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(54) **Grain refinement of titanium alloys**

(57) A process for casting titanium alloy based parts includes the steps of melting a quantity of titanium alloy to form a molten titanium alloy; adding to the molten titanium alloy a quantity of boron in an amount of about 0.2 weight percent to about 1.3 weight percent of the molten titanium alloy to form a molten boron modified titanium alloy; and casting a boron modified titanium alloy based part.

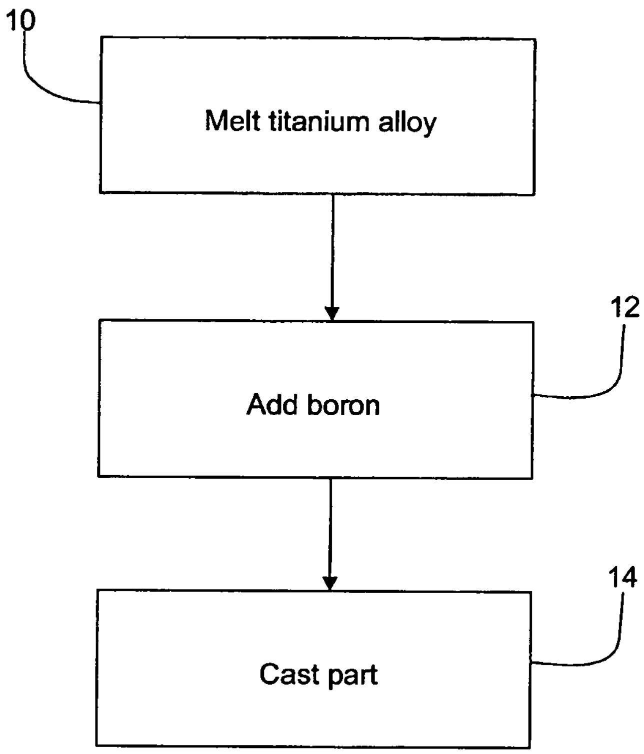

FIG. 1

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Description

[0001] This invention relates to titanium alloys and, more particularly, to the grain refinement of titanium alloys.

[0002] Grain refinement of TiAl-based and Ti-based alloys has been a priority in the manufacture of parts for use in the aerospace industry. Prior to modifying Ti-based alloys with boron, TiAl-based alloys were modified using boron additions. Like Ti-based alloys, TiAl-based alloys possess a boron solubility level where borides begin forming above certain boron concentrations. In a publication authored by T.T. Cheng entitled, "The Mechanism of Grain Refinement in TiAl Alloys by Boron Addition - An Alternative Hypothesis", the effect of boron additions on the as-cast structure of TiAl-based alloys of the general formula Ti-44Al-8(Nb, Zr, Ta) was studied. At least two noteworthy results reported therein included (1) the addition of more than a critical level of boron leads to a refined grain structure with reduced segregation and a variety of different boride particles as observed previously in other TiAl-based alloys; (2) the critical level of boron is composition dependent with higher levels required for alloys which contain strong boride formers, such as Ta; and (3) alloys with boron contents close to the critical level can contain both unrefined and refined regions, the latter corresponding to the regions cooled most rapidly. These results were attributed to the renucleation in the constitutionally supercooled region ahead of the solidification front in the boron modified TiAl-based alloy.

[0003] Turning now to Ti-based alloys, the standard processing route for wrought titanium alloys is first via a billet conversion process of ingot followed typically by forging or ring-rolling to achieve a duplex microstructure of transformed beta with a grain size of 100-200 μm plus primary alpha (15-25% volume fraction) with a grain size of 20-50 μm. This rather coarse microstructure leads to poorer fatigue capabilities in wrought Ti-based alloys. Ti alloy products produced by casting processes have even coarser transformed beta grain size, such as 0.5 mm to 2 mm not being uncommon. In the Ti products produced by casting processes, prior attempts to refine grain size in order to improve fatigue properties were made by adding boron in amounts of 6 atomic percent to 9 atomic percent to molten titanium alloys prior to casting. However, it is recognized that such amount of boron modified Ti-based alloys also produce a coarse boride microstructure which would result in poor material properties. Based on these observations, Ti-based alloys apparently do not require boron additions significantly exceeding the critical level.

[0004] Therefore, there exists a need to further refine Ti-based alloys to produce a final microstructure of fully refined transformed beta grains or a duplex microstructure with refined transformed beta grains and fine primary alpha grains.

[0005] In accordance with one aspect of the present invention, a process for casting boron modified titanium alloy parts broadly comprises melting a quantity of titanium alloy to form a molten titanium alloy; adding to the molten titanium alloy a quantity of boron in an amount of about 0.2 weight percent to about 1.3 weight percent of the molten titanium alloy to form a molten boron modified titanium alloy; and casting a boron modified titanium alloy based part.

[0006] In accordance with another aspect of the present invention, a process for making wrought titanium alloy based parts broadly comprises melting a quantity of titanium alloy to form a molten titanium alloy; adding to the molten titanium alloy a quantity of boron in an amount of about 0.2 weight percent to about 1.3 weight percent of the molten titanium alloy to form a molten boron modified titanium alloy; casting a boron modified titanium alloy based ingot using the molten boron modified titanium alloy; processing the boron modified titanium alloy based ingot to form a boron modified titanium alloy based billet; processing the boron modified titanium alloy based billet to form a wrought titanium alloy based part.

[0007] In accordance with yet another aspect of the present invention, a titanium alloy broadly comprises about 0.2 weight percent to about 1.3 weight percent boron.

[0008] Certain preferred embodiments will now be described by way of example only and with reference to the accompanying drawings in which:

FIG. 1 is a flowchart representing an exemplary process for casting a boron modified titanium alloy based part; and

FIG.2 is a flowchart representing an exemplary process for making boron modified wrought titanium alloy based part.

[0009] Like reference numbers and designations in the various drawings indicate like elements.

[0010] The exemplary processes of the present invention refine the as-cast or forged grain structure of a titanium alloy through minor additions of boron in the melting stage. With a reduced grain size in the ingot form, the subsequent thermo-mechanical processing ("TMP"), such as converting to billet and then to forging, can be performed in either the beta or alpha plus beta phase fields to produce a final microstructure of fully refined transformed beta grains or a duplex microstructure with fully refined transformed beta grains with fine primary alpha grains. These microstructure refinements improve the fatigue and strength capabilities of the titanium alloy. Furthermore, since the as-cast grain structure may be refined, boron modified titanium alloy based parts may be produced via a casting process.

[0011] Referring now to FIG. 1, a flowchart representing an exemplary process for casting a boron modified titanium alloy based part is shown. A solid titanium alloy may be melted to form molten titanium alloy using techniques known to one of ordinary skill in the art at a step 10. Titanium alloys commonly utilized in the aerospace industry include, but are not limited to, Ti-5.8Al-4Sn-3.5Zr-0.7Nb-0.5Mo-0.35Ti-0.06C commercially available as IMI834 from IMI Titanium Ltd., London, United Kingdom; Ti-6Al-4V; Ti-6A1-2Sn-4Zr-2Mo; Ti-6A1-2Sn-4Zr-6Mo, and the like.

[0012] A quantity of boron sufficient to impart the desired grain refinement may be added to any suitable molten titanium alloy at a step 12. The amount of boron added is preferably tailored to the boron solubility of the molten titanium alloy. Each titanium alloy possesses a boron solubility value, which influences the quantity of boron that may be added. Generally, the solubility of boron in titanium may be less than about 0.05 weight percent of titanium. The quantity of boron typically added is about 0.2 weight percent to about 1.3 weight percent of the molten titanium alloy. Suitable boron sources may include, but are not limited to, AlB_{12}, TiB_2, TiB, combinations comprising at least one of the foregoing, and the like. The molten boron-modified titanium alloy may then be cast at a step 14 to form the desired part, component, etc. The resultant boron-modified titanium alloy may comprise the aforementioned titanium alloys and about 0.2 weight percent to about 1.3 weight percent of boron in the form of at least one boride or dissolved boron, or both borides and dissolved boron.

[0013] The minor addition of boron in the melting stage refines the as-cast or forged grain structure of the titanium alloy. With a reduced grain size in the ingot form, the subsequent thermo-mechanical processing ("TMP"), such as converting to billet and then to forging, can be performed in either the beta or alpha plus beta phase fields to produce a final microstructure of fully refined transformed beta grains or a duplex microstructure with fully refined transformed beta grains with fine primary alpha grains. These microstructure refinements improve the fatigue and strength capabilities of the titanium alloy. Furthermore, since the as-cast grain structure may be refined, boron modified titanium alloy based parts may be produced via a casting process.

[0014] Referring now to FIG. 2, an exemplary process for forging a boron modified titanium based part is shown. Any suitable titanium alloy composition may be melted to form a molten titanium alloy using techniques known to one of ordinary skill in the art at a step 20. As described, a quantity of boron sufficient to impart the desired grain refinement, and preferably tailored to the boron solubility of the molten titanium alloy, may be added to the molten titanium alloy at a step 22. The boron modified titanium alloy may then be cast into an ingot at a step 24 using any one of a number of techniques known to one of ordinary skill in the art. In order to form a wrought part, the cast ingot may undergo a primary processing technique to form a billet at a step 26 as known to one of ordinary skill in the art. The billet composed of the boron modified titanium alloy may then undergo a secondary processing technique at a step 28 to further refine the grain microstructure of the titanium alloy as known to one of ordinary skill in the art. Lastly, the processed billet may be forged to form a wrought part, or "mill product", at a step 30 using any one of a number of techniques known to one of ordinary skill in the art.

[0015] One or more embodiments of the present invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the scope of the invention. Accordingly, other embodiments are within the scope of the following claims.

Claims

1. A process for casting boron modified titanium alloy based parts, comprising:

melting a quantity of titanium alloy to form a molten titanium alloy;
adding to said molten titanium alloy a quantity of boron in an amount of about 0.2 weight percent to about 1.3 weight percent of said molten titanium alloy to form a molten boron modified titanium alloy; and
casting a boron modified titanium alloy based part.

2. The process of claim 1, wherein adding further comprises forming said molten boron modified titanium alloy containing at least one boride particle in a solute form.

3. The process of either of claims 1 or 2, wherein adding comprises adding at least one of: AlB_{12}, TiB_2 and TiB.

4. The process of any of claims 1, 2 or 3, wherein melting comprises melting at least one of:

Ti- 5.8Al- 4Sn- 3.5Zr- 0.7Nb- 0.5Mo- 0.35Ti- 0.06C;
Ti-6Al-4V;
Ti-6Al-2Sn-4Zr-2Mo; and
Ti-6Al-2Sn-4Zr-6Mo.

5. A process for making wrought titanium alloy based parts, comprising:

melting a quantity of titanium alloy to form a molten titanium alloy;
adding to said molten titanium alloy a quantity of boron in an amount of about 0.2 weight percent to about 1.3 weight percent of said molten titanium alloy to form a molten boron modified titanium alloy;
casting a boron modified titanium alloy based ingot using said molten boron modified titanium alloy;
processing said boron modified titanium alloy

based ingot to form a boron modified titanium alloy based billet;
processing said boron modified titanium alloy based billet to form a wrought titanium alloy based part.

6. The process of claim 5, wherein melting comprises melting Ti-6Al-2Sn-4Zr-6Mo.

7. The process of either of claims 5 or 6, wherein adding further comprises forming said molten boron modified titanium alloy containing at least one boride particle in a solute form.

8. The process of any of claims 5, 6 or 7, wherein adding comprises adding at least one of: AlB_{12}, TiB_2 and TiB.

9. The process of any of claims 5 to 8, wherein melting comprises melting at least one of:

Ti- 5.8Al- 4Sn- 3.5Zr- 0.7Nb- 0.5Mo- 0.35Ti-0.06C;
Ti-6Al-4V;
Ti-6Al-2Sn-4Zr-2Mo; and
Ti-6Al-2Sn-4Zr-6Mo.

10. A titanium alloy comprising about 0.2 weight percent to about 1.3 weight percent boron.

11. The titanium alloy of claim 10, wherein the boron comprises at least one boride or a dissolved boron or both said at least one boride and said dissolved boron.

12. The titanium alloy of claim 11, wherein said at least one boride comprises at least one of the following: AlB_{12}, TiB_2 and TiB.

13. The titanium alloy of any of claims 10 to 12, wherein the titanium alloy comprises at least one of:

Ti- 5.8Al- 4Sn- 3.5Zr- 0.7Nb- 0.5Mo- 0.35Ti-0.06C;
Ti-6Al-4V;
Ti-6Al-2Sn-4Zr-2Mo; and
Ti-6Al-2Sn-4Zr-6Mo.

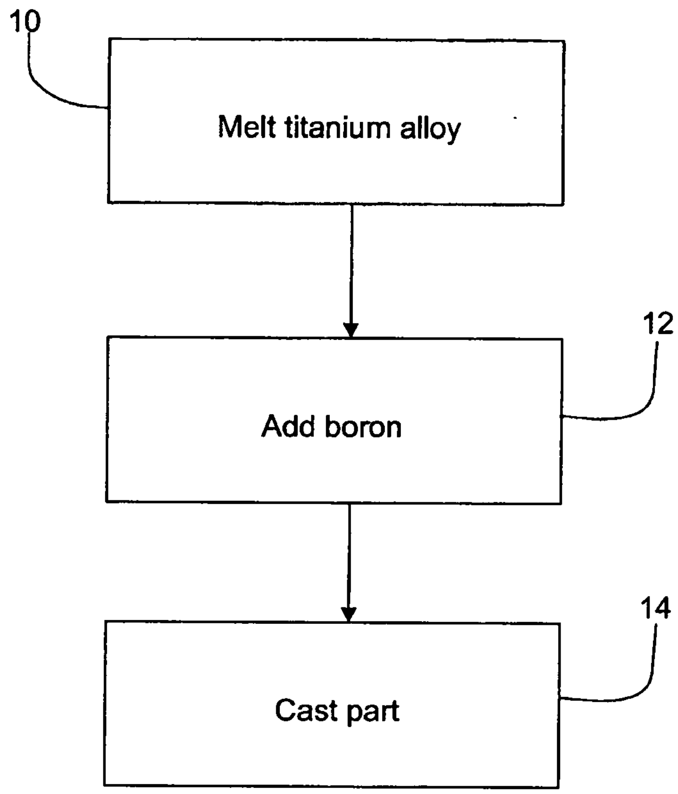

FIG. 1

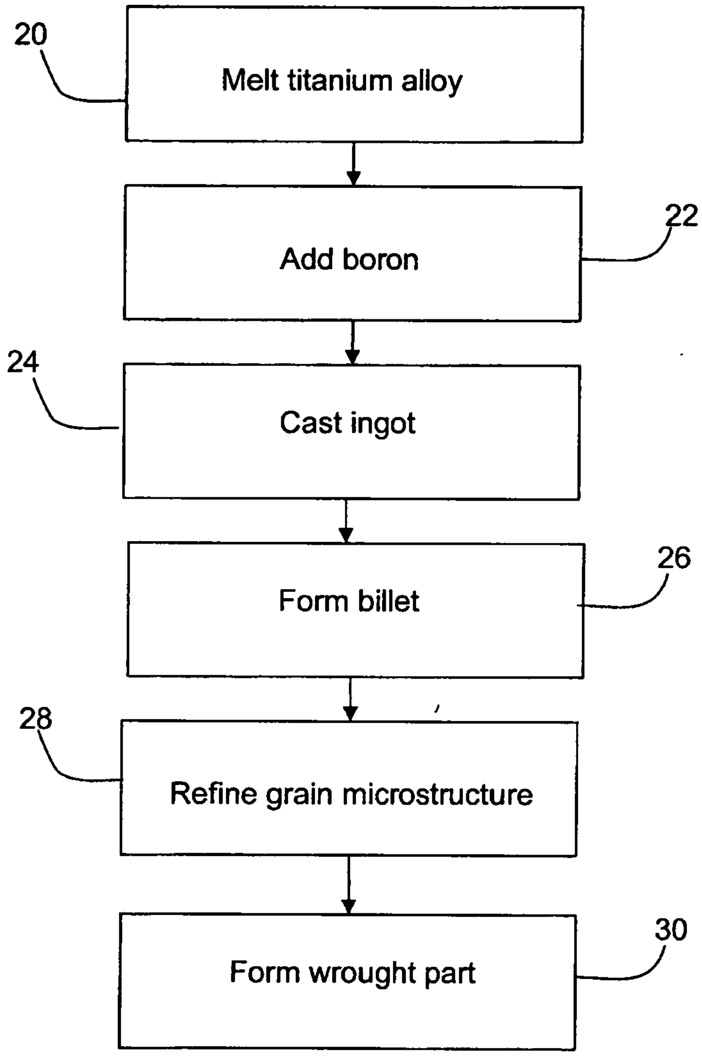
20
Melt titanium alloy
22
Add boron
24
Cast ingot
26
Form billet
28
Refine grain microstructure
30
Form wrought part

FIG. 2

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EUROPEAN SEARCH REPORT

Application Number
EP 07 25 3058

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 2005/060631 A (UNIV OHIO [US]; MIRACLE DR DANIEL B [US]; TAMIRISAKANDALA DR SESHACHAR) 7 July 2005 (2005-07-07) * paragraphs [0005] - [0011], [0036], [0037] * -----	1-13	INV. C22C1/10 C22C14/00 C22F1/18
X	US 5 955 207 A (LEDERICH RICHARD J [US] ET AL) 21 September 1999 (1999-09-21) * column 3, line 17 - column 4, line 16; claims 1-14; figure 6 * -----	1-13	
X	EP 1 295 955 A (SUMITOMO METAL IND [JP]; HONDA MOTOR CO LTD [JP]) 26 March 2003 (2003-03-26) * paragraphs [0012], [0026] - [0034]; examples 1,2 * -----	1-13	
X	BILOUS, O. O. ET AL: "Effect of boron on the structure and mechanical properties of Ti - 6Al and Ti - 6Al -4V" MATERIALS SCIENCE & ENGINEERING, A: STRUCTURAL MATERIALS: PROPERTIES, MICROSTRUCTURE AND PROCESSING , A402(1-2), 76-83 CODEN: MSAPE3; ISSN: 0921-5093, 2005, XP002458713 *Table 1, results and discussion* -----	1-4, 10-13	TECHNICAL FIELDS SEARCHED (IPC) C22C C22F
X	TAMIRISAKANDALA, S. ET AL: "Grain refinement of cast titanium alloys via trace boron addition" SCRIPTA MATERIALIA , 53(12), 1421-1426 CODEN: SCMAF7; ISSN: 1359-6462, 2005, XP002458714 *Table 1, experimental, results and discussion* -----	1-4, 10-13	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	15 November 2007	Badcock, Gordon

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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