



(19) **United States**

(12) **Patent Application Publication**

Hu

(10) **Pub. No.: US 2004/0003877 A1**

(43) **Pub. Date:**

Jan. 8, 2004

(54) **METHOD OF HEAT TREATING TITANIUM ALUMINIDE**

(52) **U.S. Cl.** **148/669**

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(57) **ABSTRACT**

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A gamma titanium aluminide alloy consisting of 48 at % aluminium, 2 at % chromium, 2 at % niobium and the balance titanium plus incidental impurities was heat treated according to the present invention. The gamma titanium aluminide alloy has an alpha transus temperature $T_{\alpha}=1360^{\circ}$ C. The gamma titanium aluminide alloy was heated to a temperature $T_1=1380^{\circ}$ C. and was held at $T_2=1380^{\circ}$ C. for 1 hour. The gamma titanium aluminide alloy was oil cooled. The gamma titanium aluminide alloy was heated to a temperature $T_2=1320^{\circ}$ C. and was held at $T_2=1320^{\circ}$ C. for 2 hours. The gamma titanium aluminide alloy was air cooled to ambient temperature. The gamma titanium aluminide alloy has a fine duplex microstructure comprising differently orientated alpha plates in a massively transformed gamma matrix.

(21) Appl. No.: **10/455,613**

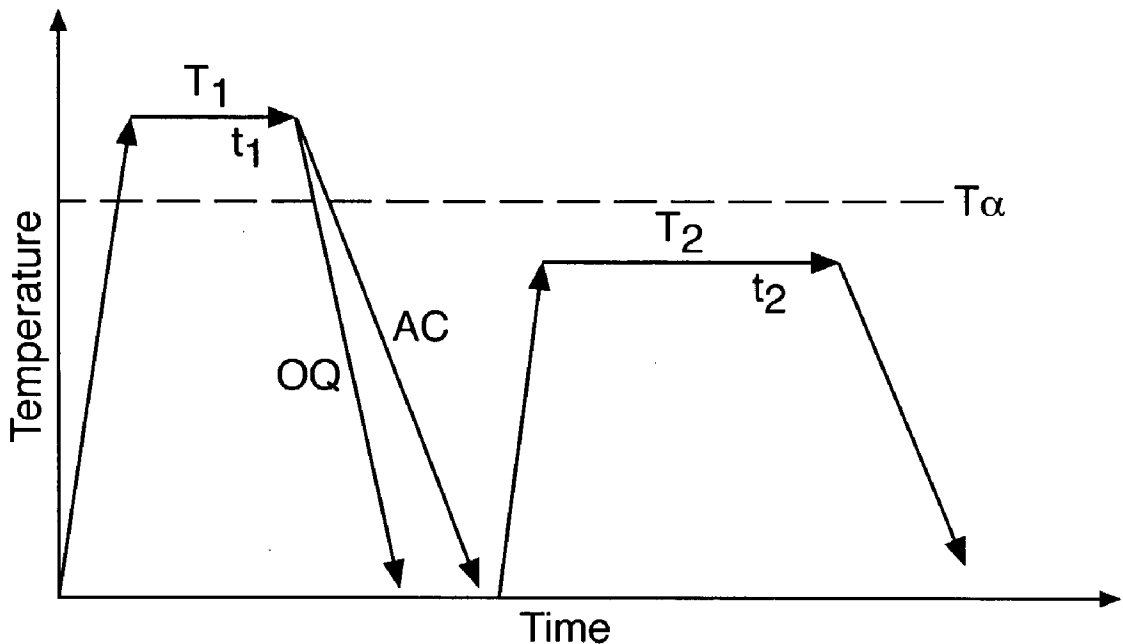
(22) Filed: **Jun. 6, 2003**

(30) **Foreign Application Priority Data**

Jul. 5, 2002 (GB) 0215563.8

Publication Classification

(51) **Int. Cl.⁷** **C22F 1/18**



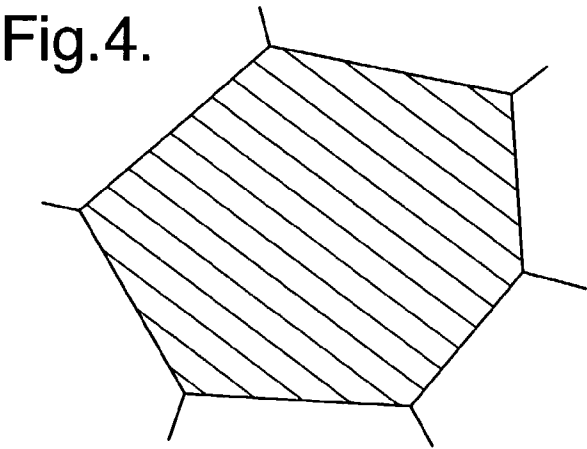
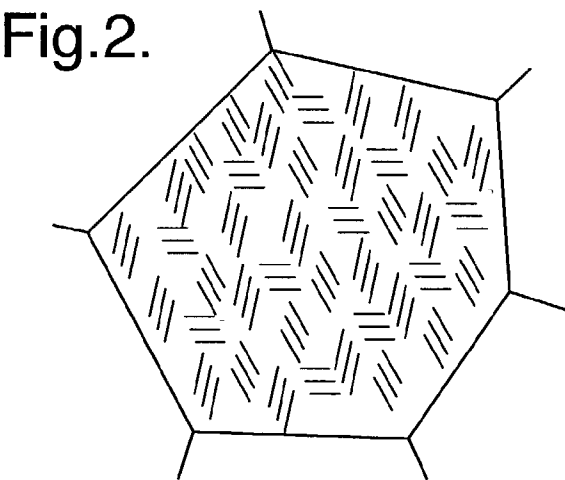
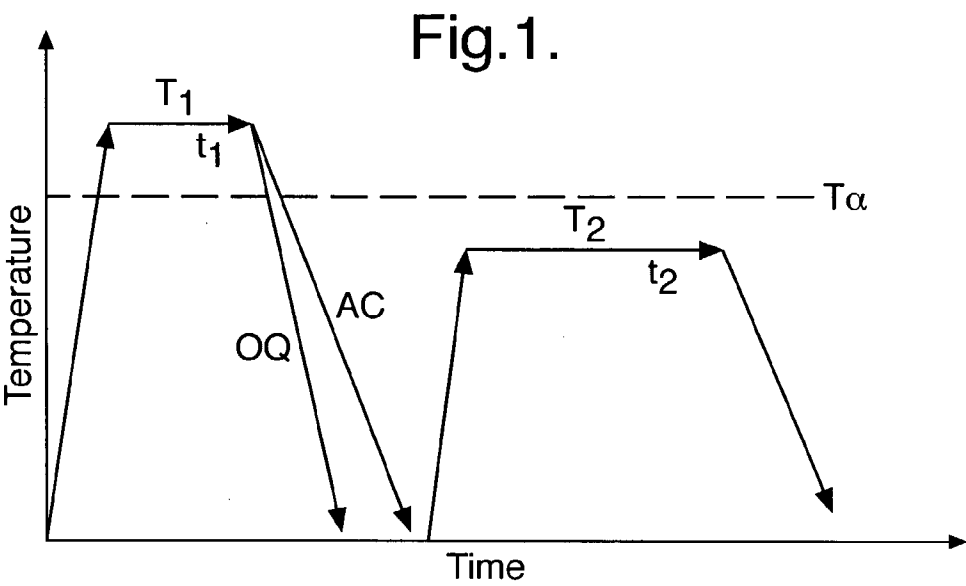


Fig.3.

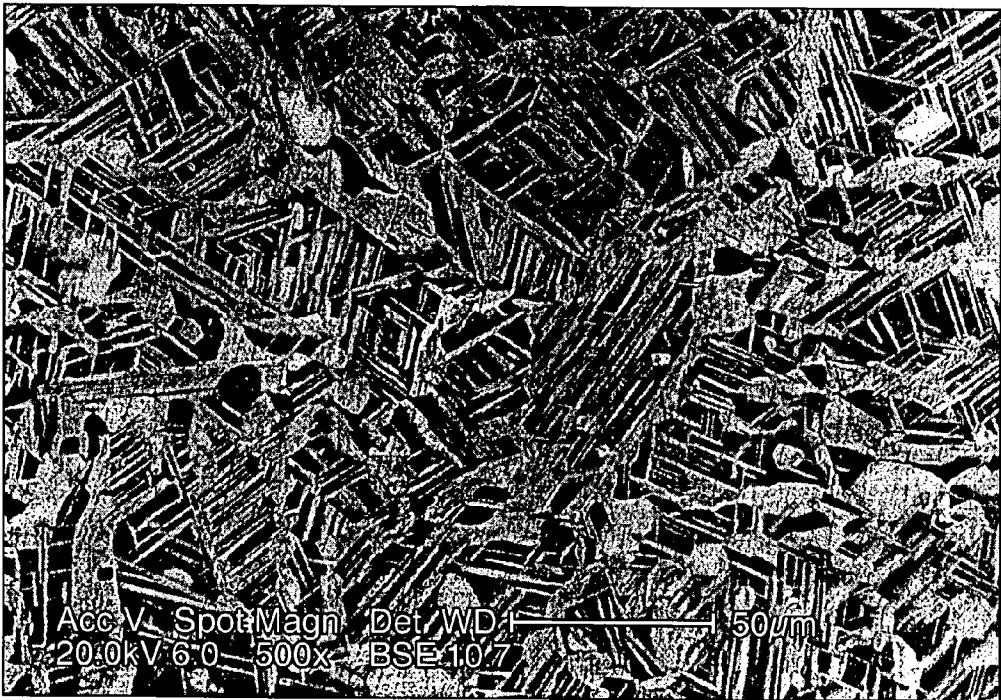
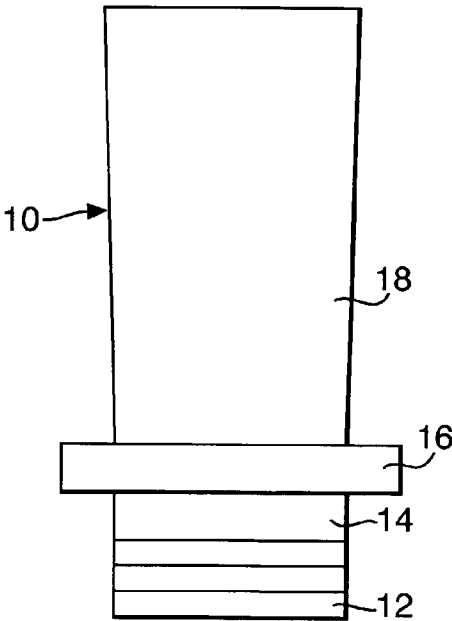


Fig.5.



METHOD OF HEAT TREATING TITANIUM ALUMINIDE

[0001] The present invention relates to a method of heat-treating titanium aluminide and in particular to a method of heat-treating.

[0002] There is a requirement to refine the microstructure of a titanium aluminide alloy, in particular cast titanium aluminide alloy, which does not involve hot working of the titanium aluminide alloy.

[0003] It is known to use six to eight rapid heating and rapid cooling cycles of a titanium aluminide alloy to obtain satisfactory fineness of the microstructure, as disclosed by Wang J N, Xia K in *Intermetallics* 2000, 8, 545. But this is only practical on a laboratory scale. The rapid heating and rapid cooling is beyond the ability of conventional heat treatment facilities. In order to achieve rapid heating and rapid cooling of a titanium aluminide component, the size of the titanium aluminide component is limited and cracks may be produced in an irregular shaped titanium aluminide component.

[0004] It is also known to use a first long term soak at a sub alpha transus temperature and a second short term soak at a temperature just above the alpha transus temperature followed by furnace or air cooling of a titanium aluminide alloy, as disclosed by Yang J, Wang J N, Wang Y, Xia Q F and Zhang B in *Intermetallics* 2001, 9, 369. However, the first long term soaking temperature has to be as close to the alpha transus temperature as possible in order to minimise the soaking time. During the first long term soaking the original lamellar microstructure transforms into granular gamma and alpha with a high volume fraction of the alpha phase. The remaining gamma grains act as pinning points to prevent the rapid growth of alpha phase. The second short term soaking temperature has to be above the alpha transus temperature and as close as possible to the alpha transus temperature and the second short term soaking should be as short as possible. This heat treatment requires precision control and rapid heating to the second short term soaking temperature. The aim is to leave the titanium aluminide alloy in the alpha phase field for the shortest possible time to prevent excessive alpha grain growth but this is difficult to realise in a production environment.

[0005] Furthermore it is known to provide rapid heating at a rate of about $1500^{\circ}\text{C s}^{-1}$ to a temperature above the alpha transus temperature, a short holding of about 5 minutes at this temperature and normal cooling to produce a fully lamellar refined microstructure in a titanium aluminide alloy, as disclosed by Salishnov G A, Imayev R M, Kuznetsov A V, Shagiev M R, Imayev V M, Shenkov O N, Froes F H, In Kim Y W, Dumiduk D M, Loretto M H, editors of *Gamma Titanium Aluminides* 1999, Warrendale, PA: TMS, 1999, p291. However, the rapid heating rate required is difficult to achieve using a conventional furnace and the very short holding time is difficult to control. Additionally prolonged holding at a temperature above the alpha transus temperature results in rapid growth of alpha grains, which limits the use of this technique in industrial applications.

[0006] Accordingly the present invention seeks to provide a novel method of heat-treating titanium aluminide alloy which reduces, preferably overcomes, the above-mentioned problems.

[0007] Accordingly the present invention provides a method of heat-treating titanium aluminide alloy, the titanium aluminide alloy having a single alpha phase field and being capable of producing a massively transformed gamma microstructure, the method comprising the steps of

[0008] (a) heating a titanium aluminide alloy to a temperature above the alpha transus temperature,

[0009] (b) maintaining the titanium aluminide alloy at a temperature above the alpha transus temperature in the single alpha phase field for a predetermined time period,

[0010] (c) cooling the titanium aluminide alloy from the single alpha phase field to produce a massively transformed gamma microstructure,

[0011] (d) heating the titanium aluminide alloy to a temperature below the alpha transus temperature in the alpha and gamma phase field,

[0012] (e) maintaining the titanium aluminide alloy at the temperature below the alpha transus temperature for a predetermined time period to precipitate alpha plates in the massively transformed gamma microstructure such that a refined microstructure is produced in the titanium aluminide alloy,

[0013] (f) cooling the titanium aluminide alloy to ambient temperature.

[0014] Preferably in step (b) the predetermined time period is up to 2 hours.

[0015] Preferably in step (e) the predetermined time period is up to 4 hours.

[0016] Preferably step (d) comprises heating the titanium aluminide alloy to a temperature about 30°C . to 60°C . below the alpha transus temperature.

[0017] Preferably step (a) comprises heating the titanium aluminide alloy to a temperature of about 20°C . to 30°C . above the alpha transus temperature.

[0018] Preferably step (f) comprises air-cooling or furnace cooling.

[0019] Preferably step (c) comprises air-cooling or oil cooling.

[0020] Preferably the titanium aluminide alloy consists of at least 46 at % aluminium. The titanium aluminide alloy may comprise 48 at % aluminium, 2 at % chromium, 2 at % niobium and the balance titanium and incidental impurities.

[0021] The alpha transus temperature is about 1360°C ., step (a) comprises heating to a temperature of 1380°C ., step (b) comprises maintaining the titanium aluminide alloy at a temperature of about 1380°C . for about 1 hour, step (c) comprises oil cooling the titanium aluminide alloy from a temperature of 1380°C . to produce a massively transformed gamma microstructure, steps (d) and (e) comprise heating the titanium aluminide alloy to a temperature of about 1320°C . for about 2 hours to precipitate alpha plates in the massively transformed gamma microstructure such that a refined microstructure is produced in the titanium aluminide alloy, and step (f) comprises air cooling the titanium aluminide alloy to ambient temperature.

[0022] The titanium aluminide alloy may comprise 46 at % aluminium, 8 at % niobium, up to 0.07 at % carbon and the balance titanium and incidental impurities.

[0023] The alpha transus temperature is about 1335° C., step (a) comprises heating to a temperature of 1360° C., step (b) comprises maintaining the titanium aluminide alloy at a temperature of about 1360° C. for about 1 hour, step (c) comprises oil cooling, or air cooling, the titanium aluminide alloy from a temperature of 1360° C. to produce a massively transformed gamma microstructure, steps (d) and (e) comprise heating the titanium aluminide alloy to a temperature of about 1300° C. for about 4 hours to precipitate alpha plates in the massively transformed gamma microstructure such that a refined microstructure is produced in the titanium aluminide alloy, and step (f) comprises air cooling the titanium aluminide alloy to ambient temperature.

[0024] The present invention is applicable to a gamma titanium aluminide alloy consisting of 45-46 at % aluminium, 8 at % niobium, up to 0.07 at % carbon and the balance titanium and incidental impurities, for example 45.5 at % aluminium, 8 at % niobium and the balance titanium and incidental impurities. The present invention is also applicable to a gamma titanium aluminide alloy consisting of 45-46 at % aluminium, 2-6 at % niobium, 2-6 at % hafnium and the balance titanium and incidental impurities, for example 46 at % aluminium, 4 at % niobium, 4 at % hafnium and the balance titanium and incidental impurities.

[0025] The titanium aluminide alloy may be a cast titanium aluminide component.

[0026] The method may comprise hot isostatic pressing of the cast titanium aluminide alloy component.

[0027] Preferably the hot isostatic pressing of the cast titanium aluminide alloy component is concurrent with step (e).

[0028] Preferably the hot isostatic pressing comprises applying a pressure of about 150 Mpa for about 4 hours.

[0029] The titanium aluminide alloy may be a compressor blade or a compressor vane.

[0030] The present invention will be more fully described by way of example with reference to the accompanying drawings in which:—

[0031] FIG. 1 is graph of temperature versus time illustrating the method of heat-treating a titanium aluminide alloy according to the present invention.

[0032] FIG. 2 is a schematic view of the microstructure of a titanium aluminide alloy heat treated according to the present invention.

[0033] FIG. 3 is a view of the microstructure of a titanium aluminide alloy heat treated according to the present invention.

[0034] FIG. 4 is a schematic view of the microstructure of a titanium aluminide alloy heat treated according to the prior art.

[0035] FIG. 5 is a gamma titanium aluminide alloy gas turbine engine compressor blade heat treated according to the present invention.

[0036] A method of heat-treating a titanium aluminide alloy according to the present invention is described with reference to FIG. 1. The present invention is concerned with heat-treating gamma titanium aluminide alloys with at least 46 at % aluminium and a single alpha phase field.

[0037] The heat treatment process comprises heating the gamma titanium aluminide to a temperature T_1 above the alpha transus temperature T_α . The gamma titanium aluminide alloy is then maintained at a temperature T_1 above the alpha transus temperature T_α in the single alpha phase field for a predetermined time period t_1 . The gamma titanium aluminide is quenched, for example air cooled, or oil cooled, from the single alpha phase field at temperature T_1 to produce a massively transformed gamma microstructure. The gamma titanium aluminide alloy is then heated to a temperature T_2 below the alpha transus temperature T_α . The gamma titanium aluminide alloy is maintained at the temperature T_2 in the alpha and gamma phase field for a predetermined time period t_2 to precipitate alpha plates in the massively transformed gamma microstructure such that a refined microstructure is produced in the titanium aluminide alloy. The gamma titanium aluminide is cooled, for example air cooled, or furnace cooled, to ambient temperature.

[0038] FIG. 2 illustrates a very fine duplex microstructure of a gamma titanium aluminide alloy treated according to the present invention. In the present invention differently orientated alpha plates precipitated in a massive gamma phase matrix effectively reduce the grain size of the gamma titanium aluminide alloy and these are produced by the massive gamma to alpha+gamma phase transformation.

[0039] For comparison FIG. 4 illustrates a coarse lamellar microstructure of a gamma titanium aluminide alloy treated according to a prior art method. In the prior art the coarse lamellar microstructure is produced by the alpha to alpha+gamma phase transformation.

[0040] In particular, the gamma titanium aluminide is heated to a temperature T_1 about 20° C. to 30° C. above the alpha transus temperature T_α . The gamma titanium aluminide alloy is maintained at the temperature T_1 for up to 2 hours. The gamma titanium aluminide alloy is then quenched, for example air cooled, or oil cooled, at a rate sufficient to induce a massively transformed gamma microstructure. The gamma titanium alloy is heated to a temperature T_2 about 30° C. to 60° C. below the alpha transus temperature T_α . The gamma titanium aluminide alloy is maintained at the temperature T_2 for up to 4 hours to precipitate fine alpha plates with different orientations in the massively transformed gamma microstructure due to the massive gamma to alpha+gamma phase transformation. This gives rise to a very fine duplex microstructure. The differently orientated alpha plates precipitated in the massive gamma phase matrix effectively reduce the grain size of the gamma titanium aluminide. The gamma titanium aluminide alloy is then cooled, for example air cooled, or furnace cooled, to ambient temperature.

[0041] The holding at temperature T_1 for a time period t_1 also acts a homogenisation process for cast titanium aluminide alloys.

EXAMPLE 1

[0042] A gamma titanium aluminide alloy consisting of 48 at % aluminium, 2 at % chromium, 2 at % niobium and the

balance titanium plus incidental impurities was heat treated according to the present invention. This gamma titanium aluminide alloy has an alpha transus temperature $T_{\alpha}=1360^{\circ}$ C. The gamma titanium aluminide alloy was heated to a temperature $T_1=1380^{\circ}$ C. and was held at $T_1=1380^{\circ}$ C. for 1 hour. The gamma titanium aluminide alloy was oil cool quenched. The gamma titanium aluminide alloy was heated to a temperature $T_2=1320^{\circ}$ C. and was held at $T_2=1320^{\circ}$ C. for 2 hours. The gamma titanium aluminide alloy was air cooled to ambient temperature. The microstructure of the gamma titanium aluminide alloy is shown in **FIG. 3**.

EXAMPLE 2

[0043] A gamma titanium aluminide alloy consisting of 46 at % aluminium, 8 at % niobium, up to 0.07 at % carbon and the balance titanium plus incidental impurities was heat treated according to the present invention. This gamma titanium aluminide alloy has an alpha transus temperature $T_{\alpha}=1335^{\circ}$ C. The gamma titanium aluminide alloy was heated to a temperature $T_1=1360^{\circ}$ C. and was held at $T_1=1360^{\circ}$ C. for 1 hour. The gamma titanium aluminide alloy was oil quenched. The gamma titanium aluminide alloy was heated to a temperature $T_2=1300^{\circ}$ C. and was held at $T_2=1300^{\circ}$ C. for 4 hours. The gamma titanium aluminide alloy was air cooled to ambient temperature.

[0044] The present invention is applicable to a gamma titanium aluminide alloy consisting of 46 at % aluminium, 5 at % niobium, 0.3 at % boron, 0.2 at % carbon and the balance titanium plus incidental impurities. The present invention is applicable to a gamma titanium aluminide alloy consisting of 47 at % aluminium, 2 at % niobium, 1 at % tungsten, 1 at % chromium, 1 at % boron, 0.2 at % silicon and the balance titanium plus incidental impurities. The present invention is applicable to gamma titanium aluminide alloy consisting of 47 at % aluminium, 2 at % tantalum, 1 at % chromium, 1 at % manganese, 1 at % boron, 0.2 at % silicon and the balance titanium plus incidental impurities. The present invention is also applicable to gamma titanium aluminide alloy consisting of 46 at % aluminium, 5 at % niobium, 1 at % tungsten and the balance titanium plus incidental impurities.

[0045] The present invention is applicable to a gamma titanium aluminide alloy consisting of 45-46 at % aluminium, 8 at % niobium, up to 0.07 at % carbon and the balance titanium and incidental impurities, for example 45.5 at % aluminium, 8 at % niobium and the balance titanium and incidental impurities. The present invention is also applicable to a gamma titanium aluminide alloy consisting of 45-46 at % aluminium, 2-6 at % niobium, 2-6 at % hafnium and the balance titanium and incidental impurities, for example 46 at % aluminium, 4 at % niobium, 4 at % hafnium and the balance titanium and incidental impurities.

[0046] The present invention may be used to refine the microstructure of titanium aluminide alloys without the need for hot working. The present invention has the advantage of simplicity and practicality over the prior art previously discussed. The heat treatment at temperature T_1 for time t_1 in the single alpha phase field and does not have a rigid holding time and this allows the process to be carried out in conventional heat treatment facilities. The gamma titanium aluminide alloys must be capable of producing massively transformed gamma microstructures. The cooling rate dur-

ing the quenching is not excessive and most gamma titanium aluminide alloys with at least 46 at % aluminium and with at least 4 at % refractory alloying elements may be quenched in air or oil depending on the size of the gamma titanium aluminide alloy component. This significantly reduces the possibility of cracking of the gamma titanium aluminide alloy component during quenching. The temperature range for heat treatment at temperature T_2 for time t_2 is relatively wide and is not close to the alpha transus temperature T_{α} , which reduces the technical requirement of the heat treatment facilities and makes the heat treatment process easier. The present invention is particularly useful for gamma titanium aluminide alloy castings in which hot working is not possible. The present invention refines the microstructure of gamma titanium aluminide alloy castings and reduces the scatter in mechanical properties and improves the room temperature ductility.

[0047] In the case of cast gamma titanium aluminide alloy components it may be necessary to remove porosity from the cast gamma titanium aluminide alloy component. In this case the cast gamma titanium aluminide alloy component may be hot isostatically pressed (HIP) to remove the porosity. The hot isostatic pressing preferably occurs at the same time as the heat treatment temperature T_2 and for the time period of about 4 hours at a pressure of about 150 Mpa and this is beneficial because this dispenses with the requirement for a separate hot isostatic pressing step.

[0048] The present invention is particularly suitable for gamma titanium aluminide gas turbine engine compressor blades as illustrated in **FIG. 5**. The compressor blade **10** comprises a root **12**, a shank **14**, a platform **16** and an aerofoil **18**. The present invention is also suitable for gamma titanium aluminide gas turbine engine compressor vanes or other gamma titanium aluminide gas turbine engine components. The present invention may also be suitable for gamma titanium aluminide components for other engine, machines or applications.

I claim:

1. A method of heat-treating a titanium aluminide alloy, the titanium aluminide alloy having a single alpha phase field and being capable of producing a massively transformed gamma microstructure, the method comprising the steps of

- (a) heating a titanium aluminide alloy to a temperature above the alpha transus temperature,
- (b) maintaining the titanium aluminide alloy at the temperature above the alpha transus temperature in the single alpha phase field for a predetermined time period,
- (c) cooling the titanium aluminide alloy from the single alpha phase field to produce a massively transformed gamma microstructure,
- (d) heating the titanium aluminide alloy to a temperature below the alpha transus temperature in the alpha and gamma phase field,
- (e) maintaining the titanium aluminide alloy at the temperature below the alpha transus temperature for a predetermined time period to precipitate alpha plates in

the massively transformed gamma microstructure such that a refined microstructure is produced in the titanium aluminide alloy,

(f) cooling the titanium aluminide alloy to ambient temperature.

2. A method as claimed in claim 1 wherein in step (b) the predetermined time period is up to 2 hours.

3. A method as claimed in claim 1 wherein in step (e) the predetermined time period is up to 4 hours.

4. A method as claimed in claim 1, wherein step (d) comprises heating the titanium aluminide alloy to a temperature about 30° C. to 60° C. below the alpha transus temperature.

5. A method as claimed in claim 1 wherein step (a) comprises heating the titanium aluminide alloy to a temperature of about 20° C. to 30° C. above the alpha transus temperature.

6. A method as claimed in claim 1 wherein step (f) comprises air-cooling or furnace cooling.

7. A method as claimed in claim 1 wherein step (c) comprises air-cooling or oil cooling.

8. A method as claimed in claim 1 wherein the titanium aluminide alloy consists of at least 46 at % aluminium.

9. A method as claimed in claim 8 wherein the titanium aluminide alloy comprises 48 at % aluminium, 2 at % chromium, 2 at % niobium and the balance titanium and incidental impurities.

10. A method as claimed in claim 9 wherein the alpha transus temperature is about 1360° C., step (a) comprises heating to a temperature of 1380° C., step (b) comprises maintaining the titanium aluminide alloy at a temperature of about 1380° C. for about 1 hour, step (c) comprises oil cooling the titanium aluminide alloy from a temperature of 1380° C. to produce a massively transformed gamma microstructure, steps (d) and (e) comprise heating the titanium aluminide alloy to a temperature of about 1320° C. for about 2 hours to precipitate alpha plates in the massively transformed gamma microstructure such that a refined microstructure is produced in the titanium aluminide alloy, and step (f) comprises air cooling the titanium aluminide alloy to ambient temperature.

11. A method as claimed in claim 8 wherein the titanium aluminide alloy comprises 46 at % aluminium, 8 at % niobium, up to 0.07 at % carbon and the balance titanium and incidental impurities.

12. A method as claimed in claim 11 wherein the alpha transus temperature is about 1335° C., step (a) comprises heating to a temperature of 1360° C., step (b) comprises maintaining the titanium aluminide alloy at a temperature of about 1360° C. for about 1 hour, step (c) comprises oil cooling, or air cooling, the titanium aluminide alloy from a temperature of 1360° C. to produce a massively transformed gamma microstructure, steps (d) and (e) comprise heating the titanium aluminide alloy to a temperature of about 1300° C. for about 4 hours to precipitate alpha plates in the massively transformed gamma microstructure such that a refined microstructure is produced in the titanium aluminide alloy, and step (f) comprises air cooling the titanium aluminide alloy to ambient temperature.

13. A method as claimed in claim 1 wherein the titanium aluminide alloy consists of 45-46 at % aluminium, 8 at % niobium, up to 0.07 at % carbon and the balance titanium and incidental impurities.

14. A method as claimed in claim 1 wherein the titanium aluminide alloy consists of 45-46 at % aluminium, 2-6 at % niobium, 2-6 at % hafnium and the balance titanium plus incidental impurities.

15. A method as claimed in claim 14 wherein the titanium aluminide alloy consists of 46 at % aluminium, 4 at % niobium, 4 at % hafnium and the balance titanium plus incidental impurities.

16. A method as claimed in claim 1 wherein the titanium aluminide alloy is a cast titanium aluminide alloy component.

17. A method as claimed in claim 16 comprising hot isostatic pressing of the cast titanium aluminide alloy component.

18. A method as claimed in claim 17 wherein the hot isostatic pressing of the cast titanium aluminide alloy component is concurrent with step (e).

19. A method as claimed in claim 18 wherein the hot isostatic pressing comprises applying a pressure of about 150 MPa for about 4 hours.

20. A method as claimed in claim 1 wherein the titanium aluminide alloy is a compressor blade or a compressor vane.

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