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(54) High strength low cost titanium and method for making same

(57) A titanium alloy and method of making the same are provided. The alloy comprises one or more elements selected from the group consisting of chromium, iron, and manganese. In an as-cast condition, the alloy has a

yield strength of at least about 135,000 psi, a tensile strength of at least about 155,000 psi and a percent elongation of at least about 5.0 percent.

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Description**Field of the Invention**

5 [0001] The present invention relates generally to titanium alloys, and more particularly, to a new titanium alloy and method for making the same which can be manufactured from recycled titanium.

Background of the Invention

10 [0002] Titanium alloys offer attractive combinations of physical and mechanical properties which make them ideal for applications requiring high strength, low weight, and good corrosion properties. However, titanium alloys are expensive to manufacture, which severely limits their application. A number of processing steps are required to refine titanium from its raw form to a usable form. In addition, because of its highly reactive nature, the refining process must be carefully controlled, further increasing manufacturing costs. As a result, the use of titanium is typically limited to military vehicles, airplane engine and air-frame components, chemical processing, and sports hardware.

15 [0003] It is desirable to use recycled titanium to reduce manufacturing costs. However, the ability to use recycled materials is limited. To obtain the desired strength and ductility, the oxygen content of most conventional medium and high strength titanium alloys is typically limited to 0.2 percent by weight of the alloy. This relatively low oxygen limit makes it difficult to use recycled titanium materials. During the recycling process, the titanium materials are exposed to air while being melted and subsequently cooled. As a result they tend to absorb oxygen and other interstitial elements each time they are recycled.

20 [0004] As a result, a need has arisen for a new titanium alloy and a method of making the same.

Summary of the Preferred Embodiments

25 [0005] In accordance with one aspect of the present invention, a titanium alloy is provided. The alloy comprises titanium and one or more elements selected from the group consisting of chromium, manganese, and iron, wherein in an as-cast condition, the alloy has a yield strength of at least about 135,000 psi.

30 [0006] The alloy preferably comprises aluminum in a range of about 3.5 to about 6.25 percent by weight of the alloy, with ranges of about 4.5 to about 6.0 percent and about 5.0 to about 6.0 percent being more preferred and especially preferred, respectively. In a preferred embodiment, the alloy comprises vanadium in a range of about 3.0 to about 4.5 percent by weight of the alloy, with ranges of about 3.3 to about 4.5 percent and about 3.5 to about 4.5 percent being more preferred and especially preferred, respectively. In accordance with another preferred embodiment, the amount of chromium is in a range of up to about 3.8 percent by weight of the alloy, with ranges of about 1.0 to about 2.5 percent and about 1.2 to about 2.0 percent being more preferred and especially preferred, respectively. In other preferred

35 [0007] In yet other preferred embodiments, the amount of manganese is in a range of up to about 2.0 percent by weight of the alloy, with ranges of up to about 1.5 percent and about 0.75 to about 1.25 percent being more preferred and especially preferred, respectively. [0007] In yet other preferred embodiments, the alloy comprises oxygen in a range of up to about 0.3 percent by weight, with ranges of up to about 0.29 percent and up to about 0.27 percent being more preferred and especially preferred, respectively. It is further preferred that the combined amount of chromium, manganese, and iron is in a range of about 1.0 to about 5.0 percent by weight of the alloy, with ranges of about 1.0 to about 4.5 percent and about 2.0 to about 3.5 percent being more preferred and especially preferred, respectively.

40 [0008] In accordance with another aspect of the present invention, a titanium alloy is provided. The alloy comprises aluminum, in a range of about 3.5 to about 6.25 percent by weight of the alloy; vanadium, in a range of about 3.0 to about 4.5 percent by weight of the alloy; and one or more elements selected from the group consisting of chromium, iron, and manganese, wherein the one or more elements are present in a range of about 1.0 to about 5.0 percent by weight of the alloy. Titanium is present in a remaining amount, and in an as-cast condition, the alloy preferably has a yield strength of at least about 135,000 psi.

45 [0009] The amount of aluminum is more preferably in a range of about 4.5 to about 6.0 percent by weight of the alloy, with a range of about 5.0 to about 6.0 percent being especially preferred. The amount of vanadium is more preferably in a range of about 3.3 to about 4.5 percent by weight of the alloy, with a range of about 3.5 to about 4.5 percent being especially preferred. The amount of chromium in the alloy is preferably in a range of up to about 3.8 percent by weight of the alloy, with ranges of about 1.0 to about 2.5 percent and about 1.2 to about 2.0 percent being more preferred and especially preferred, respectively. The amount of manganese is preferably in a range of up to about 2.0 percent by weight of the alloy, with ranges of up to about 1.5 percent and about 0.75 to about 1.25 percent being more preferred and especially preferred, respectively. The amount of iron is preferably in a range of up to about 1.0 percent by weight of the alloy. The amount of oxygen is preferably in a range of up to about 0.3 percent by weight of the alloy, with ranges of up to about 0.29 percent and up to about 0.27 percent being more preferred and especially preferred, respectively.

The alloy preferably has a tensile strength of at least about 155,000 psi and a percent elongation of at least about 5.0 percent.

[0010] In accordance with yet another aspect of the present invention, a titanium alloy is provided which comprises chromium, in an range of up to about 3.8 percent by weight of the alloy; iron, in a range of up to about 1.0 percent by weight of the alloy; and manganese, in a range of about 0.75 to about 1.25 percent by weight of the alloy, wherein the combined amount of chromium, iron, and manganese is in a range of about 1.0 to about 5.0 percent by weight of the alloy. Titanium is present in a remaining amount.

[0011] In accordance with still another aspect of the present invention, a titanium alloy is provided which comprises aluminum in a range of about 3.5 to about 6.25 percent by weight of the alloy; vanadium, in a range of about 3.0 to about 4.5 percent by weight of the alloy; chromium, in range of up to about 3.8 percent by weight of the alloy; manganese, in a range of up to about 2.0 percent by weight of the alloy; iron, in a range of up to about 1.0 percent by weight of the alloy; oxygen, in a range of more than about 0.2 to about 0.3 percent by weight of the alloy; and titanium in a remaining amount, wherein the combined amount of chromium, manganese, and iron is in a range of about 2.0 to about 3.5 percent by weight of the alloy.

[0012] In accordance with another aspect of the present invention, a method of making a titanium alloy is provided. The method comprises combining a titanium material with one or more elements selected from the group consisting of chromium, manganese, and iron, wherein in an as-cast condition, the titanium alloy has a yield strength of at least about 135,000 psi. In a preferred embodiment, the combined amount of chromium, manganese, and iron in the alloy is in a range of about 1.0 to about 5.0 percent by weight of the alloy. In still other preferred embodiments, the combined amount of chromium, manganese, and iron in the alloy is in a range of about 2.0 to about 3.5 percent by weight of the alloy.

[0013] Preferably, the alloy comprises oxygen in range of up to about 0.3 percent by weight of the alloy. Even more preferably, the amount of oxygen in the alloy is greater than about 0.2 percent by weight of the alloy. In another preferred embodiment, the amount of manganese in the alloy is in a range of about 0.75 to about 1.25 percent of the alloy. In additional preferred embodiments, the amount of chromium in the alloy is in a range of up to about 3.8 percent by weight of the alloy, with a range of about 1.0 to about 2.5 percent being more preferred. In other preferred embodiments, the amount of iron in the alloy is in a range of up to about 1.0 percent by weight of the alloy.

[0014] In a preferred embodiment, the titanium material is a recycled titanium material. In other preferred embodiments, the titanium material is a Ti-6Al-4V material. In yet other preferred embodiments, the titanium material is a commercially pure titanium material. In still other preferred embodiments, the titanium material is a Ti-3Al-2.5Al material.

[0015] In accordance with an additional aspect of the present invention, a method of making a titanium alloy is provided which comprises providing a titanium material and combining it with manganese, such that the amount of manganese in the alloy is in a range of about 0.75 to about 1.25 percent by weight of the alloy; chromium, such that the amount of chromium in the alloy is in an range of up to about 3.8 percent by weight of the alloy; and iron, such that the amount of iron in the alloy is in an range of up to about 1.0 percent by weight of the alloy, wherein the combined amount of chromium, manganese, and iron in the alloy is in a range of about 1.0 to about 5.0 percent by weight of the alloy.

Detailed Description of the Preferred Embodiments

[0016] The present invention is directed to titanium alloys that can be produced from recycled commercial titanium alloys. As indicated in Table 1, in order to maintain desirable strength and ductility, commercial titanium alloys are typically limited to an oxygen content of no more than 0.2 percent by weight of the alloy.

Table 1--Conventional Titanium alloys

Alloy	Al	V	Mo	Sn	Zr	Cr	Fe	Mn	O
Ti-6Al-4V	5.5-6.75	3.5-4.5					0.3 max		0.2 max
Ti-6Al-2Sn-2Mo-2Zr-2Cr	5.25-6.25		1.75-2.25	1.75-2.25	1.75-2.25	1.75-2.25			0.13 max

Table continued

Alloy	Al	V	Mo	Sn	Zr	Cr	Fe	Mn	O
Ti-6Al-2Sn-4Zr-6Mo	5.5-6.5		5.5-6.5	1.75-2.25	3.5-4.5		0.15 max		0.15 max
Ti-15V-3Cr-3Al-3Sn	2.5-3.5	14.0-1about 6.0		2.5-3.5		2.5-3.5	0.25 max		0.13 max
Ti-10V-2Fe-3Al	2.6-3.4	9.0-11.0					1.6-2.2		0.13 max

[0017] As is known to those skilled in the art, at temperatures below approximately 880°C, titanium assumes a close-packed hexagonal structure referred to as the "alpha" phase. At temperatures of 880°C and above, titanium assumes a body centered cubic structure known as the "beta" phase. It has been found that by adding at least one beta-eutectoid stabilizing element, preferably one selected from the group consisting of chromium, iron and manganese, titanium alloys of the present invention can tolerate higher levels of oxygen, and therefore, can be manufactured from increased amounts of recycled materials. Alloys of the present invention preferably have yield strengths of at least about 135,000 psi, tensile strengths of at least about 155,000 psi and percent elongation values of at least about 5 percent.

[0018] The base titanium material used to form alloys of the present invention is preferably a Ti-3Al-2.5V alloy, a Ti-6Al-4V alloy or commercially pure titanium. As used herein, the term "commercially pure titanium" refers to a titanium material in which the amount of titanium is at least about 98 percent by weight of the material. Ti-6Al-4V alloys and commercially pure titanium are abundantly available in various forms, including electrodes, scrap and plate material and are readily available for recycling.

[0019] A first preferred embodiment of the present invention will now be described. According to this embodiment, the alloy preferably comprises aluminum in a range of about 3.5 to about 6.25 percent by weight of the alloy. A range of about 4.5 to about 6.0 percent is more preferred, and a range of about 5.0 to about 6.0 percent is especially preferred. Aluminum is an alpha-phase stabilizer which helps increase alloy strength. As is known to those skilled in the art, Rosenberg's empirical formula describes a relationship between titanium alloying elements which can be used to prepare alloys having good ductility, strength and metallurgical stability. In particular, it is used to develop high temperature titanium alloys having maximum aluminum equivalents. Rosenberg's formula is as follows:

$$\text{Al} + 1/3 \text{ Sn} + 1/6 \text{ Zr} + 10 \text{ Oxygen} \leq 9$$

[0020] In accordance with this embodiment, the alloy preferably contains no tin or zirconium. It is especially preferred that the aluminum content not exceed about 6.0 percent aluminum, because in the absence of tin and zirconium, such an alloy will satisfy Rosenberg's formula at oxygen levels of up to 0.3 percent by weight of the alloy.

[0021] In accordance with this embodiment, the alloy preferably contains vanadium in a range of about 3.0 to about 4.5 percent by weight of the alloy. Vanadium is a beta-isomorphous stabilizer which is used to increase the strength of the alloy. The ratio of vanadium to aluminum may impact the alloy's phase balance and is preferably maintained at a level which allows for optimization of mechanical properties by precipitation hardening alpha-beta and metastable beta titanium alloys.

[0022] The alloy also preferably contains at least one beta-eutectoid stabilizing element selected from the group consisting of chromium, iron and manganese. The combined amount of chromium, iron, and manganese is preferably in a range of about 1.0 to about 5.0 percent by weight of the alloy. A range of about 1.0 to about 4.5 percent is more preferred, and a range of about 2.0 to about 3.5 percent is especially preferred.

[0023] Chromium is preferably present in a range of up to about 3.8 percent by weight of the alloy. A chromium range of about 1.0 to about 2.5 percent is more preferred, and a range of about 1.2 to about 2.0 percent is especially preferred.

[0024] In accordance with this embodiment, iron is preferably present in a range of up to about 1.0 percent by weight. Manganese is preferably present in a range of up to about 2.0 percent by weight of the alloy. A manganese range of up to about 1.5 percent is more preferred, and a range of about 0.75 to about 1.25 percent by weight is especially preferred. It has been found that adding Manganese in the foregoing levels improves alloy strength.

[0025] Chromium, iron, and manganese are effective beta-eutectoid stabilizers. They are used to increase strength and control ductility and the alloy's response to thermal treatment. They are easy to melt and can be added in their elemental forms. As a result, they are relatively inexpensive to process. Although all three elements are beta-eutectoid stabilizers, it has been found that combining them is especially preferred for obtaining alloys with excellent strength and ductility from recycled titanium materials.

[0026] As explained previously, it has been found that the addition of the foregoing beta-eutectoid stabilizing elements allows the alloys of the present invention to tolerate increased oxygen levels while still maintaining excellent ductility. In accordance with this embodiment, oxygen is present in a range of up to about 0.3 percent by weight of the alloy. Oxygen ranges of up to 0.29 percent are more preferred, and an oxygen range of up to about 0.27 percent is especially preferred. The ability of alloys of this embodiment to tolerate such levels of oxygen allows them to be manufactured from increased amounts of recycled titanium materials. In addition, the increased levels of oxygen improve alloy ductility.

[0027] In accordance with this embodiment, other elements may also be present. Preferably, nitrogen levels are not more than about 0.05 percent by weight of the alloy. Nitrogen levels of not more than about 0.04 percent are more preferred, and nitrogen levels of not more than about 0.035 percent are especially preferred. The alloy preferably contains carbon levels of not more than about 0.1 percent by weight of the alloy. Carbon levels of not more than about 0.05 percent are more preferred, and carbon levels of not more than about 0.03 are especially preferred.

[0028] Hydrogen levels are preferably maintained at not more than about 150 ppm of the alloy weight. Hydrogen levels of not more than about 125 ppm are especially preferred. If present, it is preferred that any elements other than the foregoing are present in amounts of not more than about 0.1 percent by weight each, with their combined amounts not exceeding 0.4 percent by weight. For ease of reference, set forth below in Table 2 are the preferred, most preferred, and especially preferred ranges of ingredients used in this embodiment of the present invention:

Table 2 Ranges of elements as weight percent of alloy

Element	Preferred Range	More Preferred Range	Especially Preferred Range
aluminum	about 3.5-about 6.25	about 4.5-about 6.0	about 5.0-about 6.0
vanadium	about 3.0-about 4.5	about 3.3-about 4.5	about 3.5-about 4.5
chromium	up to about 3.8	about 1.0 to about 2.5	about 1.2 to about 2.0
manganese	up to about 2.0	up to about 1.5	about 0.75-about 1.25
iron	up to about 1.0	up to about 1.0	up to about 1.0
oxygen	up to about 0.3	up to about 0.29	up to about 0.27
nitrogen	not more than about 0.05	not more than about 0.04	not more than about 0.035
hydrogen	not more than about 150 ppm	not more than about 125 ppm	not more than about 125 ppm
carbon	not more than about 0.1	not more than about 0.05	not more than about 0.03
others, each	not more than about 0.1	not more than about 0.1	not more than about 0.1
others, total	not more than about 0.4	not more than about 0.4	not more than about 0.4
Cr+Mn+Fe	about 1.0 to about 5.0	about 1.0 to about 4.5	about 2.0 to about 3.5.

[0029] In their as-cast condition, alloys prepared in accordance with this embodiment will preferably have a tensile strength of at least about 135,000 psi. They will also preferably have a yield strength of at least about 155,000 psi and a percent elongation of at least about 5.0 percent. As used herein, the term "as-cast" refers to the condition of the alloy following casting but prior to any heat treatment, annealing, forming, or any other thermo-mechanical treatment. It is expected that wrought products which have undergone such processes will have even higher yield strengths, tensile strengths and percent elongation values.

[0030] An embodiment of a method of making a titanium alloy in accordance with the present invention will now be described. According to this embodiment, a pre-existing commercially pure titanium material, which is preferably recycled or scrap titanium, is provided. In this embodiment, Grade 1 commercially pure titanium designated as UNS (Unified Numbering System) R50250 is used. In addition to titanium, R50250 comprises 0.20 weight percent iron and 0.18 weight

percent oxygen. Because it is recycled, however, the oxygen level will be higher than that of virgin R50250 material.

[0031] According to this embodiment, the R50250 material is melted and combined with an aluminum/vanadium master alloy. Preferably, the amount of aluminum in the Al/V master alloy is such that the aluminum composition in the titanium alloy is in a range of about 3.5 to about 6.25 percent by weight of the alloy. The amount of vanadium in the Al/V master alloy is preferably such that the vanadium composition of the titanium alloy is in a range of about 3.0 to about 4.5 percent by weight of the alloy. At least one beta-eutectoid stabilizer selected from the group consisting of chromium, iron and manganese is added such that their combined amount in the alloy is in a range of about 1.0 to about 5.0 percent by weight of the alloy. The amount of chromium in the alloy is preferably in a range of up to about 3.8 percent by weight of the alloy, and the amount of manganese in the alloy is preferably in a range of up to about 2.0 percent by weight of the alloy. The amount of iron in the alloy is preferably in a range of up to about 1.0 percent by weight of the alloy. The amount of oxygen in the alloy is preferably in a range of up to about 0.3 percent by weight of the alloy. Oxygen levels are preferably controlled by selecting scrap titanium or sponge with suitably low oxygen content. If present, carbon, hydrogen, nitrogen and additional impurities are preferably kept within the ranges specified in the "preferred range" in Table 1. Levels of these elements in the alloy are also preferably controlled by selecting recycled titanium materials with suitably low levels of them.

[0032] It is more preferable to add amounts of aluminum, vanadium, chromium, manganese and iron which yield the weight percentages specified in the "more preferred range" column of Table 2 and to control the levels of oxygen, nitrogen, hydrogen, carbon and other impurities in the alloy to the levels specified in the more preferred range column. It is especially preferred that alloys prepared in accordance with this embodiment contain the amounts of the foregoing elements listed in the "especially preferred range" column of Table 2. Alloys prepared according to the method of this embodiment will preferably have a yield strength of at least about 135,000 psi, a tensile strength of at least about 155,000 psi, and a percent elongation of at least about 5.0 percent.

[0033] In accordance with another embodiment of the present invention, a method of preparing a titanium alloy from a pre-existing Ti-6Al-4V material is provided. The Ti-6Al-4V material is preferably a recycled or scrap material. Commercially produced Ti-6Al-4V contains 5.5 to 6.75 percent by weight aluminum, 3.5 percent to 4.5 percent by weight vanadium, up to 0.3 percent by weight iron, and up to 0.2 percent by weight oxygen. However, due to the use of recycled material, the oxygen content will typically exceed 0.2 percent. In accordance with this embodiment, the aluminum content in the Ti-6Al-4V will preferably not exceed about 6.0 percent by weight of the alloy.

[0034] At least one beta-eutectoid stabilizer selected from the group consisting of chromium, manganese, and iron is combined with the Ti-6Al-4V material such that the combined amount of chromium, manganese, and iron is within the preferred range specified in Table 2. It is more preferred to use the range specified in the more preferred column of Table 2 and especially preferred to use the range specified in the especially preferred column of Table 2. Oxygen, carbon, hydrogen, nitrogen, and other impurities are also preferably kept within the ranges specified in Table 2. Alloys prepared according to the method of this embodiment will preferably have a yield strength of at least about 135,000 psi, a tensile strength of at least about 155,000 psi, and a percent elongation of at least about 5.0 percent.

[0035] According to another embodiment of the present invention, a method of making a titanium alloy from a pre-existing Ti-3Al-2.5V alloy is provided. The alloy is preferably recycled. According to this embodiment, aluminum and vanadium are combined with the recycled Ti-3Al-2.5V material such that the resulting alloy contains aluminum in a range of about 3.5 to about 6.25 percent by weight of the alloy and vanadium in a range of about 3.0 to about 4.5 percent by weight of the alloy. At least one beta-eutectoid stabilizer selected from the group consisting of chromium, manganese, and iron is added such that their combined amounts in the alloy are in a range of about 1.0 to about 5.0 percent by weight of the alloy. Preferably, the alloy has an oxygen content in a range of up to about 0.3 percent by weight of the alloy. The remaining preferred, more preferred, and especially preferred values for the various elements in Table 2 are applicable to this method as well.

[0036] The invention may be better understood by referring to the following examples of titanium alloys prepared in accordance with the present invention. All samples were heat treated by hipping (hot isostatically pressing) at 1650°F and 15,000 ± 500 psi for 2 hours followed by aging in a range of from 900°F to 1100°F for periods of from 4 to 12 hours.

Table 3--Examples

Element	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8
Al	5.81	5.76	5.5	5.8	5.89	5.7	5.44	5.62
V	3.77	3.73	3.69	3.8	3.71	3.7	3.64	3.83
Cr	1.37	2.22	1.8	1.16	1.15	1.93	1.28	--
Mn	--	--	1.03	--	1.15	1.58	0.98	1.84
Fe	0.19	0.15	0.17	0.12	0.17	0.014	0.96	0.17

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Table continued

Element	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8
O	0.27	0.26	0.27	0.24	0.27	0.29	0.28	0.29
N	0.022	0.02	0.023	0.018	0.024	0.03	0.038	0.03
H	0.0029	0.007	0.0075	0.0037	0.0049	0.0014	0.0034	0.0015
C	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.01
Ti	bal.							
Condition	as cast							
YS, ksi	138	143	143	136	145			149
UTS, ksi	161	164	164	159	166			169
% elong.	8.5	8.5	7.5	9.5	6.5			7
% RA	19	23	18	17	17			14
Condition	heat treat							
YS, ksi	144	146	150	145	150	152	153	149
UTS, ksi	160	162	165	165	171	167	165	164
% elong.	9.5	11	10	9	7	9	8	7.5
% RA	23	22	22	15	14	17	21	16.5
Key: bal.= balance, YS=yield strength, ksi=1000 lb/(.in) ² , UTS=Ultimate Tensile Strength, % elong.= percent elongation, % RA= percent reduction in area. The term "heat treat" refers to the material following heat treating.								

[0037] As the data indicates, the alloys in Table 3 all had oxygen levels well above the conventional limit of 0.2 weight percent, yet attained as-cast yield strengths of greater than 135,000 psi, tensile strengths of greater than 155,000 psi, and percent elongation values of greater than 5%. In addition, strength and ductility were further improved with heat treating.

[0038] Table 4 provides a comparison of the yield strength, tensile strength, and percent elongation of certain of the alloys in Table 3 with several commercial alloys:

Table 4 Comparison of Commercial Alloys to Embodiments of the Present Invention

Alloy and condition	YS ksi	UTS ksi	% elongation
Ti-6Al-4V (cast and heat treated)	120	134	8
Ti-6Al-4V (wrought mill annealed)	137	151	14
Ti-6Al-2Sn-2Mo-2Zr-2Cr (cast and heat treated)	131	155	5
BT-22 (cast and heat treated)	151	151	1.5
Sample 1 (cast and heat treated)	144	160	9.5
Sample 3 (cast and heat treated)	150	165	10
Sample 7 (cast and heat treated)	153	165	8
Sample 8 (cast and heat treated)	149	164	7.5

[0039] As indicated in Table 4, the samples prepared in accordance with the foregoing embodiments of the present invention achieved yield and tensile strengths comparable or superior to those found in virgin Ti-6Al-4V and Ti-6Al-2Sn-2Mo-2Zr-2Cr, while tolerating significantly higher oxygen levels (See Tables 1 and 3). As a result of their increased oxygen tolerance, alloys of the present invention can be manufactured from greater amounts of recycled materials than

alloys with lower oxygen tolerances.

[0040] The embodiments described above are exemplary embodiments of a the present invention. Those skilled in the art may now make numerous uses of, and departures from, the above-described embodiments without departing from the inventive concepts disclosed herein. Accordingly, the present invention is to be defined solely by the scope of the following claims.

Claims

1. A titanium alloy, comprising:

aluminum, in a range of about 3.5 to about 6.25 percent by weight of the alloy;
vanadium, in a range of about 3.0 to about 4.5 percent by weight of the alloy;
one or more elements selected from the group consisting of chromium, iron, and manganese, wherein said one or more elements are present in a range of about 1.0 to about 5.0 percent by weight of the alloy;
titanium being present in a remaining amount;
wherein in an as-cast condition, the alloy has a yield strength of at least about 135,000 psi.

2. The alloy of claim 1, wherein in an as-cast condition, the alloy has a tensile strength of at least about 155,000 psi.

3. The alloy of claim 1, wherein in an as-cast condition, the alloy has a percent elongation of at least about 5 percent.

4. The alloy of claim 1, wherein the amount of chromium is in a range of about 1.0 to about 2.5 percent by weight of the alloy.

5. The alloy of claim 1, wherein the amount of chromium is in a range of about 1.2 to about 2.0 percent by weight of the alloy.

6. The alloy of claim 1, wherein the amount of manganese is in a range of up to about 2.0 percent by weight of the alloy.

7. The titanium alloy of claim 1, wherein the amount of manganese is in a range of about 0.75 to about 1.25 percent by weight of the alloy.

8. The titanium alloy of claim 1, wherein the amount of iron is in a range of up to about 1.0 percent by weight of the alloy.

9. The titanium alloy of claim 1, wherein the amount of aluminum is in a range of about 5.0 to about 6.0 percent by weight of the alloy.

10. The titanium alloy of claim 1, wherein the amount of vanadium is in a range of about 3.3 to about 4.5 percent by weight of the alloy.

11. The titanium alloy of claim 1, wherein the combined amount of chromium, manganese, and iron is in a range of about 2.0 percent to about 3.5 percent by weight of the alloy.

12. The titanium alloy of claim 1, further comprising oxygen in a range of up to about 0.3 percent by weight of the alloy.

13. A titanium alloy, comprising:

titanium; and
one or more elements selected from the group consisting of chromium, manganese, and iron, wherein in an as-cast condition, the alloy has a yield strength of at least about 135,000 psi.

14. The titanium alloy of claim 13, further comprising aluminum.

15. The titanium alloy of claim 14, wherein the amount of aluminum is in a range of about 3.5 to about 6.25 percent by weight of the alloy.

16. The titanium alloy of claim 13, further comprising vanadium.

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17. The titanium alloy of claim 16, wherein the amount of vanadium is in a range of about 3.0 to about 4.5 percent by weight of the alloy.
- 5 18. The titanium alloy of claim 13, wherein the amount of chromium is in a range of up to about 3.8 percent by weight of the alloy.
19. The titanium alloy of claim 13, further comprising oxygen.
- 10 20. The titanium alloy of claim 19, wherein the amount of oxygen is in a range of up to about 0.3 percent by weight of the alloy.
21. The titanium alloy of claim 13, wherein the amount of manganese is in a range of up to about 2.0 percent by weight of the alloy.
- 15 22. The titanium alloy of claim 13, wherein the amount of manganese is in a range of about 0.75 to about 1.25 percent by weight of the alloy.
23. The titanium alloy of claim 13, wherein the amount of chromium is in a range of about 1.0 to about 2.5 percent by weight of the alloy.
- 20 24. The titanium alloy of claim 13, wherein the amount of iron is in a range of up to about 1.0 percent by weight of the alloy.
- 25 25. The titanium alloy of claim 13, wherein the combined amount of chromium, manganese, and iron is in a range of about 1.0 to about 5.0 percent by weight of the alloy.
- 26 26. The titanium alloy of claim 13, wherein the combined amount of chromium, manganese, and iron is in a range of about 2.0 to about 3.5 percent by weight of the alloy.
- 30 27. The titanium alloy of claim 13, wherein in an as-cast condition, the alloy has a tensile strength of at least about 155,000 psi.
28. The titanium alloy of claim 13, wherein in an as-cast condition, the alloy has a percent elongation of at least about 5.0 percent.
- 35 29. A method of making a titanium alloy, comprising:
- combining a titanium material with one or more elements selected from the group consisting of chromium, manganese, and iron,
- 40 wherein in an as-cast condition, the titanium alloy has a yield strength of at least about 135,000 psi.
30. The method of claim 29, wherein the combined amount of chromium, manganese, and iron in the alloy is in a range of about 1.0 to about 5.0 percent by weight of the alloy.
- 45 31. The method of claim 29, wherein the combined amount of chromium, manganese, and iron in the alloy is in a range of about 2.0 to about 3.5 percent by weight of the alloy.
32. The method of claim 29, wherein the alloy comprises oxygen in a range of up to about 0.3 percent by weight of the alloy.
- 50 33. The method of claim 32, wherein the amount of oxygen in the alloy is greater than about 0.2 percent by weight of the alloy.
34. The method of claim 29, wherein the amount of manganese in the alloy is in a range of up to about 2 percent by weight of the alloy.
- 55 35. The method of claim 29, wherein the amount of manganese in the alloy is in a range of about 0.75 to about 1.25 percent by weight of the alloy.

36. The method of claim 29, wherein the amount of chromium in the alloy is in a range of up to about 3.8 percent by weight of the alloy.
- 5 37. The method of claim 29, wherein the amount of chromium in the alloy is in a range of about 1.0 to about 2.5 percent by weight of the alloy.
38. The method of claim 29, wherein the amount of iron in the alloy is in a range of up to about 1.0 percent by weight of the alloy.
- 10 39. The method of claim 29, wherein the titanium material is a recycled titanium material.
40. The method of claim 29, wherein the titanium material is a Ti-6Al-4V material.
41. The method of claim 29, wherein the titanium material is a commercially pure titanium material.
- 15 42. The method of claim 41, further comprising the step of combining aluminum with the titanium material, wherein the amount of aluminum in the alloy is in a range of about 3.5 to about 6.25 percent by weight of the alloy.
- 20 43. The method of claim 41, further comprising the step of combining vanadium with the titanium material, wherein the amount of vanadium in the alloy is in a range of about 3.0 to about 4.5 percent by weight of the alloy.
44. The method of claim 29, wherein the titanium material is a Ti-3Al-2,5V material.
- 25 45. The method of claim 44, further comprising the step of combining aluminum with the titanium material, wherein the amount of aluminum in the alloy is in a range of about 3.5 to about 6.25 percent by weight of the alloy.
46. The method of claim 44, further comprising the step of combining vanadium with the titanium material, wherein the amount of vanadium in the alloy is in a range of about 3.0 to about 4.5 percent by weight of the alloy.
- 30 47. The method of claim 29, wherein the titanium material is scrap titanium material.
48. The method of claim 29, wherein the titanium material comprises aluminum in a range of about 3.5 to about 6.25 percent by weight of the alloy.
- 35 49. The method of claim 29, wherein the titanium material comprises vanadium in a range of about 3.0 to about 4.5 percent by weight of the alloy.
50. The method of claim 29, wherein in an as-cast condition, the alloy has a tensile strength of at least about 155,000 psi.
- 40 51. The method of claim 29, wherein in an as-cast condition, the alloy has a percent elongation of at least about 5.0 percent.
52. A method of making a titanium alloy, comprising:
- 45 providing a titanium material comprising aluminum in a range of about 3.5 to about 6.25 percent by weight of the alloy, oxygen in a range of up to about 0.3 percent by weight and vanadium in a range of about 3.0 to about 4.5 percent by weight of the alloy;
- 50 combining the titanium material with manganese, such that the amount of manganese in the alloy is in a range of about 0.75 to about 2.0 percent by weight of the alloy, chromium, such that the amount of chromium in the alloy is in a range of up to about 3.8 percent by weight of the alloy, and iron, such that the amount of iron in the alloy is in a range of up to about 1.0 percent by weight of the alloy, wherein the combined amount of manganese, chromium, and iron in the alloy is in a range of about 1.0 to about 5.0 percent by weight of the alloy.
- 55 53. The method of claim 52, wherein the combined amount of manganese, chromium, and iron in the alloy is in a range of about 2.0 to about 3.5 percent by weight of the alloy.
54. The method of claim 52, wherein the amount of chromium in the alloy is in a range of about 1.0 to about 2.5 percent by weight of the alloy.

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55. The method of claim 52, wherein in an as-cast condition, the alloy has a yield strength of at least about 135,000 psi.
56. The method of claim 52, wherein in an as-cast condition, the alloy has a tensile strength of at least about 155,000 psi.
- 5 57. The method of claim 52, wherein in an as-cast condition, the alloy has a percent elongation of at least about 5.0 percent.
58. A titanium alloy, comprising:
- 10 chromium, in a range of up to about 3.8 percent by weight of the alloy;
iron, in a range of up to about 1.0 percent by weight of the alloy;
manganese, in a range of about 0.75 to about 1.25 percent by weight of the alloy;
titanium, being present in a remaining amount;
15 wherein the combined amount of chromium, iron and manganese is in a range of about 1.0 to about 5.0 percent by weight of the alloy.
59. The titanium alloy of claim 58, further comprising oxygen in a range of up to about 0.3 percent by weight of the alloy.
- 20 60. The titanium alloy of claim 58, further comprising aluminum in a range of about 3.5 to about 6.25 percent by weight of the alloy.
61. The titanium alloy of claim 58, further comprising vanadium in a range of about 3.0 to about 4.5 percent by weight of the alloy.
- 25 62. The titanium alloy of claim 58, wherein the combined amount of chromium, manganese, and iron is in a range of about 2.0 to about 3.5 percent by weight of the alloy.
63. The titanium alloy of claim 58, wherein in an as-cast condition, the alloy has a yield strength of at least about 135,000 psi.
- 30 64. The titanium alloy of claim 58, wherein in an as-cast condition, the alloy has a tensile strength of at least about 155,000 psi.
65. The titanium alloy of claim 58, wherein in an as-cast condition, the alloy has a percent elongation of at least about 5.0 percent.
- 35 66. An titanium alloy, comprising:
- 40 aluminum, in a range of about 3.5 to about 6.25 percent by weight of the alloy;
vanadium, in a range of about 3.0 to about 4.5 percent by weight of the alloy;
iron, in a range of up to about 1.0 percent by weight;
chromium, in a range of up to about 3.8 percent by weight of the alloy;
manganese, in a range of about 0.75 to about 2.0 percent by weight of the alloy; and
45 oxygen, in an range of up to about 0.3 percent by weight of the alloy; and
titanium, being present in a remaining amount;
wherein the combined amount of manganese, chromium and iron is in a range of about 1.0 to about 5.0 percent by weight of the alloy.
- 50 67. The titanium alloy of claim 66, wherein the amount of chromium is in a range of about 1.0 to about 2.5 percent by weight of the alloy.
68. The titanium alloy of claim 66 further comprising a pre-existing titanium material.
69. The titanium alloy of claim 68, wherein the pre-existing titanium material is a recycled titanium material.
- 55 70. The titanium alloy of claim 66, wherein the combined amount of manganese, chromium and iron is in a range of about 2.0 to about 3.5 percent by weight of the alloy.

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71. The titanium alloy of claim 66, wherein in an as-cast condition, the alloy has a yield strength of at least about 135,000 psi.
- 5 72. The titanium alloy of claim 66, wherein in an as-cast condition, the alloy has a tensile strength of at least about 155,000 psi.
73. The titanium alloy of claim 66, wherein in an as-cast condition, the alloy has a percent elongation of at least about 5.0 percent.
- 10 74. A titanium alloy, comprising:
- aluminum, in a range of about 3.5 to about 6.25 percent by weight of the alloy;
 - vanadium, in a range of about 3.0 to about 4.5 percent by weight of the alloy;
 - 15 chromium, in a range of up to about 3.8 percent by weight of the alloy;
 - manganese, in a range of up to about 2.0 percent by weight of the alloy;
 - iron, in a range of up to about 1.0 percent by weight of the alloy;
 - oxygen, in a range of more than about 0.2 percent to about 0.3 percent by weight of the alloy; and
 - titanium present in a remaining amount;
 - 20 wherein, the combined amount of chromium, manganese and iron is in a range of about 2.0 to about 3.5 percent by weight of the alloy.
75. The alloy of claim 74, wherein the amount of aluminum is in a range of about 5.0 to about 6.0 percent by weight of the alloy.
- 25 76. The alloy of claim 74, wherein the amount of vanadium is in a range of about 3.3 to about 4.5 percent by weight of the alloy.
77. The alloy of claim 74, wherein the amount of manganese is in a range of up to about 1.5 percent by weight of the alloy.
- 30 78. The alloy of claim 74, wherein the amount of manganese is in a range of about 0.75 to about 1.25 percent by weight of the alloy.
79. The alloy of claim 74, wherein the amount of chromium is in a range of about 1.0 to about 2.5 percent by weight of the alloy.
- 35 80. The alloy of claim 74, wherein in an as-cast condition, the alloy has a yield strength of at least about 135,000 psi.
81. The alloy of claim 74, wherein in an as-cast condition, the alloy has a percent elongation of at least about 5.0 percent by weight.
- 40 82. The alloy of claim 74, wherein in an as-cast condition, the alloy has a tensile strength of at least about 155,000 psi.
83. The alloy of claim 74, further comprising nitrogen in a range of up to about 0.05 percent by weight of the alloy.
- 45 84. The alloy of claim 83, further comprising carbon in a range of up to about 0.1 percent by weight.
85. The alloy of claim 84, further comprising other elements, wherein each said other element is present in a range of up to about 0.1 percent by weight of the alloy and the combined amount of said other elements is in a range of up to about 0.4 percent by weight of the alloy.
- 50 86. A method of making a titanium alloy, comprising:
- providing a titanium material;
 - 55 combining the titanium material with manganese, such that the amount of manganese in the alloy is in a range of about 0.75 to about 1.25 percent by weight of the alloy, chromium, such that the amount of chromium in the alloy is in a range of up to about 3.8 percent by weight of the alloy, and iron, such that the amount of iron in the alloy is in a range of up to about 1.0 percent by weight of the alloy;
 - wherein the combined amount of chromium, manganese, and iron in the alloy is in a range of about 1.0 to about

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5.0 percent by weight of the alloy.

5 **87.** The method of claim 86, wherein the titanium material comprises aluminum in a range of about 3.5 to about 6.25 percent by weight of the alloy.

88. The method of claim 86, wherein the titanium material comprises vanadium in a range of about 3.0 to about 4.5 percent by weight of the alloy.

10 **89.** The method of claim 86, wherein the titanium material comprises commercially pure titanium.

90. The method of claim 89, further comprising the step of combining aluminum with the titanium material, wherein the amount of aluminum in the alloy is in a range of about 3.5 to about 6.25 percent by weight of the alloy.

15 **91.** The method of claim 89, further comprising the step of combining vanadium with the titanium material, wherein the amount of vanadium in the alloy is in a range of about 3.0 to about 4.5 percent by weight of the alloy.

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