United States Patent Office 3,306,739 Patented Feb. 28, 1967

3,306,739

TITANIUM ALLOYS

Evan William Evans, Hagley, and Peter Hall, Great Barr, England, assignors to Imperial Metal Industries (Kynoch) Limited, London, England, a corporation of Great Britain

No Drawing. Filed May 8, 1964, Ser. No. 366,138
Claims priority, application Great Britain, May 9, 1963, 18,407/63
3 Claims. (Cl. 75—175.5)

This invention relates to titanium alloys containing molybdenum, vanadium and aluminum and suitable for welding.

Pure titanium has a body-centered cubic structure known as the beta phase at high temperatures and a hexagonal close-packed structure known as the alpha phase at low temperatures. Some alloying elements increase the tendency for the alpha phase to be formed and others the beta phase. Most high strength alloys of titanium consist either of the alpha phase or of a mixture of the two phases at room temperature. A further phase known as the omega phase is also sometimes present.

Highly strengthened alloys consisting mainly of alpha phase tend to be difficult to cold work and the mechanical properties of welded joints in such alloys are usually not satisfactory. Formation of the omega phase, giving rise to extreme embrittlement is extremely undesirable. In addition the mechanical properties of alpha plus beta alloys which are heat-treated to develop high strength are usually impaired when they are welded.

Alloys are known which have a stable all-beta structure at room temperature but these are usually not of high strength and are often undesirably dense so that the strength/weight ratio is low.

The present invention provides a titanium alloy consisting of 5–20 wt. percent vanadium, 16–30 wt. percent molybdenum and 2–6 wt. percent aluminum, balance titanium apart from impurities and incidental alloying elements. Preferably the said alloy has a density of not more than 5.3 gms./cc.

Alloys near to the middle of the ranges of composition covered by the present invention have an all-beta phase structure which is stable at temperatures down to room temperature and they are easy to cold work. The alloys when welded have good mechanical properties (i.e. high strength and adequate ductility) and the ratio of strength to density is high.

Both molybdenum and vanadium are solid solution strengtheners and beta stabilizers, molybdenum being more effective weight for weight. Aluminum increases the strength and decreases the density but is an alpha stabilizer. The total weight percentage of molybdenum and vanadium together should be sufficient to stabilize the beta phase completely in the presence of aluminum and in practice a minimum of between 15–20 molybdenum is required when 2 wt. percent aluminum is present. It will usually be desirable, in order to obtain balanced properties, for the total molybdenum and vanadium content to be kept at about the same level in a given range of alloys so that if larger amounts of molybdenum are present the vanadium content is correspondingly reduced. When molybdenum and vanadium are present together it is found that the beneficial effects upon beta stability, cold-workability and strength are proportionately greater as compared with the effects of the elements alone. Molybdenum and vanadium increase the density of the alloys but vanadium to a lesser extent. At the upper limit of the ranges of composition for molybdenum and vanadium the ratio of the strength to density decreases and the alloys are less easily cold-worked.

Aluminum at 2 wt. percent decreases the density but does not increase the strength appreciably. At 6% a greater decrease in density is obtained and the alloys are strong but there is a tendency for the alpha phase to be formed and consequently the cold-workability and mechanical properties of welded joints are impaired. The presence of aluminum has an incidental beneficial side effect since aluminothermic vanadium containing a small percentage of aluminum can be used and this is cheaper than other sources of vanadium.

Preferred ranges of composition are 20–25 wt. percent molybdenum, 10–15 wt. percent vanadium and 3–5 wt. percent aluminum inclusive. A preferred composition is about 20% molybdenum, 10% vanadium and 4% aluminum.

According to another aspect of the present invention there is provided a welded structure comprising any of the alloys as described above.

By "incidental alloying elements" we mean those elements which it is well-known to add to titanium and its alloys in small amounts without affecting the properties appreciably except in a way which can be predicted. A knowledge of the metallurgy of titanium will reveal several such elements. In the case of the present alloys such alloying elements will be beta-isomorphous elements such as niobium, tantalum, zirconium and hafnium which may be added to replace partially, or in addition to, molybdenum and vanadium. These elements however are not as effective as molybdenum and vanadium as beta stabilizers and furthermore they increase the density to an undesirable degree. Small amounts of the eutectoid forming elements such as iron, nickel, chromium, cobalt, silicon and manganese might also be added but large amounts would impair the mechanical properties.

A part of the aluminum might be replaced by tin but with the disadvantage that the density is increased and that the tin is not such an effective strengthener as aluminum. Typical impurities in titanium alloys are: oxygen up to 0.1%, nitrogen up to 0.01%, hydrogen up to 0.01%, carbon up to 0.1%, sodium up to 0.02%, chlorine up to 0.001%, iron up to 0.075%, silicon up to 0.075%.

Alloys provided by the present invention will now be particularly described by way of example only and with reference to the tables in which Table I lists for purposes of comparison hardnesses and densities for alloys within and without the present invention and Table II lists the mechanical properties of selected alloys before and after welding.

In Table I hardnesses at room temperature are listed and used as a very approximate indication of strength and as a basis for selection for more detailed investigation. Additions of molybdenum alone produced an all-beta phase structure at room temperature and a maximum in hardness/density ratio at about 20 wt. percent (alloys 1 to 3). Additions of 5 to 10 wt. percent vanadium decreased density for a given total percentage of molybdenum plus vanadium compared with the same total of molybdenum alone and a stable beta structure was maintained. Alloys having a total of about 30 wt. percent molybdenum plus vanadium (alloys 5 and 6) had high hardness/density ratios but were not very readily cold rolled and were used to explore the effect of additions of aluminum (alloys 7 to 15). It was found that in such alloys containing 15 wt. percent molybdenum the alpha stabilising effect of aluminum rendered the beta phase structure unstable. At 20 and 25 wt. percent molybdenum alloys containing between 2 and 4% aluminum possessed a stable beta structure but at 6% aluminum the beta structure was not completely stable. Aluminum decreased the density and improved cold rollability but 2 wt. percent

aluminum did not increase the hardness. At 6 wt. percent aluminum although the hardness/density ratio was high

TABLE II.—COMPARISON OF TENSILE PROPERTIES BEFORE AND AFTER WELDING OF SELECTED BETA TITANIUM ALLOYS

Alloy Composition, Weight Percent	As-annealed ½ hour at 900° C.					As-welded			Density, gm./cc.
	0.1% PS, t.s.i.	UTS, t.s.i.	Percent Elongation		Min. Bend Radius	UTS, t.s.i.	Percent Elongation		
			1″	2″			1″	2″	
Ti-30 Mo	51.3	54.5	17	11	2.8T	56.5	15	9	5.39
Ti-30 Mo-2 Al	56.2	58.2	22	13	2.8T	56.25	18	10	5.31
Ti-20 Mo-20 V	55.2	58.3	19	14	3.5T	58.4	14	8	5.36
Ti-20 Mo-20 V-2 Al	57.8	59.8	25	22	3.7T	60.5	14	13	5.28
Ti-20 Mo-10 V-2 Al	51.3	55.0	20	12	1.4T	56.9	14	8	5.12
Ti-20 Mo-10 V-2 Al at 300° C	34.7	40.7	25	20					
Ti-20 Mo-10 V-2 Al cold-rolled 81%	74.4	78.1	4	2	3T				
Ti-20 Mo-10 V-4 Al	60.8	63.5	18	11	<1.1T	62.9	12	10	5.05
Ti-20 Mo-10 V-4 Al at 300° C	44.0	47.6	20	17					
Ti-20 Mo-10 V-4 Al cold-rolled 84%	86.5	90.1	2	1	6.7T				
Ti-30 Mo-5 Al	Brittle on cold rolling								
Ti-20 Mo-10 V-5 Al	Brittle on cold rolling								

the beta phase structure was not completely stable and the ductility was consequently very low.

Alloys containing 20 wt. percent molybdenum and 10 wt. percent vanadium were slightly better than those containing 25 wt. percent molybdenum and 5 wt. percent vanadium.

Table II gives detailed mechanical properties for selected alloys having an all-beta phase structure both before and after welding in appropriate cases. The alloys generally combined medium strength and adequate ductility both before and after welding except for those containing 5% aluminum which were brittle on cold rolling. The alloy containing 20 wt. percent molybdenum, 10 wt. percent vanadium and 4 wt. percent aluminum displayed outstanding properties in that it combined a high UTS of about 63 t.s.i. both before and after welding with a low density and adequate ductility, enabling a cold rolling reduction of 84% to be employed.

TABLE I.—HARDNESS/DENSITY VALUES

	Alloy Composition, Weight Percent	Density (gm./cc.)	R. T. Hardness (D.P.N.)	Hardness/Density, ×1/10
1	Ti-20 Mo	5.06	295	5.8
2	Ti-25 Mo	5.22	293	5.6
3	Ti-30 Mo	5.39	286	5.3
4	Ti-20 Mo-5 V	5.13	288	5.6
5	Ti-20 Mo-10 V	5.20	322	6.2
6	Ti-25 Mo-5 V	5.29	334	6.3
7	Ti-15 Mo-15 V-2 Al	5.04	286	5.7
8	Ti-15 Mo-15 V-4 Al	4.96	295	5.9
9	Ti-15 Mo-15 V-6 Al	4.89	320	6.5
10	Ti-20 Mo-10 V-2 Al	5.12	287	5.7
11	Ti-20 Mo-10 V-4 Al	5.05	295	5.8
12	Ti-20 Mo-10 V-6 Al	4.97	317	6.4
13	Ti-25 Mo-5 V-2 Al	5.21	290	5.5
14	Ti-25 Mo-5 V-4 Al	5.13	296	5.8
15	Ti-25 Mo-5 V-6 Al	5.06	298	5.9

We claim:

1. A beta titanium base alloy having an improved combination of weldability, rollability, good strength-to-weight ratio and a density of not more than 5.3 gms./cc. consisting essentially of 5–20 wt. percent vanadium, 16–30 wt. percent molybdenum and 2–6 wt. percent aluminum balance titanium apart from impurities.

2. A beta titanium base alloy having an improved combination of weldability, rollability, good strength-to-weight ratio and a density of not more than 5.3 gms./cc. consisting essentially of 20–25 wt. percent molybdenum, 10–15 wt. percent vanadium and 3–5 wt. percent aluminum apart from impurities.

3. A beta titanium base alloy having an improved combination of weldability, rollability, good strength-to-weight ratio and a density of not more than 5.3 gms./cc. consisting essentially of about 20 wt. percent molybdenum, 10 wt. percent vanadium and 4 wt. percent aluminum apart from impurities.

References Cited by the Examiner

UNITED STATES PATENTS

2,754,204	7/1956	Jaffee et al.	75—175.5
2,804,409	8/1957	Kessler et al.	75—175.5 X
2,819,960	1/1958	Bomberger	75—175.5
2,821,475	1/1958	Jaffee et al.	75—175.5
2,864,697	12/1958	Busch et al.	75—175.5
2,918,367	12/1959	Crossley et al.	75—175.5

FOREIGN PATENTS

776,440	6/1957	Great Britain.

DAVID L. RECK, *Primary Examiner.*

C. N. LOVELL, *Assistant Examiner.*