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3,370,946

TITANIUM ALLOY

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ABSTRACT OF THE DISCLOSURE

A titanium base alloy having 5 to 9% Al, 0.33 to 3.33% Cb and 0.3 to 2.5% Mo, and which may optionally contain 0.33 to 1.5% Ta. The alloy is characterized by a minimum yield strength in the annealed condition of 100,000 p.s.i. and resistance to crack propagation as measured by the ratio of the failure stress in sea water to the failure stress in air of at least 0.9.

This invention relates to titanium alloys. More particularly, the invention relates to titanium alloys which have a minimum yield strength in the annealed condition of 100,000 p.s.i. yet are resistant to so-called "rapid crack propagation" (sometimes referred to as "stress corrosion cracking") in certain environments such as sea water. The expression "rapid crack propagation" as used herein refers to the phenomenon whereby cracks in titanium alloy articles subjected to stress propagate rapidly in such environments resulting in premature failure of the article, but is distinguished from the phenomenon known in the art as "hot salt stress corrosion."

Many titanium alloys have been developed with strength and other properties sufficient for structural applications. Titanium alloys typically provide the highest strength to weight ratio available in commercial structural materials. For this reason, these alloys have been selected for use in designs of supersonic transport air vehicles and for deep submergence marine vehicles. However, the development of particular titanium alloys possessing any desirable combinations of properties is made difficult by the complex metallurgical properties of titanium and titanium alloys.

An illustration of unforeseeable difficulties encountered in designing with titanium alloys is the phenomenon observed with a number of otherwise satisfactory titanium alloys wherein the load carrying capability of structural forms of the alloys may be considerably reduced in environments such as sea water. Titanium alloys containing aluminum and columbium and alloys containing aluminum, columbium and tantalum such as disclosed in U.S. Patents 2,864,698 and 2,864,699, have been thought to be particularly satisfactory for a number of structural applications; however, it was discovered that these alloys exhibited so-called rapid crack propagation in environments conducive to this phenomenon, such as sea water.

The present invention provides improved titanium alloy compositions which avoid the above-described disadvantages. According to the invention, an alloy is provided consisting essentially of (in percent by weight) 5 to 9% Al, 0.33 to 3.33% Cb, 0.3 to 2.5% Mo, and which may additionally contain 0.33 to 3.33% Ta, the balance being commercially pure titanium.

A test has been devised to determine the relative susceptibility of certain titanium alloys to rapid crack propagation. The essence of the test is to obtain a ratio of the failure stress of the alloy in sea water to the failure stress of the same alloy in air using pre-cracked test specimens. Obviously, the closer the ratio approaches unity, the less the alloy is susceptible to the phenomenon and, accordingly, the more nearly the alloy's strength in the phenomenon-conducive environment approaches its strength

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in air. The test is performed on titanium alloy plate specimens, usually between $\frac{3}{8}$ and 1-inch thick. The plate specimens are provided with a notch to a depth of from about 25% to about 30% of the specimen's thickness, for example by cutting with a band saw, and then a second thinner notch is introduced beyond the first notch by use of a finer blade. A fatigue crack is developed at the second notch by cycling, i.e., deflecting the specimen, about 500 times on a hydraulic compression machine. The cracked specimens are then stressed to failure in a jig which supports the specimen at two spaced points (from below) and a measured load is applied from above the specimen at the area of the fatigue crack. One specimen is stressed to failure in air and a second specimen (of the same material) is stressed to failure in the test medium. In our tests, the ASTM synthetic sea salt solution was used. The specimens are stressed to failure in air and sea water by step loading with constant loads maintained for 5-minute periods and successively increased loads are applied until failure occurs. The results of extensive testing indicates that with susceptible materials, the conducive environment, e.g. sea water, accelerates the growth rate of the fatigue crack once the stress is great enough to initiate crack growth. The ratio of the failure stress in sea water divided by the failure stress in air provides a useful indication of the alloy's susceptibility to the phenomenon. A ratio value of 1.0 indicates no environmental effect; however, alloys showing a ratio of 0.9 or better are satisfactory for many purposes.

Another indication of a material's susceptibility to rapid crack propagation is the appearance of the fracture surface. In materials having little or no susceptibility, the fracture surface of specimens broken in air and in sea water are generally of similar texture throughout the specimen's cross section. The fracture surface of susceptible materials broken in sea water generally do not appear the same as specimens of the same materials broken in air, and the texture throughout the cross section of the specimen's fracture is not the same. The section of the fracture surface of a susceptible material adjacent to and just below the fatigue crack may have a different texture and appear rougher or more jagged than the balance of the fracture surface.

It has been discovered that titanium base alloys containing aluminum and columbium and alloys containing aluminum, columbium and tantalum can be rendered substantially unsusceptible to rapid crack propagation in environments conducive to this phenomenon by the addition thereto of a small but effective amount of a beta isomorphous element such as molybdenum sufficient to materially increase rapid crack propagation resistance. Such alloys not only possess a satisfactory degree of rapid crack propagation resistance but maintain a high yield strength in the annealed condition. Titanium base alloys of this type contain from about 5 to about 9% Al, from about 0.33 to about 3.33% Cb, from 0.3 to about 2.5% Mo, and may also contain from about 0.33 to about 3.33% Ta. The data in Table I illustrate how the presence of at least 0.3% Mo significantly increases the rapid crack propagation resistance of the above described titanium alloys without materially reducing the high yield strength characteristic of these materials. In many cases, the molybdenum-containing alloys possess an even higher yield strength than the alloys without molybdenum and, in every case, the rapid crack propagation resistance is materially improved while maintaining a minimum yield strength in the annealed condition of about 100,000 p.s.i. Typical commercial alloys within these systems contain 5 to 7.5% Al, 1 to 3% Cb and when tantalum is present, from about 0.3 to about 1.3% Ta, the remainder being titanium with normal impurities. Commercially available titanium may contain both metallic and nonmetallic im-

purities. The metallic impurities may include Fe, Mn and Si and the nonmetallic impurities may include C, N₂, H₂ and O₂. Some of the impurities may be in solution and thus the impurities may be either substitutional or interstitial. It is not uncommon that these impurities actually improve certain properties, e.g. strength, of the alloys. The data presented in Table I are the results of tests on typical alloys within these alloy systems such as titanium base alloys containing: 7% Al-3% Cb, 6% Al-3% Cb, 7% Al-2% Cb-1% Ta, 6% Al-2% Cb-1% Ta; each containing molybdenum within the range of 0.5 to 2.5%,

1. A titanium base alloy consisting essentially of 5 to 9% Al, 0.33 to 3.33% Cb and 0.3 to 2.5% Mo having a minimum yield strength in the annealed condition of about 100,000 p.s.i. and a crack propagation resistance as measured by the ratio of the failure stress in sea water to the failure stress in air of at least about 0.9.

2. A titanium base alloy according to claim 1 containing 5 to 7.5% Al, 1 to 3% Cb and 0.5 to 2.5% Mo.

3. A titanium base alloy according to claim 1 containing about 7% Al, about 3% Cb and 0.5 to 2.5% Mo.

TABLE I

Alloy ¹	UTS, p.s.i. (²)	0.2% YS, p.s.i. (²)	Elong., percent (²)	R.A., percent (²)	-80° Impact Energy, Ft.-Lb. (²)	Crack Propagation Resistance, S _{a.w} /S _a
Ti-7Al-3Cb-----	125.9	104.2	15.2	28.0	21.8	0.75
Ti-7Al-3Cb-0.22Mo----	130.7	107.7	13.6	29.6	26.0	0.60
Ti-7Al-3Cb-0.79Mo----	135.1	112.0	13.1	29.7	26.0	1.0+
Ti-7Al-3Cb-0.8Mo-----	129.8	103.0	15.0	27.2	21.1	1.0+
Ti-7Al-3Cb-1.0Mo-----	137.9	112.8	12.6	23.7	19.0	1.0
Ti-7Al-3Cb-2.0Mo-----	142.3	117.1	10.2	15.7	16.8	1.0+
Ti-6Al-3Cb-0.8Mo-----	126.0	105.8	10.9	24.0	28.6	0.96
Ti-6Al-3Cb-1.0Mo-----	122.5	99.4	16.1	39.6	23.1	1.0+
Ti-6Al-3Cb-2.0Mo-----	136.1	114.7	12.5	29.8	18.1	0.72
Ti-7Al-2Cb-1Ta-----	121.3	103.9	13.4	27.1	35.9	0.99
Ti-7Al-2Cb-1Ta-0.5Mo----	130.7	109.5	13.0	28.7	31.8	0.91
Ti-7Al-2Cb-1Ta-0.8Mo----	128.5	109.0	11.5	21.6	31.5	0.98
Ti-7Al-2Cb-1Ta-1.0Mo----	133.0	109.3	12.0	24.5	24.0	0.92
Ti-7Al-2Cb-1Ta-2.0Mo----	147.6	122.4	10.1	14.5	16.8	0.88
Ti-6Al-2Cb-1Ta-----	118.2	100.6	13.4	28.0	30.9	0.99
Ti-6Al-2Cb-1Ta-0.8Mo----	126.0	105.8	10.8	24.0	28.6	0.99
Ti-6Al-2Cb-1Ta-1.0Mo----	130.2	109.5	12.1	26.2	26.8	0.99
Ti-6Al-2Cb-1Ta-2.0Mo----	140.8	117.1	13.1	30.8	28.1	1.0

¹ Beta fabricated or beta annealed and air cooled.

² Average of longitudinal and transverse properties.

typically within the range of about 0.5 to about 2.0%.

Titanium alloys as described are of the near-alpha type at room temperature; consisting of predominantly the alpha (hexagonal-close-packed) phase and some beta (body-centered-cubic) phase. Aluminum, nitrogen, oxygen and carbon are alpha-stabilizing and molybdenum, columbium, tantalum, hydrogen, iron and manganese are beta-stabilizing; the result is that mixtures of these form a near-alpha alloy. These alloys are also characterized as being weldable in the sense that the alloy is able to be joined by conventional welding practices without embrittlement of the material in or adjacent to the weld joint.

It has been determined that less than about 0.3% molybdenum does not provide any increase in the resistance to rapid crack propagation. Some increase in resistance is obtained with molybdenum additions of 0.3% and the presence of at least about 0.5% molybdenum results in uniformly improved rapid crack propagation resistance. As the molybdenum content increases, the weldability of the alloy diminishes, and if more than about 2.5% molybdenum is employed, the resulting alloy may not be satisfactorily weldable.

It is apparent from the above that certain modifications are permissible within the scope of the invention and, accordingly, the invention should only be limited by the appended claims.

We claim:

4. A titanium base alloy according to claim 1 containing 6% Al, 3% Cb and 0.5 to 2.5% Mo.

5. A titanium base alloy consisting essentially of 5 to 9% Al, 0.33 to 3.33% Cb, 0.33 to 3.33% Ta and 0.3 to 2.5% Mo having a minimum yield strength in the annealed condition of about 100,000 p.s.i. and a crack propagation resistance as measured by the ratio of the failure stress in sea water to the failure stress in air of at least about 0.9.

6. A titanium base alloy according to claim 5 containing 5 to 7.5% Al, 1 to 3% Cb, 0.33 to 1.5% Ta and 0.5 to 2.5% Mo.

7. A titanium base alloy according to claim 5 containing about 7% Al, about 2% Cb, about 1% Ta and 0.5 to 2.5% Mo.

8. A titanium base alloy according to claim 5 containing about 6% Al, about 2% Cb, about 1% Ta and 0.5 to 2.5% Mo.

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