

UNITED STATES PATENT OFFICE

2,666,698

ALLOYS OF TITANIUM CONTAINING
ALUMINUM AND IRON

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No Drawing. Application July 24, 1951,
Serial No. 238,392

2 Claims. (Cl. 75-177)

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This invention relates to titanium base alloys, and more particularly to ductile wrought alloys of titanium, aluminum and iron.

It is an object of the present invention to provide strong ductile alloys of titanium.

It is another object of the present invention to provide ductile wrought alloys of titanium, aluminum and iron which have good resistance to oxidation and high hardness at elevated temperatures, as well as tensile properties improved over the metal titanium alone.

A further object of the present invention is to provide ternary alloys of titanium, aluminum and iron and to which may be added the element silicon to form a quaternary alloy. It is, therefore, an object of the present invention to provide alloys of titanium, aluminum and iron to which may be added the element silicon providing a new quaternary alloy of titanium, aluminum, iron and silicon.

Another object of the present invention is to provide strong ductile alloys of titanium, aluminum and iron to which the elements carbon or silicon may be added to form additional alloys of titanium, aluminum, iron, carbon, and/or alloys of titanium, aluminum, iron, carbon and silicon.

Another object of the present invention is to provide methods for forming ductile alloys of titanium containing predominantly aluminum and iron and to which may be added the elements silicon and/or carbon to form quaternary or quinary alloys having as a prime base therefor the elements titanium, aluminum and iron.

It is also within the contemplation of the invention to provide means for making titanium base alloys containing aluminum, iron and titanium of improved physical properties on a practical and industrial scale at low cost.

It has been discovered that aluminum and iron form strong ductile ternary alloys within titanium. It has also been found that carbon may be added to the aforesaid ternary alloy containing aluminum, titanium and iron and by such addition the properties of the alloy may be materially affected. If carbon is added to the ternary alloy of titanium, aluminum and iron, it has been found that the range of carbon introduced therein may be from 0.25% to 0.75% thereof. Below this range, the beneficial effects of the carbon, it has been found, decrease materially, while above this range the elongation of the alloy to which the carbon has been added is reduced appreciably.

Thus, in accordance with the results obtained

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from experimentation with these alloys, an alloy has been provided which contains 3% aluminum, 3% iron, and 0.44% carbon, with the remainder thereof being essentially all titanium. This alloy was found to have the following properties:

Ultimate tensile strength (p. s. i.)	146,000
Proportional limit (p. s. i.)	112,000
Elongation (per cent in 2'')	13.3
Reduction in area (per cent)	39.7
Modulus of elasticity (p. s. i.)	18×10^6
Electrical resistivity (ohm-cm.)	138×10^{-6}

For comparison, unalloyed titanium had the following properties when containing the same impurities as the alloy above:

Ultimate tensile strength (p. s. i.)	87,000
Proportional limit (p. s. i.)	53,000
Elongation (per cent in 2'')	16
Modulus of elasticity (p. s. i.)	16×10^6
Electrical resistivity (ohm-cm.)	60×10^{-6}

It is to be noted, the basic alloy of the present invention is a ternary alloy of aluminum, iron and titanium. The ternary alloy thus formed is significantly improved over the binary alloys of aluminum and titanium and iron and titanium. The former binary alloy, it has been found, are difficult to hot work. For example, when the aluminum content is greater than 2.5% in such a binary alloy, it is very difficult to hot work. On the other hand, alloys consisting of titanium and iron are very quench hardenable and it is difficult to prevent cracking during forming operations.

When the alloy of titanium, iron and aluminum is provided, however, entirely unexpected results result. This is readily observable from a comparison of properties as disclosed in the alloys containing (1) titanium, aluminum and carbon; (2) titanium, iron and carbon; as compared to (3) ternary alloy of aluminum, iron, titanium, plus the addition of carbon:

(1)

Composition:

3% aluminum.

0.66% carbon.

Balance titanium.

Ultimate tensile strength (p. s. i.)	135,300
Proportional limit (p. s. i.)	-----
Elongation (per cent in 2'')	0
Electrical resistivity (ohm-cm.)	135×10^{-6}
Forgeability	Bad

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(2)

Composition:

5% iron.

0.41% carbon.

Balance titanium.

Ultimate tensile strength (p. s. i.)	155,000
Proportional limit (p. s. i.)	87,000
Elongation (per cent in 2'')	8.6
Electrical resistivity (ohm-cm.)	80×10^{-6}
Forgeability	Fair

(3)

Composition:

3% aluminum.

5% iron.

0.37% carbon.

Balance titanium.

Ultimate tensile strength (p. s. i.)	161,500
Proportional limit (p. s. i.)	120,000
Elongation (per cent in 2'')	10.9
Electrical resistivity (ohm-cm.)	139×10^{-6}
Forgeability	Good

It is noted that the tensile strength, proportional limit and elongation have thus been materially increased by the combination of aluminum and iron in titanium with the addition of the carbon thereto. As shown above, the tensile strength and elongation characteristics of titanium aluminum or titanium iron alloys has been increased by forming a ternary alloy of titanium, aluminum and iron. It may be seen, also, by referring to the table below, that the tensile strength and elongation of such ternary alloys formed by the combination of aluminum and iron with titanium depends upon the amount of aluminum and iron which is present in the ternary alloy. After experimentation, it was found that the characteristics of tensile strength and elongation are dependent upon the amount of aluminum and iron present, as follows:

Percent Aluminum	Percent Iron	Ultimate Tensile Strength (p. s. i.)	Elongation (percent in 2'')
3	1	135,800	15.6
2	6	170,200	8.2
5	5	181,700	7.0

In addition to the alloys thus formed by the combination of aluminum, iron and titanium to form a ternary alloy, the alloy may be modified by an addition of up to 1% silicon to form a new quaternary alloy or a five element alloy consisting of titanium, aluminum, iron, silicon and carbon.

The addition of silicon to any one of the ternary alloys of aluminum, iron and titanium was found to generally improve the tensile strength and proportional limit thereof. It was also found that silicon does not affect the hot workability of these alloys.

A preferred alloy, as shown below, had the following properties:

Composition:

3% aluminum.

1% iron.

0.5% silicon.

Balance titanium.

Ultimate tensile strength (p. s. i.)	161,800
Proportional limit (p. s. i.)	147,000
Elongation (per cent in 2'')	10.9
Modulus of elasticity (p. s. i.)	18×10^6
Electrical resistivity (ohm-cm.)	148×10^{-6}

The alloys are made in an inert atmosphere, typified by argon or helium, provided the alloy is

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melted or sintered. The alloys can also be made in a vacuum environment. If the alloys are melted, the crucible can be graphite or a highly refractory oxide, preferably thoria or stabilized zirconia or carbides of tungsten and boron. If the alloys are arc-melted, in which case an inert atmosphere or vacuum must still be used, the crucible can be water cooled copper. Powder metallurgy methods can also be used. The tensile properties of the alloys, herein described, will vary according to the method used, but are better than the unalloyed titanium in every case.

The subject alloys are not modified appreciably by heat treatments. Quenching from 1000° C. does, however, increase the strength and embrittle the alloys. The hardness of the alloys is not increased by quenching but does increase when heated at 500° C. for 4 hours after quenching after 1 hour at 900° C. It was found that a heat treatment of 5 hours at 700° C., followed by furnace cooling, did not affect the ultimate tensile strength of a 5% aluminum-5% iron-titanium alloy, but it did increase the proportional limit from 144,000 p. s. i. to 162,000 p. s. i. and decreased the elongation from 7.0% to 6.2% in 2'.

The forming of alloys containing aluminum and iron is done by forging to the desired shape at a metal temperature not to exceed 1200° C. The normal forging temperature of 950° C. does not cause excessive oxidation.

An alloy containing approximately 2% aluminum and 2% iron was hot rolled at 800° C. The alloy was cold rolled to 37% reduction in area and annealed. The properties of this sheet were:

	Hot Rolled	Cold Rolled and Annealed
Ultimate Tensile Strength (p. s. i.)	161,500	133,000
Proportional Limit (p. s. i.)	105,000	108,000
Elongation (percent in 2'')	10.2	14.4

The minimum bend radius of this alloy 0.040" thick cold rolled and annealed was .140".

While the present invention as to its objects and advantages has been described herein as carried out in specific embodiments thereof, it is not desired to be limited thereby, but it is intended to cover the invention within the spirit and scope of the appended claims.

What is claimed is:

1. Titanium alloys consisting of from 6.75% to 6% aluminum, 0.75% to 7% iron, from 0.25% to 1% silicon, the rest being essentially all titanium.
2. A titanium base alloy consisting of 0.75% to 6% aluminum, 0.75% to 7% iron, 0.25% to 0.75% carbon, 0.25% to 1% silicon, the rest being essentially all titanium.

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