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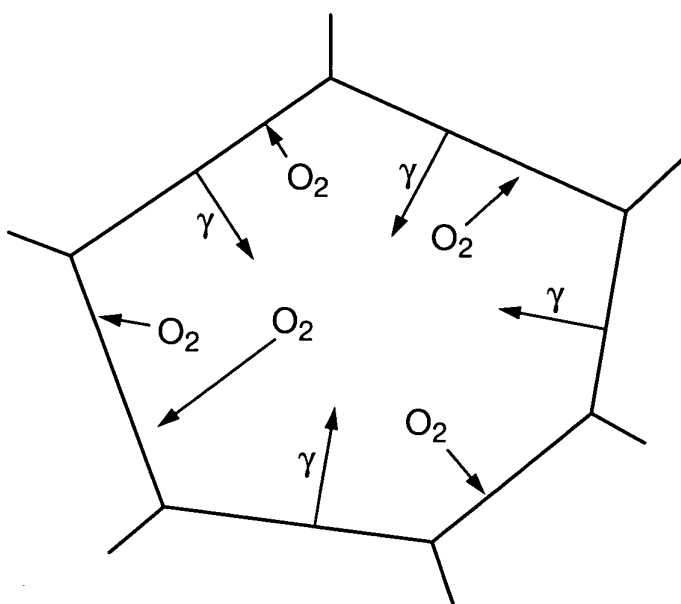
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(54) **An alloy and method of treating titanium aluminide**

(57) A method of treating a titanium aluminide alloy having a single alpha phase field and being capable of producing a massively transformed gamma microstructure by subjecting the alloy to a temperature cycle that

produces the massively transformed microstructure having a refined microstructure; the method being characterised in that oxygen securing means are provided within the alloy to prevent diffusion of oxygen to the grain boundary.

Fig.3.



Description

[0001] The present invention relates to an alloy and a method of improving massive transformation in gamma titanium aluminide.

[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.

[0003] Our published European patent application EP1378582A1 discloses a method of heat-treating a titanium aluminide alloy having a single alpha phase field and being capable of producing a massively transformed gamma microstructure. In that method of heat-treating the titanium aluminide alloy is heated to a temperature above the alpha transus temperature, is maintained above the alpha transus temperature in the single alpha phase field for a predetermined time period, is cooled from the single alpha phase field to ambient temperature to produce a massively transformed gamma microstructure, is heated to a temperature below the alpha transus temperature in the alpha and gamma phase field, is maintained 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 and is then cooled to ambient temperature.

[0004] A problem with this heat-treatment is that the normal rapid cooling or quenching, of the titanium aluminide from above the alpha transus to ambient temperature induces quenching stresses in the titanium aluminide. The quenching stresses may result in cracking, particularly of castings. A further problem is that the heat-treatment is only suitable for relatively thin castings due to limiting cross-section.

[0005] Cracking during cooling or quenching from above the alpha transus temperature, is related to both cooling rate and the dimensions of the titanium aluminide casting. Generally, cracking is promoted by relatively high cooling rates, by relatively large dimension castings and by large differences in cross section.

[0006] However, the cooling rate also affects the massive transformation of the gamma titanium aluminide. If the quench is too fast then the microstructure will remain as retained alpha phase, too slow and the alloy will precipitate gamma grains.

[0007] It has now been found that with conventional massively transformed alloys there can be areas with little transformation at the grain boundary. This discovery is surprising as it is believed that the massive phase transformation starts at the grain boundary and grows into the centre of the grain.

[0008] Such discontinuity within the grain is undesirable as it affects the properties of the alloy, giving areas of reduced ductility.

[0009] It is an object of the present invention to seek to provide an improved alloy and an improved method of producing a massively transformed alloy of titanium aluminide.

[0010] It is a further object of the present invention to seek to provide an improved method of producing a massively transformed gamma titanium aluminide from an alloy containing greater quantities of dispersed oxygen.

[0011] According to a first aspect of the invention there is provided a method of enhancing massive transformation of a titanium aluminide alloy having a single alpha phase field by incorporating into the alloy up to 0.5 at% of oxygen scouring means which inhibits diffusion of oxygen within the alpha phase field to the grain boundary as the alloy is subjected to a temperature cycle which produces a massively transformed gamma microstructure.

[0012] Preferably the oxygen scouring means is incorporated up to 0.2 at%.

[0013] Preferably the temperature cycle comprises the steps a) heating the titanium aluminide alloy to a temperature above the alpha transus temperature, b) maintaining the titanium aluminide alloy at a temperature above the alpha transus temperature for a predetermined time period, c) cooling the titanium aluminide alloy from the single alpha phase field to produce a massively transformed gamma microstructure.

[0014] The heat treatment may further comprise the step of d) heating the titanium aluminide to a temperature below the alpha transus temperature in the alpha and gamma phase field, e) maintaining the titanium aluminide 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, and f) cooling the titanium aluminide to ambient temperature.

[0015] Preferably the oxygen securing means is yttrium. Preferably the alloy consists at least 43at% aluminium, 0 to 9at% niobium, 0 to 10at% tantalum, 0.01 to 0.15at% yttrium, the balance being titanium plus incidental impurities.

[0016] Step c) may comprise cooling the titanium aluminide to ambient temperature. The titanium aluminide may be cooled by gas cooling, oil cooling, fluidised bed cooling or salt cooling.

[0017] Step c) may comprise cooling the titanium aluminide at a cooling rate of $4^{\circ}\text{C. S}^{-1}$ to $150^{\circ}\text{C. S}^{-1}$.

[0018] Preferably the titanium aluminide alloy is a cast titanium aluminide component.

[0019] The method may further comprise the step of hot isostatic pressing the cast titanium aluminide component.

[0020] Preferably the titanium aluminide alloy provides a compressor or turbine blade or vane.

[0021] According to a second aspect of the invention there is provided an alloy consisting of 43at% to 50at% aluminium, 0 to 9at% niobium, 0 to 10at% tantalum, 0.01 to 0.15at% yttrium, the balance being titanium plus incidental impurities.

[0022] Preferably the alloy consists of 45 to 46 at% aluminium, 7 to 9 at% niobium, 0.02 to 0.15 at% yttrium, the balance being titanium plus incidental impurities.

[0023] Preferably the niobium plus tantalum is less than or equal to 10 at%.

[0024] The titanium aluminide alloy may be a cast titanium aluminide component.

[0025] The invention will now be described by way of example only with reference to the accompanying drawings in which:

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

Fig. 2 is a schematic view of the microstructure of a titanium aluminide alloy according to the present invention

Fig. 3 is a schematic view depicting O₂ diffusion to the grain boundary.

Fig. 4 is a schematic of gamma phase transformation with scoured oxygen.

Fig. 5 is a gamma titanium aluminide alloy gas turbine engine compressor blade according to the present invention.

[0026] A method of heat-treating a titanium aluminide alloy is described with reference to Fig. 1. 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.

[0027] With the alloys described in EP1378582A1 it has been found that in some cases there can be areas with little transformation at the grain boundary - only inside the grain is transformed. This discovery was surprising as massive phase transformation normally starts at the grain boundary and precipitates to the centre of the grain.

[0028] It has now been found that within the grain dissolved oxygen diffuses to the grain boundary during the quench stage, rather than remaining dispersed within the grain, to provide concentrations at the boundary that are sufficiently high such that nucleation of the massive transform is prevented and consequently massive transformation throughout the grain is inhibited. Such a process is depicted schematically in Figure 3.

[0029] The diffusion has been found to occur even at low concentrations of around 500 to 1500 ppm dissolved oxygen, which means that even at overall low concentrations within the grain quite high concentrations at the grain boundary can be observed sufficient to inhibit massive transformation. Where the quench rate is slower, for example to avoid cracking of the cast component, the relative oxygen diffusion is greater with more of the dissolved oxygen being given time to diffuse to the grain boundary. Consequently the overall inhibition of massive transformation may be greater.

[0030] In the present invention a cast component is formed from an alloy having 45.5at% aluminium, 8at% niobium, 0.1at% yttrium and the balance titanium plus incidental impurities. The yttrium combines with dissolved oxygen at the casting solidification stage to form yttria.

[0031] The cast alloy is heat treated by a process comprising heating the titanium aluminide to a temperature T_1 above the alpha transus temperature T_α . The titanium aluminide alloy is maintained at the temperature T_1 in the single alpha phase field for a predetermined time period t_1 , up to 2 hours. T_1 is about 20°C to 30°C above the alpha transus temperature T_α , which is about 1300°C. By holding at temperature T_1 for a period t_1 the cast titanium aluminide alloys are homogenised.

[0032] The titanium aluminide is quenched by, for example fluidised bed, salt bath or air cooling, from the single alpha phase field at temperature T_1 to a temperature T_2 . As depicted in Figure 4, the yttrium scours the oxygen as yttria within the grain and prevents it diffusing to the grain boundary during the quench process, which keeps the dissolved oxygen content at the grain boundary low and particularly below concentrations that inhibit massive transformation.

[0033] Since the oxygen is secured the quench rate can be slower as build-up of oxygen at the grain boundary is prevented. A more complete massive transformation is achieved and the risk of component cracking significantly reduced.

[0034] Temperature T_2 is preferably ambient, but may be a temperature in the range 900°C to 1200°C. Following the cool or quench the titanium aluminide alloy is heated to a temperature of about 1250°C to about 1290°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. The precipitated alpha plates have different orientations within the massively transformed microstructure which gives rise to a very fine duplex microstructure.

[0035] Such a microstructure is depicted schematically in Figure 2. 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.

[0036] The present invention is applicable generally to gamma titanium aluminide alloys having at least 43at%

aluminium, 0 to 9at% niobium, 0 to 10% tantalum and 0.01 to 0.15at% yttrium with the balance being titanium plus incidental impurities. The gamma titanium aluminide alloy must have a single alpha phase field, the alloy must have a massive phase transformation normally requiring high aluminium concentration.

[0037] Other oxygen scouring materials e.g. hafnium may be used within the current alloy either in place of, or in combination with the yttrium. Low quantities of the scouring medium are required to avoid a reduction in the qualities of the alloy. For example, higher quantities [above what level?] of the scouring material can cause the formation of large oxide particles which are detrimental to mechanical properties such as fatigue and ductility.

[0038] The advantages of the present invention are that the limitation of oxygen diffusion allows the quench to be performed at slower rate as less oxygen can migrate to the grain boundary and allows the alloy to be cast in both thick and thin sections. Quench rate is generally faster at the surface of the component and slower within the body of the component. Thicker sections are enabled as within the body the oxygen migration to the grain boundary is reduced over the longer quench time. The enabled slower cooling rate also allows the gamma titanium aluminide to be grain refined with reduced likelihood of cracking, distortion and potential scrap rates.

[0039] Casting is an economically competitive manufacturing route but its commercial use is dependent on grain refinement which can be achieved from the massive transformation that is applied by quenching current gamma titanium aluminide alloys. This is a problem for large components of variable cross section as cracking is likely to occur and the transformation may not extend to the centre of the section where the cooling rate is much smaller.

[0040] Additionally, by limiting the oxygen diffusion to the grain boundary more of the alloy will be massively transformed. Beneficially, the invention allows the use of alloys that have a higher initial dissolved oxygen content than previously. The invention opens the possibility of being able to reuse recycled material.

[0041] The advantage of this invention lies in the ease of application of the air cool and ageing process to give a strong, ductile material through a small addition to the alloy composition. The ability to soak in the single alpha phase field with an unrestricted holding time allow this process to be carried out in normal heat treatment facilities and it also acts as a homogenisation treatment when applied to cast TiAl alloys. The low cooling rate requirement in air lowers the possibility of cracking and distortion of the component.

[0042] It may be necessary to remove porosity from the cast titanium aluminide alloy component. In this case the cast alloy may be hot isostatically pressed (HIP). The HIP process may occur before the alloy is heat treated, or more preferably it occurs at the same time as the alloy is aged after quenching. This is beneficial because it dispenses with the requirement for a separate HIP step.

[0043] The present invention is particularly suitable for gamma titanium aluminide gas turbine engine compressor blades as illustrated in Figure 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 engines, machines or applications.

Claims

1. A method of enhancing massive transformation of a titanium aluminide alloy having a single alpha phase field **characterised in that** up to 0.5 at% of oxygen scouring means is incorporated into the alloy which inhibits diffusion of oxygen within the alpha phase field to the grain boundary as the alloy is subjected to a temperature cycle which produces a massively transformed gamma microstructure.
2. A method according to claim 1, wherein the oxygen scouring means is incorporated up to 0.2 at%.
3. A method according to claim 1 or claim 2, wherein the temperature cycle comprises the steps a) heating the titanium aluminide alloy to a temperature above the alpha transus temperature, b) maintaining the titanium aluminide alloy at a temperature above the alpha transus temperature for a predetermined time period, c) cooling the titanium aluminide alloy from the single alpha phase field to produce a massively transformed gamma microstructure.
4. A method according to claim 3, wherein the heat treatment further comprises the step of d) heating the titanium aluminide to a temperature below the alpha transus temperature in the alpha and gamma phase field, e) maintaining the titanium aluminide 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, and f) cooling the titanium aluminide to ambient temperature.
5. A method according to any preceding claim, wherein the oxygen securing means is selected from the group comprising yttrium and hafnium.
6. A method according to any preceding claim, wherein the alloy consists at least 43at% aluminium, 0 to 9at% niobium, 0 to 10at% tantalum, 0.01 to 0.15at% yttrium, the balance being titanium plus incidental impurities.

7. A method according to any preceding claim, wherein step c) comprises cooling the titanium aluminide to ambient temperature.
8. A method according to any preceding claim, wherein the titanium aluminide is cooled by gas cooling, oil cooling, fluidised bed cooling or salt cooling. 5
9. A method according to any preceding claim, wherein step c) comprises cooling the titanium aluminide at a cooling rate of $4^{\circ}\text{C}.\text{S}^{-1}$ to $150^{\circ}\text{C}.\text{S}^{-1}$. 10
10. A method as claimed in any of claims 1 to 9, wherein the titanium aluminide alloy is a cast titanium aluminide component. 15
11. A method as claimed in claim 10, wherein the method further comprises the step of hot isostatic pressing the cast titanium aluminide component. 20
12. A method as claimed in any preceding claim, wherein the titanium aluminide alloy provides a compressor blade or a compressor vane.
13. An alloy consisting of 43 to 50 at% aluminium, 0 to 9 at% niobium, 0 to 10 at% tantalum, 0.01 to 0.2 at% of yttrium and/or hafnium, the balance being titanium plus incidental impurities. 25
14. An alloy according to claim 13, consisting of 45 to 46 at% aluminium, 7 to 9 at% niobium, 0.02 to 0.15 at% yttrium, the balance being titanium plus incidental impurities. 30
15. An alloy according to claim 13 or claim 14, wherein the niobium plus tantalum is less than or equal to 10at%. 35
16. An alloy claimed in any of claims 13 to 15, wherein the titanium aluminide alloy is a cast titanium aluminide component. 40

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Fig.1.

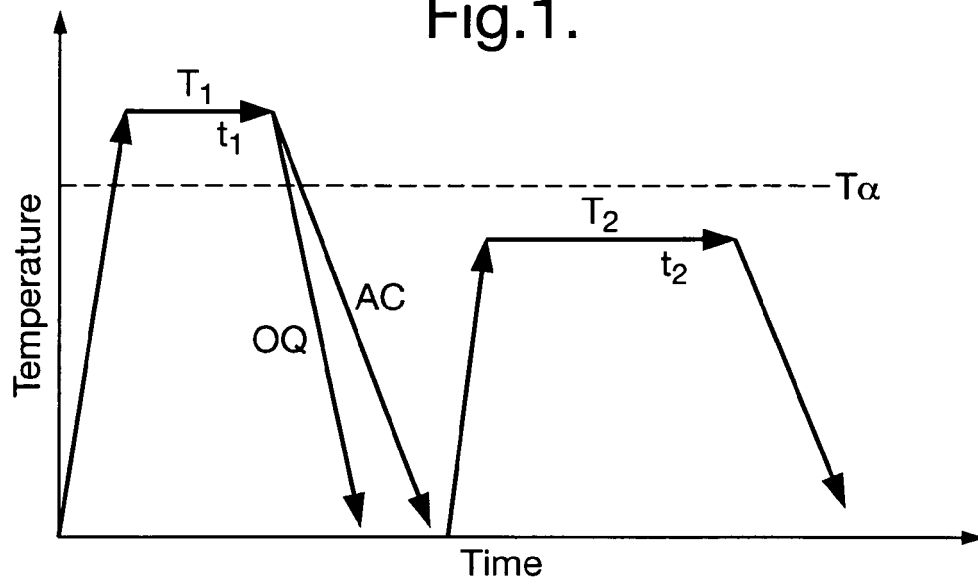


Fig.2.

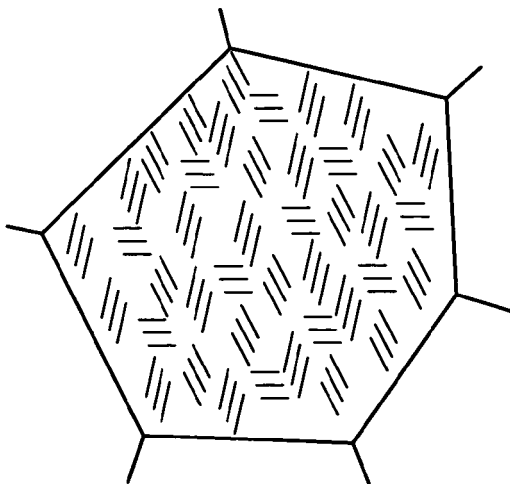


Fig.5.

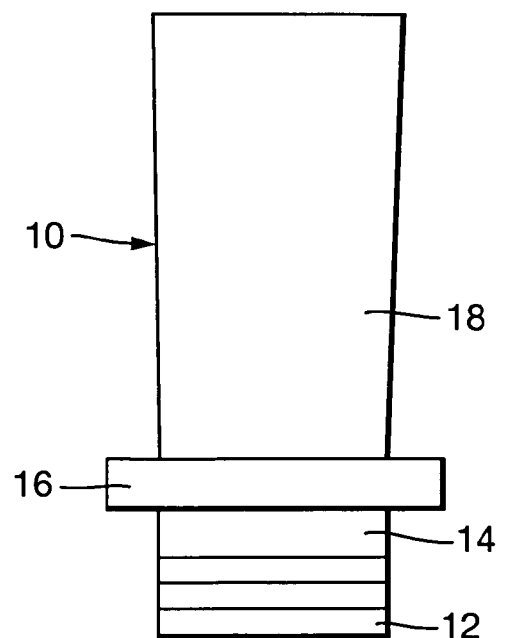


Fig.3.

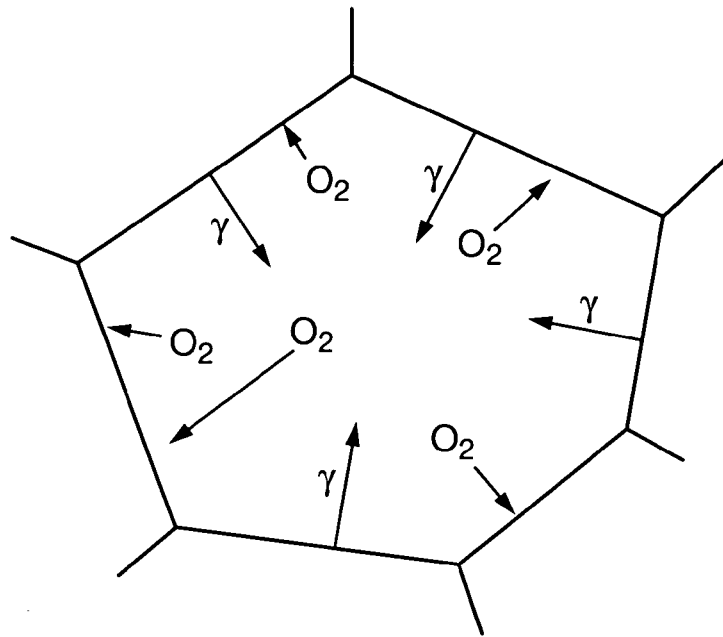
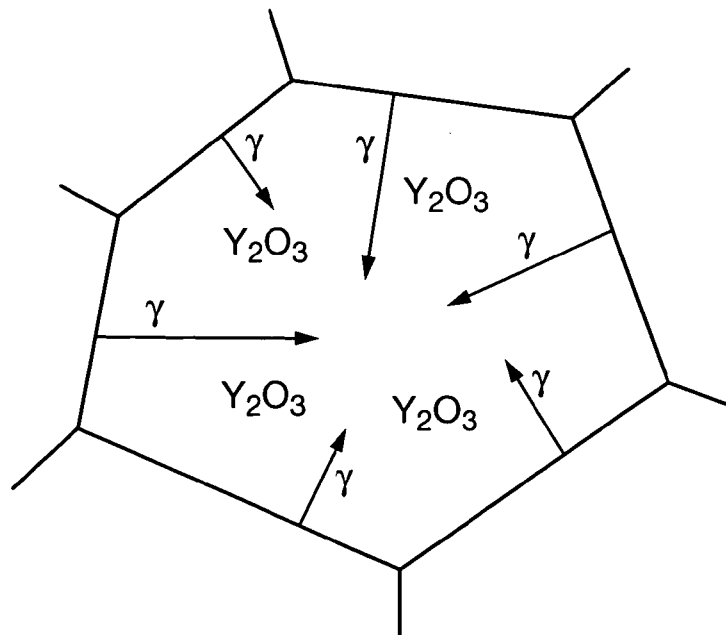


Fig.4.



REFERENCES CITED IN THE DESCRIPTION

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