United States Patent Office 3,199,980 Patented Aug. 10, 1965

3,199,980

TITANIUM ALLOYS

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No Drawing. Filed Aug. 29, 1962, Ser. No. 220,157
Claims priority, application Great Britain, Sept. 4, 1961, 31,678/61
3 Claims. (Cl. 75—175.5)

This invention relates to titanium base alloys and is more particularly directed to solving the difficulty experienced in using many titanium alloys for structural purposes owing to the relatively low modulus of elasticity of these alloys.

It is known that alloys of titanium and aluminum show increased modulus and strength as the aluminum content is increased until at about 8% aluminum they become brittle. This addition of aluminum does not, however, improve properties of the alloy to the desired level. Further it has been shown that the addition of a dispersed phase of high modulus and strength alloying elements such as carbon and boron to a titanium base alloy may improve the strength and modulus of elasticity of the original material.

According to the present invention a series of alloys having a titanium-aluminum α solid solution matrix containing from 1% to 7% by weight of aluminum is strengthened and has its Young's modulus raised by the simultaneous addition of boron not exceeding 2.00% by weight and carbon not exceeding 1.2% by weight, the said additions being precipitated from the melt on cooling and forming a dispersed phase within the α solid solution matrix.

In a preferred composition the limits of the proportions by weight of the alloying elements are aluminum 3 to 7%, boron 0.5 to 2.0% and carbon 0.1 to 1.2%.

It should be noted that below 3% aluminum the strengthening effect of the aluminum on the Ti–Al solid solution is not significant, and above 7% aluminum the alloys containing boron and carbon become unworkable.

Similarly below 0.5% boron the effect on Young's modulus and strength is not significant. Above 2.0% boron the formation of primary boride in the alloys results in undesirable properties.

The limits of carbon content are set for similar reasons.

Generally, alloys according to the invention may be prepared by any of the normal processes used for the production of titanium alloys, such as, for instance,

(a) Powder metallurgy techniques
(b) Non-consumable arc melting under inert gas and
(c) Vacuum consumable arc melting.

Experimentally the raw materials consisting of titanium (sponge or powder), aluminum (foil or wire), graphite powder, and boron or titanium diboride powder are mixed in the required proportions. In the non-consumable arc melting process small cylinders of the compacted mixture are pre-melted under inert gas to "buttons" of alloy, the buttons being subsequently remelted in a larger furnace to build an ingot. In the consumable arc melting process the components are pressed into the form of an electrode (or if a large enough press is not available into sections of an electrode which are subsequently welded togther). This electrode is then melted in a consumable electrode vacuum arc furnace to produce an alloy ingot.

The ingots are then forged in the normal way and subsequently rolled to bar, or clad with commercially pure titanium sheet and rolled to sheet as described in British Patent No. 822,750.

Several examples of the invention will now be described.

Example 1

36 compacts each of 10 gram weight and containing Ti+5%Al+1.5%B+0.3% C. (by weight) were made up from titanium sponge, aluminum foil, powdered crystalline boron, and powdered graphite. The aluminum foil was formed into a small envelope and the boron and carbon powders were enclosed in this envelope which was then pressed into the centre of the alloy compact. The compacts were melted into buttons in a tungsten electrode non-consumable arc furnace under a pressure of 20 cms. Hg of argon. Melting was for 2 mins. at 300 amps. The buttons were then turned over and remelted under the same conditions.

These buttons were then melted into a 360 gram ingot about 2½" diameter in a second tungsten electrode non-consumable arc furnace, under a pressure of 20 cms. Hg of argon at 400–750 amps.

The ingot was removed, heated to 1100–1120° C. in a muffle furnace and hammer forged to ½" x ½" section bar.

The bar was annealed for 4 hrs. at 850° C. in vacuo (pressure—approx. 10^{-5} mm. Hg) and then machined into test pieces for tensile tests, determination of dynamic Young's modulus, and Izod impact strength. The composition and results of tests at room temperature were as follows.

Nominal Composition ____ 5% Al, 1.5% B, 0.3% C.
Actual Composition ____ 4.85% Al, 1.45% B, 0.28% C.
0.1% proof stress ____ tons/sq. in__ 66.7
U.T.S. ____ tons/sq. in__ 77.2
Elongation ____ percent__ 13.0
E_{Static} ____ p.s.i__ 21.2×10^6
$E_{Dynamic}$ ____ p.s.i__ 20.9×10^6
Impact strength ____ ft. lb__ 3

Example 2

A second ingot was produced using the same method as described in Example 1.

The ingot was heated to 1120° C. and hammer forged to a slab approximately 1" thick. This slab was machined on its major surfaces, and clad with 0.060" thick commercially pure titanium sheet. It was then hot rolled to 0.064" thick sheet, using approximately 10% reduction per pass and rolling at 1080° C.

The sheet was grit blasted and pickled in an aqueous solution of HF and HNO_3. Blank specimens for tensile testing, and dynamic Young's modulus determination were guillotined from the sheet. The blanks were annealed in vacuo (10^{-5} mm. Hg) for 4 hrs. at 850° C. and furnace cooled, and then finally machined. The composition and properties obtained were as follows:

Nominal Composition: 5% Al, 1.5% B, 0.3% C.

	Room Temp.	400°C.
0.1% Proof stress, tons/sq. in	61.0	29.1
U.T.S., tons/sq. in	72	44.3
Elongation, percent	5	5
E_{Static}, p.s.i	19.5×10^6	15.7×10^6
$E_{Dynamic}$, p.s.i	20.1×10^6	

Example 3

An alloy with the nominal composition 5% Al, 1.5% B, 0.3% C, balance titanium was prepared by melting compacts of this composition made up from titanium sponge, super purity aluminum, crystalline boron and pure graphite in a non-consumable electrode vacuum furnace. The buttons so produced were remelted in a

non-consumable arc vacuum furnace to produce an ingot. The ingot was hammer forged to a flat slab, and machined on its major faces. These faces were clad with pure titanium sheet prior to rolling to sheet (in accordance with British Patent No. 822,750). The forging temperature was about 1100° C. and the rolling temperature 1050° C.

The 0.060" thick sheet produced by the rolling was machined into test pieces, and the results of tests gave the following properties.

	Room Temp.	400° C.
0.1% Proof stress, tons/in.²	61	29
Ultimate Tensile strength, tons/in.²	72	44.3
Elongation, percent	5	5
Young's modulus, p.s.i.²	19.5	15.7

Example 4

Sheet material prepared as in Example 3 to the nominal compositions listed gave the properties indicated in the table below.

Example	Composition (by weight, balance titanium in each case)	0.1% Proof Stress, tons/in.²	Ultimate Tensile Strength, tons/in.²	Elongation	Young's modulus, p.s.i.²
4a	5Al, 1.7B, 0.1C	[1] 50.6	61.6	4	19.9
		[2] 51.6	57.2	2.5	21
4b	5Al, 1.1B, 0.7C	58.2	68	2.5	19.6
4c	3Al, 1.1B, 0.7C	49.7	56	5	19.6
4d	3Al, 0.7B, 1.1C	46.5	52.5	4	18.9

[1] Longitudinal.
[2] Transverse.

Example 5

An alloy prepared as in Example 3 was forged at 1100° C. and then rolled at 1050° C. into bar form. The mechanical properties determined on the bar were as given below. The nominal composition of the alloy was 5% Al, 1.5% B, 0.3% C by weight, balance titanium.

0.1% proof stress, tons/in.²	66.7
Ultimate tensile strength, tons/in.²	77.2
Elongation, percent	13.0
Young's modulus, p.s.i.²	21.2

Example 6

An ingot of nominal composition by weight 5% Al, 1.5% B, 0.3% C, balance titanium was prepared by melting an electrode formed from compressed titanium sponge, pure aluminum wire, crystalline boron and pure graphite in a consumable electrode vacuum melting furnace. The arc voltage was 24 volts and the arc current 1400 amperes. The ingot was processed to sheet as described in Example 3. This material had a Young's modulus of 19.5×10^{-6} p.s.i.

We claim:

1. A quaternary alloy consisting essentially of, by weight, from 1 to 7% aluminum, 0.5 to 2% boron, 0.1 to 1.2% carbon and the balance titanium, said alloy having a titanium-aluminum α solid solution matrix with the boron and carbon in the form of a precipitated dispersed phase within said matrix.

2. A quaternary alloy consisting essentially of, by weight, from 3 to 7% aluminum, 0.5 to 2% boron, 0.1 to 1.2% carbon and the balance titanium, said alloy having a titanium-aluminum α solid solution matrix with the boron and carbon in the form of a precipitated dispersed phase within said matrix.

3. A quarternary alloy consisting essentially of, by weight, about 5% aluminum, about 1.5% boron, about 0.3% carbon and the balance titanium, said alloy having a titanium-aluminum α solid solution matrix with the boron and carbon in the form of a precipitated dispersed phase within said matrix.

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