy impact energy, ft. lbs./ −40° C.
930° F. (1 hr.) WQ	145,500	159,200	336	14.3	39.4	15.0
930° F. (1 hr.) WQ	147,500	161,500	336	15.0	43.6	15.8
930° F. (1 hr.) WQ	141,500	153,000	331	16.4	46.1	18.0
930° F. (1 hr.) WQ	144,000	156,000	331	17.1	49.4	17.5
930° F. (1 hr.) WQ, 950° F. (1 hr.) AC	154,000	168,200	349	14.3	40.2	14.0
930° F. (1 hr.) WQ, 750° F. (3 hrs.) AC	154,500	170,200	352	12.9	37.6	13.8
1,650° F. (1 hr.) WQ, 600° F. (2 hrs.) AC	154,000	171,400	352	15.0	49.8	13.2
1,650° F. (1 hr.) WQ, 800° F. (2 hrs.) AC	165,000	185,400	375	11.4	37.1	12.0
1,650° F. (1 hr.) WQ, 1,000° F. (2 hrs.) AC	165,000	182,000	363	12.9	45.7	12.7
1,750° F. (1 hr.) WQ, 600° F. (2 hrs.) AC	164,500	188,000	375	12.1	43.2	11.8
1,750° F. (1 hr.) WQ, 800° F. (2 hrs.) AC	170,500	192,800	388	14.3	45.3	11.0
1,750° F. (1 hr.) WQ, 1,000° F. (2 hrs.) AC	178,000	190,400	388	[1] 3.6	[1] 5.5	11.0
930° F. (1 hr.) WQ, 1,200° F. (2 hrs.) AC	134,500	142,600	305	15.7	46.5	21.5
1,800° F. (1 hr.) WQ, 1,000° F. (2 hrs.) AC	163,500	179,400	380	6.4	12.4	7.5
1,800° F. (1 hr.) WQ, 1,200° F. (2 hrs.) AC	153,000	166,000	350	10.7	16.6	10.5
1,650° F. (1 hr.) WQ, 1,200° F. (2 hrs.) AC	148,000	154,000	331	17.1	51.7	18.2
1,650° F. (1 hr.) AC, 1,200° F. (2 hrs.) AC	134,500	·141,400	302	16.4	51.7	22.5
1,650° F. (1 hr.) AC, 1,000° F. (2 hrs.) AC	138,000	147,000	316	18.6	56.3	32.0

[1] Flaw in specimen—break in outer third.
WQ=water quench; AC=air cool.

The best heat treatment for the preferred 6% Al–4% V alloy was found to be a solution treatment at 1750° F. for one hour followed by a two-hour treatment at 800° F. and air-cooled since it provides the optimum combination of 192,000 p.s.i. tensile strength and 42% reduction in area in thicknesses of approximately one-half inch. Even in the annealed condition provided by 930° F. anneal for one hour and water-quenched, the tensile strength has been found to reach 160,000 p.s.i. and at the same time provide excellent ductility as shown by the 45% reduction in area.

In addition to the outstanding properties of tensile strength, ductility, and toughness at room temperatures, the 6% Al–4% V titanium base alloy is also characterized by its ability to maintain tensile strengths up to 110,000 p.s.i. at such elevated temperatures as 700° F.

Although a particular embodiment of the invention has been described in detail herein, it is evident that many variations may be devised within the spirit and scope thereof and the following claims are intended to include such variations.

I claim:

A titanium base alloy consisting of about 6% aluminum, about 4% vanadium, and the balance of titanium with incidental impurities, said alloy having been heat treated for one hour at 1750° F. and then quenched and then further heat treated for two hours at 800° F. and then air cooled to provide a tensile strength of about 192,000 p.s.i., a reduction in area of about 45%, and a Charpy V-notch impact energy of at least 11 foot pounds at −40° C.

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