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TITANIUM BASE ALLOYS

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4 Claims. (Cl. 75—175.5)

This application is a continuation-in-part of my copending application Ser. No. 312,350, filed Sept. 30, 1963, now abandoned.

This invention relates to titanium base alloys and more particularly to such an alloy characterized by a combination of high strength and ductility, toughness, weldability, corrosion resistance and low density.

Submarines capable of diving to extreme depths have been envisioned. Such a craft, however, poses an important problem insofar as hull construction is concerned. The metal or alloy used for hull construction must be of high strength to resist the tremendous hydraulic pressures encountered at extreme depths. Even so, the hull must be constructed of plates of substantial thickness, the density of which must be as low as possible so that the weight of the hull will not affect, to a serious degree, the buoyancy produced by its enclosed volume. Toughness is desired in the metal or alloy employed to insure safety, and toughness at low temperatures is particularly desirable to permit operation of the craft in polar regions. Weldability is necessary so that the hull may be fabricated from plates into an integral unit. Resistance to corrosion, specifically in salt water, is also a necessary characteristic.

It is a principal object of this invention to provide an improved titanium base alloy of utility for applications above stated. Another object of this invention is to provide a strong, ductile, tough, weldable, light and corrosion resistant titanium base alloy. These and other objects of this invention will be apparent from the following description thereof.

The alloy of this invention consists essentially of by weight 5.5% to 7.5% aluminum, from 3.5% to 4.5% zirconium, from 0.7% to 2.3% vanadium, oxygen up to 0.15%, nitrogen up to 0.1%, with a total interstitial content including carbon not to exceed about 0.35%, and the balance titanium and incidental impurities. Such an alloy will possess as rolled or forged and annealed, an ultimate strength above 120,000 p.s.i., toughness above 25 foot-pounds measured by the Charpy impact test at —80° F., low density and excellent corrosion resistance, particularly to salt water, good weldability, a tensile elongation of at least 10% and an area reduction of at least 25%.

A preferred composition within the ranges defined above consists essentially of about 6% aluminum, about 4% zirconium, about 1% vanadium, up to 0.12% oxygen, with the balance titanium and incidental impurities. This alloy possesses, when heat treated, good ultimate strength of over 120,000 p.s.i. and a Charpy impact test of over 25 foot-pounds at —80° F. showing good toughness. At the same time, the alloy is light, that is has low density, less than that of unalloyed titanium, and shows no corrosion when immersed in sea water for an indefinite period. Its weldability is good.

Another highly desirable composition consists essentially of about 7% aluminum, about 4% zirconium, about 1% vanadium, up to 0.12% oxygen with the balance titanium and incidental impurities. This alloy is slightly lighter and a little stronger than the 6% Al-4% Zr-1% V-0.12% O_2 alloy.

Still another highly desirable composition consists essentially of about 6% aluminum, about 4% zirconium, about 2% vanadium and up to 0.12% oxygen, with the balance titanium and incidental impurities. This alloy is of about the same density as 6% Al-4% Zr-1% V-0.2% O_2 and is slightly stronger.

The nature and amounts of alloying elements in the alloy of this invention are critical. Aluminum in amount between 5.5% and 7.5% provides lightness and strength. Less than 5.5% aluminum will not provide these properties to an optimum degree and more than 7.5% aluminum renders the alloy increasingly brittle with increasing aluminum content. About 3.5 to 4.5% zirconium as employed in the alloy of this invention further increases strength without loss of ductility. The aluminum and zirconium apparently act in combination to provide strength without brittleness and to produce an essentially all-alpha type alloy at atmospheric temperature. Less than 3.5% zirconium will result in lowered strength and more than 4.5% zirconium will increase strength slightly but decrease in ductility, and also the cost and density of the alloy rises disadvantageously.

The amount of vanadium present in the alloy of this invention provides additional strength and toughness and being a beta stabilizer, provides some measure of heat treatability. Less than 0.7% vanadium will not provide these properties to an optimum degree while more than 2.3% vanadium will be disadvantageous in providing more beta stabilizing element than is desirable, thus to an extent resulting in loss of the all-alpha characteristic of the alloy. This will adversely affect weldability. In addition, vanadium is heavier than titanium and more than a minimum amount to provide the properties required raises the density inordinately.

Zirconium has been considered a beta stabilizer or promoter in titanium base alloys because it tends to lower the beta transus. In most of its effects, however, it acts more like an alpha stabilizer in that it acts as an alpha stabilizer at atmospheric temperature, and therefore can be employed in the alloy of this invention in amounts within the range defined, that is from 3.5% to 4.5%. It is necessary, however, that the zirconium content be no more than about 4.5% so that the beta transus of the alloy is not lowered to an extent where later working cannot be usefully accomplished in the alpha-beta field.

The oxygen content of the alloy of this invention is critical and this element should be present in amount only up to 0.15%. Preferably the oxygen content should be only up to 0.12% to obtain the favorable impact properties particularly at low temperature. With an oxygen content above 0.15%, the alloy will not possess the necessary toughness measured by impact test at —80° F. to make it useful as a marine alloy, particularly for submarine hull applications.

Incidental impurities which may be present in the alloy of this invention will in general include the interstitials nitrogen and carbon as well as small or trace amounts of other elements which may be present in the titanium and other constitutents from which the alloy is made. Such impurities should not in the aggregate exceed about 0.35% and should not individually or in combination exceed amounts which would significantly affect the characteristics or properties of the alloy as described. The particular effect of oxygen content has been described in some detail in the paragraph above. Nitrogen, another interstitial, will significantly affect the properties to some extent in like manner and should not ordinarily exceed 0.1%.

An alloy of this invention may be produced by a convenient method by which the titanium and alloying elements are melted together to form a substantially homogeneous composition. Preferably, titanium sponge of re-

quired purity and particularly with respect to its oxygen content is admixed with subdivided aluminum, zirconium and vanadium in proper amounts and the mixture compressed into compacts. These compacts are welded together to form an electrode which is melted in a consumable electrode arc melting, cold mold furnace to produce an ingot of alloy. The so-produced alloy ingot may be itself employed as an electrode in a subsequent remelting step to provide improved homogeneity in a final alloy ingot.

Table 1 below shows tensile strength and toughness (Charpy impact test at −90° F.) for selected alloys of this invention. The values are for small double melted ingots of each alloy with tensile and impact specimens machined directly from the as-cast ingot. Tensile specimens: standard cylindrical specimens 3.00 inches total length with 1.250-inch reduction section, 0.250 inch diameter. Impact specimens: 0.452 inch round by 2.16 inches long with central 60° notch to diameter of 0.381 inch cooled to −80° F. before testing on a Sontag impact tester.

TABLE 1

	Alloy (Bal. Ti)		
	6% Al-4% Zr-1% V-0.12% O_2	7% Al-4% Zr-1% V-0.12% O_2	6% Al-4% Zr-2% V-0.12% O_2
Ultimate Tensile Strength, p.s.i.	121,000	127,000	124,000
Yield Strength, 0.2% Offset, p.s.i.	105,000	112,000	107,000
Percent Reduction in Area	25	23	29
Percent Elongation	12	14	14
Impact −80° F., ft. lbs.	43	27	38

The values in Table 1 above show good strength, ductility and toughness in the as-cast condition, and this would indicate that similar properties would be obtained in the welded areas.

As compared to these results, my further tests have shown that a previously known titanium base alloy containing about 10% aluminum, 20% zirconium, 2% vanadium and the balance titanium except for impurities within commercial tolerances, when similarly tensile tested, showed a tensile elongation of only 2% and an area reduction of only 3%, values which are entirely unacceptable for purposes of my invention.

Density of each of the alloys of Table 1 is shown compared to that of pure titanium in Table 2 below:

TABLE 2

Alloy (bal. Ti):	Density, lbs./in.^{3}
6% Al-4% Zr-1% V-0.12% O_2	0.162
7% Al-4% Zr-1% V-0.12% O_2	0.160
6% Al-4% Zr-2% V-0.12% O_2	0.162
Pure titanium	0.163

Corrosion resistance of these alloys in salt water (sea water) will correspond to that of pure titanium which is substantially immune to corrosion in this medium.

It is well known in the metallurgical arts that high strength and toughness are not generally compatible. That is, strong alloys are relatively brittle while toughness is most often found in relatively lower strength alloys. Titanium base alloys showing both high strength and toughness are rare because such strengthening is normally obtained by providing in the alloy significant amounts of both alpha and beta phases and such alloys exhibit poor toughness. However, I have found that when some beta phase titanium is present as a result of the inclusion of small and critical amounts of vanadium, both strength and toughness are enhanced and this unique effect appears to be obtained when aluminum and zirconium are employed as described as the alpha stabilizing elements.

Furthermore, the single phase alpha-type titanium base alloys possess the best weldability characteristics whereas alpha-beta type alloys containing an appreciable amount of the beta phase are difficult to weld, if weldable at all. However, in the alloy of the present invention, the beta phase is present only in a small critical amount and weldability is substantially the same as that of comparable all-alpha phase alloys.

Thus, the alloy of the present invention possesses the unique and valuable combination of high strength, toughness particularly at low temperature, and weldability and these properties are found in an alloy having a density similar to that of pure titanium and showing the superb corrosion resistance properties of titanium particularly during exposure in salt water. Such properties make it useful for applications where its particular attributes are specifically desirable such as, for example, in marine construction and especially for fabrication of submarine hulls.

The alloys of the invention may be fabricated into suitable shapes by rolling or forging at about 2200° F. and thereafter annealed at about 1300° F., followed by air cooling to room temperature.

What is claimed is:

1. An alloy consisting essentially of by weight from 5.5% to 7.5% aluminum, from 3.5% to 4.5% zirconium, from 0.7% to 2.3% vanadium, and up to 0.15% oxygen, up to 0.1% nitrogen, the total interstitial content including carbon not to exceed about 0.35%, with the balance titanium and incidental impurities, characterized at room temperature by an ultimate strength of at least 120,000 p.s.i., a tensile elongation of at least 10%, an area of reduction of at least 20%, a toughness at −80° F. measured by the Charpy impact test, of over 25 foot-pounds, and a substantially alpha microstructure.

2. An alloy according to claim 1 containing substantially about: 6% aluminum, 4% zirconium, and 1% vanadium.

3. An alloy according to claim 1 containing substantially about: 7% aluminum, 4% zirconium, and 1% vanadium.

4. An alloy according to claim 1 containing substantially about: 6% aluminum, 4% zirconium, and 2% vanadium.

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