(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 974 551 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
30.03.2022 Bulletin 2022/13

(21) Application number: **20808685.0**

(22) Date of filing: **18.03.2020**

(51) International Patent Classification (IPC):
C22C 14/00 $^{(2006.01)}$ ***B21J 5/00*** $^{(2006.01)}$
C22F 1/18 $^{(2006.01)}$ ***C22F 1/00*** $^{(2006.01)}$

(52) Cooperative Patent Classification (CPC):
B21J 5/00; C22C 14/00; C22F 1/18; C22F 1/00

(86) International application number:
PCT/JP2020/011935

(87) International publication number:
WO 2020/235200 (26.11.2020 Gazette 2020/48)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(30) Priority: **23.05.2019 JP 2019096648**

(71) Applicant: **IHI Corporation**
Tokyo 135-8710 (JP)

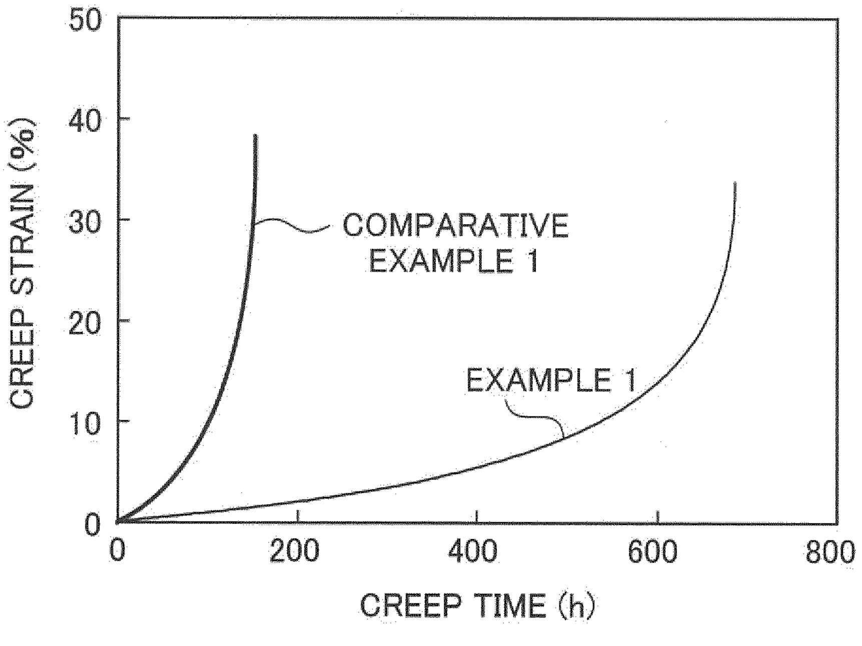
(72) Inventor: **KUBUSHIRO Keiji**
Tokyo 135-8710 (JP)

(74) Representative: **MERH-IP Matias Erny Reichl Hoffmann**
Patentanwälte PartG mbB
Paul-Heyse-Strasse 29
80336 München (DE)

(54) TIAL ALLOY AND PRODUCTION METHOD THEREFOR

(57) A TiAl alloy contains 48 at% or more and 50 at% or less of Al, 1 at% or more and 3 at% or less of Nb, 0.3 at% or more and 1 at% or less of Zr, 0.05 at% or more and 0.3 at% or less of B, and the balance being Ti and inevitable impurities.

FIG. 6



Printed by Jouve, 75001 PARIS (FR)

Description

[Technical Field]

[0001] The present disclosure relates to a TiAl alloy and a method of manufacturing the same.

[Background Art]

[0002] A TiAl (titanium aluminide) alloy is an alloy formed of an intermetallic compound of Ti and Al. The TiAl alloy is excellent in the heat resistance, and has a lighter weight and larger specific strength than an Ni-base alloy, and thus, the TiAl alloy is applied to aircraft engine components such as turbine blades. For such TiAl alloy, a TiAl alloy containing Cr and Nb is used (see Patent Literature 1).

[Citation List]

[Patent Literature]

[0003] [PTL 1] Japanese Patent Application Publication No. 2013-209750

[Summary of Invention]

[Technical Problem]

[0004] In order to reduce the weight of TiAl alloy parts such as turbine blades, to increase the specific strength of the TiAl alloy by increasing the strength thereof is needed. However, in a conventional TiAl alloy, it is difficult to increase the strength by improving the mechanical strength and the ductility in a good balance, and if the ductility is increased, the mechanical strength may decrease.

[0005] Therefore, an object of the present disclosure is to provide a TiAl alloy capable of improving the mechanical strength and the ductility of the TiAl alloy in a good balance, and a method of manufacturing the same.

[Solution to Problem]

[0006] A TiAl alloy according to the present disclosure contains 48 at% or more and 50 at% or less of Al, 1 at% or more and 3 at% or less of Nb, 0.3 at% or more and 1 at% or less of Zr, 0.05 at% or more and 0.3 at% or less of B, and the balance being Ti and inevitable impurities.

[0007] In the TiAl alloy according to the present disclosure, the content of Al may be 49 at% or more and 50 at% or less.

[0008] In the TiAl alloy according to the present disclosure, a metal structure may be formed of a lamellar grain and a γ grain, and may be free of a segregation of Zr.

[0009] In the TiAl alloy according to the present disclosure, a volume fraction of the lamellar grain may be 50 volume % or more, relative to a total of the volume fraction of the lamellar grain and the volume fraction of the γ grain being 100 volume %.

[0010] In the TiAl alloy according to the present disclosure, a room temperature ultimate tensile strength may be 400 MPa or more, and a room temperature tensile fracture strain may be 1.0 % or more.

[0011] In the TiAl alloy according to the present disclosure, creep strain after the elapse of 200 hours may be 2% or less when a temperature is 800 °C and applied stress is 150 MPa.

[0012] A method of manufacturing a TiAl alloy according to the present disclosure includes a casting step of casting a TiAl alloy raw material which contains 48 at% or more and 50 at% or less of Al, 1 at% or more and 3 at% or less of Nb, 0.3 at% or more and 1 at% or less of Zr, 0.05 at% or more and 0.3 at% or less of B, and the balance being Ti and inevitable impurities.

[0013] The method of manufacturing the TiAl alloy according to the present disclosure may include a hot isostatic pressing process step for performing a hot isostatic pressing process of applying hot isostatic pressing to the cast TiAl alloy at a temperature range from 1250 °C or higher to 1350 °C or lower, for a hour range from 1 hour or more to 5 hours or less, at an applied stress range from 158 MPa or higher to 186 MPa or lower, and then furnace cooling the cast TiAl alloy subjected to the hot isostatic pressing to 900 °C, followed by rapid cooling of the cast TiAl alloy subjected to the hot isostatic pressing from 900 °C.

[0014] The method of manufacturing the TiAl alloy according to the present disclosure may include a stress relieving step of relieving stress by holding the TiAl alloy subjected to the hot isostatic pressing process at a temperature range from 800 °C or higher to 950 °C or lower for a hour range from 1 hour or more to 5 hours or less.

[0015] According to the thus-configured TiAl alloy and the thus-configured method of manufacturing the same, the mechanical strength and the ductility of the TiAl alloy can be improved in a good balance.

[Brief Description of Drawings]

[0016]

[Fig. 1]
Fig. 1 is a diagram showing a constitution of a turbine blade in an embodiment of the present disclosure.
[Fig. 2]
Fig. 2 is a graph showing results of tensile tests in an embodiment of the present disclosure.
[Fig. 3]
Fig. 3 is a graph showing results of tensile tests in an embodiment of the present disclosure.
[Fig. 4]
Fig. 4 is photographs showing results of the observation of metal structures in an embodiment of the present disclosure.
[Fig. 5]
Fig. 5 is a graph showing results of tensile tests in an embodiment of the present disclosure.
[Fig. 6]
Fig. 6 is a graph showing results of creep tests in an embodiment of the present disclosure.
[Fig. 7]
Fig. 7 is photographs showing results of the observation of cross-sectional areas after oxidation tests in an embodiment of the present disclosure.
[Fig. 8]
Fig. 8 is a graph showing results of differential thermal analysis in an embodiment of the present disclosure.

[Description of Embodiments]

[0017] An embodiment of the present disclosure will be described in detail below with reference to the drawings. A TiAl (titanium aluminide) alloy according to an embodiment of the present disclosure contains 48 at% or more and 50 at% or less of Al, 1 at% or more and 3 at% or less of Nb, 0.3 at% more and 1 at% or less of Zr, 0.05 at% or more and 0.3 at% or less of B, and the balance being Ti and inevitable impurities. Next, the reason why a composition range of each alloy component contained in the TiAl alloy is limited will be explained.

[0018] Al (aluminium) has a function of improving the mechanical strength and the ductility such as the room temperature ductility. The content of Al is in a range from 48 at% or more to 50 at% or less. The ductility degrades if the content of Al is less than 48 at%. The ductility degrades if the content of Al is more than 50 at%. Therefore, the content of Al may be in a range from 49 at% or more to 50 at% or less, and the content of Al may be 49 at%. This can further improve the mechanical strength and the ductility.

[0019] Nb (niobium) has a function of improving the oxidation resistance and the mechanical strength. The content of Nb is in a range from 1 at% or more to 3 at% or less. If the content of Nb is less than 1 at%, the oxidation resistance and the high-temperature strength degrade. If the content of Nb is more than 3 at%, the ductility such as the room temperature ductility degrades.

[0020] Zr (zirconium) has a function of improving the oxidation resistance and the mechanical strength. The content of Zr is in a range from 0.3 at% or more to 1 at% or less. If the content of Zr is less than 0.3 at%, the oxidation resistance, the ductility such as the room temperature ductility, and the mechanical strength such as the high-temperature strength are degraded. Further, if the content of Zr is less than 0.3 at%, the castability degrades. If the content of Zr is more than 1 at%, the segregation may occur. The occurrence of the segregation of Zr may degrade the mechanical strength and the ductility. The content of Zr may be in a range from 0.3 at% or more to 0.5 at% or less.

[0021] B (boron) has a function of enhancing the ductility such as the room temperature ductility by refining crystal grains. The content of B is in a range from 0.05 at% or more to 0.3 at% or less. If the content of B is less than 0.05 at%, the crystal grains become coarse and the ductility degrades. If the content of B is more than 0.3 at%, the impact characteristic may be degraded. As the content of B is set to be in a range from 0.05 at% or more to 0.3 at% or less, the TiAl alloy is formed of fine crystal grains with a crystal grain size of 200 μm or less, and accordingly, the ductility can be improved.

[0022] B has a function of improving the mechanical strength by precipitating fine borides in the crystal grains through a hot isostatic pressing process which will be described later. The fine borides are formed by including borides with a grain size of 0.1 μm or less. The fine borides contain TiB, TiB_2 and the like. The precipitation of the fine borides in the crystal grains can improve the mechanical strength such as the tensile strength, the fatigue strength, and the creep strength.

[0023] The balance of the TiAl alloy is Ti and inevitable impurities. The inevitable impurities are impurities that have possibility to be mixed even if a user has no intention to add. The TiAl alloy does not contain Cr (chromium), and thus, the degradation in the mechanical strength can be suppressed. The TiAl alloy does not contain V (vanadium) either, and thus, the degradation in the mechanical strength and the oxidation resistance can be suppressed. The TiAl alloy does not contain Mo (molybdenum), and thus, the degradation in the specific strength can be suppressed.

[0024] Next, a method of manufacturing a TiAl alloy according to an embodiment of the present disclosure will be described.

[0025] A method of manufacturing a TiAl alloy includes a casting step of melting and casting a TiAl alloy raw material which contains 48 at% or more and 50 at% or less of Al, 1 at% or more and 3 at% or less of Nb, 0.3 at% or more and 1 at% or less of Zr, 0.05 at% or more and 0.3 at% or less of B, and the balance being Ti and inevitable impurities. The TiAl alloy raw material is melted in a vacuum induction furnace or the like and cast to form an ingot or the like. Casting of the TiAl alloy raw material may use a casting system which is used to cast a general metallic material.

[0026] The TiAl alloy has a lower solidification temperature than a conventional TiAl alloy, and thus, running properties during casting of the TiAl alloy can be improved. At the time of measuring the TiAl alloy based on differential thermal analysis (DTA), a solid-liquid coexistent temperature region of the TiAl alloy may be set in a range from 1440 °C to 1510 °C. This enables the formation of a TiAl alloy component such as a turbine blade in a net-shape or a near-net-shape, and accordingly, the manufacturing cost can be reduced. Further, according to the TiAl alloy, to take a superheat is not needed, and therefore, the castability is improved.

[0027] The method of manufacturing the TiAl alloy may include a hot isostatic pressing process step for performing a hot isostatic pressing process of applying hot isostatic pressing (HIP) to the cast TiAl alloy at a temperature range from 1250 °C or higher to 1350 °C or lower, for an hour range from 1 hour or more to 5 hours or less, and at an applied stress range from 158 MPa or higher to 186 MPa or lower, and then furnace cooling, the cast TiAl alloy subjected to the hot isostatic pressing, to 900 °C, followed by rapid cooling of the cast TiAl alloy subjected to the hot isostatic pressing from 900 °C. The application of the hot isostatic pressing process to the cast TiAl alloy can suppress casting defects such as voids and can control a metal structure.

[0028] More specifically, by applying the hot isostatic pressing to the cast TiAl alloy at a temperature range from 1250 °C or higher to 1350 °C or lower, for an hour range from 1 hour or more to 5 hours or less, and at an applied stress range from 158 MPa or higher to 186 MPa or lower, it is possible to suppress mainly casting defects including internal defects such as voids caused to the cast TiAl alloy. Further, it is possible to mainly control the metal structure by, after performing the hot isostatic pressing to the cast TiAl alloy, relieving the pressure and furnace cooling the cast TiAl alloy subjected to the hot isostatic pressing to 900 °C, and then, rapidly cooling the cast TiAl alloy subjected to the hot isostatic pressing from 900 °C. The rapid cooling from 900 °C may be performed at a cooling rate that is equal to or higher than that of air cooling, and can be performed by gas fan cooling or the like.

[0029] The method of manufacturing the TiAl alloy may include a stress relieving step of relieving stress by holding the TiAl alloy subjected to the hot isostatic pressing process at a temperature range from 800 °C or higher to 950 °C or lower for an hour range from 1 hour or more to 5 hours or less. Residual stress and the like can be relieved by heat-treating the TiAl alloy subjected to the hot isostatic pressing process and relieving stress. This can further improve the ductility of the TiAl alloy.

[0030] In order to prevent oxidation, the hot isostatic pressing process and the stress relief may be performed to the TiAl alloy in a vacuum atmosphere or an inert gas atmosphere with gas such as argon gas. For the hot isostatic pressing, HIP equipment or the like which is used for the hot isostatic pressing of general metallic materials can be used. For the stress relief, an atmosphere furnace or the like which is used for stress relief annealing of general metallic materials can be used.

[0031] Next, the metal structure of the TiAl alloy will be described. The metal structure of the TiAl alloy is formed of fine crystal grains with a crystal grain size of 200 μm or less. This can improve the ductility of the TiAl alloy. Further, the metal structure of the TiAl alloy is formed of lamellar grains and γ grains, and no segregation of Zr is caused. The lamellar grains are formed from α_2 phases formed of Ti_3Al, and γ phases formed of TiAl, which are regularly arranged one another in a layered structure. The γ grains are formed of TiAl. Boride having a grain size of 0.1 μm or less is contained in the γ grains. The boride is formed of TiB, TiB_2 and the like in a needle shape or the like.

[0032] The lamellar grains can improve the mechanical strength such as the tensile strength, the fatigue strength, and the creep strength. The γ grains can improve the ductility and the high-temperature strength. Fine borides with a grain size of 0.1 μm or less can improve the mechanical strength. In the metal structure of the TiAl alloy, a volume fraction of the lamellar grains may be 50 volume % or more, and the balance may be γ grains, relative to a total of the volume fraction of the lamellar grain and the volume fraction of the γ grain being 100 volume %. The metal structure of the TiAl alloy is mainly formed of the lamellar grains, and thus, the mechanical strength can be improved. Further, the metal structure of the TiAl alloy is free from the segregation of Zr, and thus, the degradation in the mechanical strength and the ductility can be suppressed.

[0033] Next, mechanical characteristics of the TiAl alloy according to the embodiment of the present disclosure will be described. When a tensile test is performed in accordance with JIS, ASTM, and the like, mechanical characteristics of the TiAl alloy at a room temperature may be such that a room temperature ultimate tensile strength is 400 MPa or more and a room temperature tensile fracture strain is 1.0% or more. When a creep test is performed in accordance with JIS, ASTM, and the like at a temperature of 800 °C and applied stress of 150 MPa, high-temperature creep characteristics of the TiAl alloy may be such that creep strain after the elapse of 200 hours is 2% or less. When the test is performed at a temperature of 800 °C and applied stress of 150 MPa, the high-temperature creep characteristics of the TiAl alloy may be such that creep strain after the elapse of 400 hours is 5% or less. Further, when the test is performed at a temperature of 800 °C and applied stress of 150 MPa, the high-temperature creep characteristics of the TiAl alloy may be such that creep strain after the elapse of 600 hours is 15% or less.

[0034] The TiAl alloy according to the embodiment of the present disclosure can be applied to a turbine blade or the like of aircraft engine components. Fig. 1 is a diagram showing a structure of a turbine blade 10. The TiAl alloy has high mechanical strength such as high-temperature strength, and thus, it is possible to improve the heat resistance of the turbine blade 10. Further, the TiAl alloy has excellent ductility such as room temperature ductility, and thus, even when the turbine blade 10 is assembled or fitted, it is possible to suppress damage to the turbine blade 10.

[0035] As discussed above, the TiAl alloy contains 48 at% or more and 50 at% or less of Al, 1 at% or more and 3 at% or less of Nb, 0.3 at% or more and 1 at% or less of Zr, 0.05 at% or more and 0.3 at% or less of B, and the balance being Ti and inevitable impurities. This can improve the mechanical strength and the ductility of the TiAl alloy in a good balance.

[0036] As discussed above, the method of manufacturing the TiAl alloy includes a casting step of casting a TiAl alloy raw material which contains 48 at% or more and 50 at% or less of Al, 1 at% or more and 3 at% or less of Nb, 0.3 at% or more and 1 at% or less of Zr, 0.05 at% or more and 0.3 at% or less of B, and the balance being Ti and inevitable impurities. This enables manufacturing of the TiAl alloy with the mechanical strength and the ductility which are improved in a good balance, and also the improvement of the castability because the running properties are favorable.

[Examples]

[0037] First, descriptions will be given for the TiAl alloys of Examples 1 and 2, Reference Examples 1 to 8, and Comparative Example 1. An alloy composition of each TiAl alloy is shown in Table 1.

[Table 1]

	ALLOY COMPOSITION (at%)					
	Al	Nb	Zr	B	Cr	TI AND INEVITABLE IMPURITIES
EXAMPLE 1	49.5	2	0.5	0.2	-	BALANCE
EXAMPLE 2	49.5	2	1	0.2	-	BALANCE
REFERENCE EXAMPLE 1	48	1	3	0.1	-	BALANCE
REFERENCE EXAMPLE 2	49	1	3	0.1	-	BALANCE
REFERENCE EXAMPLE 3	48	-	-	0.1	-	BALANCE
REFERENCE EXAMPLE 4	49	-	-	0.1	-	BALANCE
REFERENCE EXAMPLE 5	50	-	-	0.1	-	BALANCE
REFERENCE EXAMPLE 6	49.5	-	-	0.2	-	BALANCE
REFERENCE EXAMPLE 7	49.5	4	0.2	0.2	-	BALANCE
REFERENCE EXAMPLE 8	49.5	4	0.5	0.2	-	BALANCE
COMPARATIVE EXAMPLE 1	48	2	-	-	2	BALANCE

[0038] The TiAl alloy of Example 1 contained 49.5 at% of Al, 2 at% of Nb, 0.5 at% of Zr, 0.2 at% of B, and the balance being Ti and inevitable impurities. The TiAl alloy of Example 2 contained 49.5 at% of Al, 2 at% of Nb, 1 at% of Zr, 0.2 at% of B, and the balance being Ti and inevitable impurities. The TiAl alloy of Reference Example 1 contained 48 at% of Al, 1 at% of Nb, 3 at% of Zr, 0.1 at% of B, and the balance being Ti and inevitable impurities. The TiAl alloy of Reference Example 2 contained 49 at% of Al, 1 at% of Nb, 3 at% of Zr, 0.1 at% of B, and the balance being Ti and inevitable impurities.

[0039] The TiAl alloy of Reference Example 3 contained 48 at% of Al, 0.1 at% of B, and the balance being Ti and inevitable impurities. The TiAl alloy of Reference Example 4 contained 49 at% of Al, 0.1 at% of B, and the balance being

Ti and inevitable impurities. The TiAl alloy of Reference Example 5 contained 50 at% of Al, 0.1 at% of B, and the balance being Ti and inevitable impurities. The TiAl alloy of Reference Example 6 contained 49.5 at% of Al, 0.2 at% of B, and the balance being Ti and inevitable impurities.

[0040] The TiAl alloy of Reference Example 7 contained 49.5 at% of Al, 4 at% of Nb, 0.2 at% of Zr, 0.2 at% of B, and the balance being Ti and inevitable impurities. The TiAl alloy of Reference Example 8 contained 49.5 at% of Al, 4 at% of Nb, 0.5 at% of Zr, 0.2 at% of B, and the balance being Ti and inevitable impurities. The TiAl alloy of Comparative Example 1 contained 48 at% of Al, 2 at% of Nb, 2 at% of Cr, and the balance being Ti and inevitable impurities.

[0041] Each TiAl alloy raw material with each alloy composition shown in Table 1 was melted in a high-frequency vacuum melting furnace and cast to form an ingot of each TiAl alloy with each alloy composition. Each TiAl alloy was casted, and then, subjected to a hot isostatic pressing process. In the hot isostatic pressing process, the cast TiAl alloy was subjected to the hot isostatic pressing at a temperature of 1300 1 14 °C, for an hour of 3 ± 0.1 hours, and at applied stress of 172 ± 14 MPa, and then, furnace cooled to 900 °C after being subjected to the hot isostatic pressing, and thereafter, rapidly cooled from 900 °C by gas fan cooling.

[0042] Effects of Al in the TiAl alloy were evaluated. Tensile tests were performed at room temperature for the TiAl alloys of Reference Examples 3 to 5. The tensile tests were performed in accordance with ASTM E8. Fig. 2 is a graph showing results of the tensile tests. In the graph of Fig. 2, a horizontal axis represents the content of Al, a vertical axis represents strains, and Reference Examples 3 to 5 are shown by white circles. Strain indicates fracture strains. The graph of Fig. 2 shows that the room temperature ductility degrades, if the content of Al is less than 48 at%, or if the content of Al is more than 50 at%. Further, the strain in Reference Examples 4 and 5 was larger than that in Reference Example 3. This indicates that the room temperature ductility becomes higher, if the content of Al is 49 at% or more and 50 at% or less. The strain in Reference Example 4 was larger than that in Reference Examples 3 and 5. This indicates that the room temperature ductility becomes still higher, if the Al content is 49 at%.

[0043] Effects of Nb and Zr in the TiAl alloy were evaluated. Tensile tests were performed at room temperature for the TiAl alloys of Examples 1 to 2, and Reference Examples 6 to 8. The tensile tests were performed in accordance with ASTM E8. Fig. 3 is a graph showing results of the tensile tests. In the graph of Fig. 3, a horizontal axis represents the content of Zr, a vertical axis represents 0.2% proof stress, Reference Example 6 is indicated by a black circle, Examples 1 and 2 are indicated by black squares, and Reference Examples 7 and 8 are indicated by white diamonds shapes. Proof stress in Examples 1 and 2, and Reference Examples 7 and 8 was 0.2% greater than that in Reference Example 6. This revealed that the addition of Nb or Zr increases the mechanical strength. The room temperature ductility in Reference Example 8 was lower than that in Example 1. This revealed that the ductility such as the room temperature ductility of the TiAl alloy degrades if the content of Nb is more than 3 at%.

[0044] The metal structure of the TiAl alloy was evaluated. The metal structure of the TiAl alloy of Examples 1 and 2 and Reference Examples 1 and 2 was observed. The metal structure was observed by using an optical microscope or a scanning electron microscope. Fig. 4 is photographs showing results of the observation of the metal structures that is Fig. 4(a) is a photograph of Example 1, Fig. 4(b) is a photograph of Example 2, Fig. 4(c) is a photograph of Reference Example 1, and Fig. 4(d) is a photograph of Reference Example 2.

[0045] As shown in Figs. 4(a) and 4(b), the metal structures of Examples 1 and 2 were formed of fine crystal grains with a crystal grain size of 200 μm or less. The metal structures of Examples 1 and 2 were formed of the lamellar grains and the γ grains, and boride with a grain size of 0.1 μm or less was contained in the γ grains. In the metal structures of Examples 1 and 2, a volume fraction of the lamellar grains was 50 volume % or more, and the balance was γ grains, relative to a total of the volume fraction of the lamellar grain and the volume fraction of the γ grain being 100 volume %. An area ratio of each grain was calculated by applying image processing to information on the contrast of each grain in the photographs of the metal structures, and the thus obtained area ratio was regarded as the volume fraction of each grain.

[0046] As shown in Figs. 4(a) and 4(b), no segregation of Zr was observed in the metal structures of Examples 1 and 2. On the other hand, as shown in Figs. 4(c) and 4(d), as indicated by white arrows, the segregation of Zr was observed in the metal structures of Reference Examples 1 and 2. From this result, it was found that the segregation of Zr occurs if the content of Zr was more than 1 at%. Accordingly, it became clear that the content of Zr may be 1 at% or less.

[0047] Room temperature mechanical characteristics of the TiAl alloy were evaluated. Tensile tests were performed at room temperature for the TiAl alloys of Example 1 and Comparative Example 1. The tensile tests were performed in accordance with ASTM E8. Fig. 5 is a graph showing results of the tensile tests. Fig. 5 shows a stress-strain curve of each TiAl alloy, with a horizontal axis representing strain and a vertical axis representing stress. Example 1 had greater room temperature strength than Comparative Example 1. Further, Example 1 had greater room temperature ductility than Comparative Example 1. More specifically, the room temperature ultimate tensile strength of Example 1 was 400 MPa or more, and the room temperature tensile fracture strain was 1.0% or more.

[0048] High temperature mechanical characteristics of the TiAl alloys were evaluated. Creep tests were performed at high temperature for the TiAl alloys of Example 1 and Comparative Example 1. The creep tests were performed in accordance with ASTM E139. The creep tests were performed under a condition where a test temperature was 800 °C and applied stress was 150 MPa. Fig. 6 is a graph showing results of the creep tests. Fig. 6 shows a creep curve of each TiAl alloy, with a horizontal axis representing a creep time and a vertical axis representing creep strain. Example 1 had high temperature creep characteristics that are five times or more higher than those of Comparative Example 1. Example 1 had more improved high temperature creep characteristics than Comparative Example 1. More specifically, the high temperature creep characteristics of Example 1 were such that creep strain after the elapse of 200 hours was 2% or less, when the test was performed under a condition where a test temperature was 800 °C and applied stress was 150 MPa. Further, the high temperature creep characteristics of Example 1 were such that the creep strain after the elapse of 400 hours was 5% or less, when the test was performed under a condition where a test temperature was 800 °C and applied stress was 150 MPa. Still further, the high temperature creep characteristics of Example 1 were such that the creep strain after the elapse of 600 hours was 15% or less, when the test was performed under a condition where a test temperature was 800 °C and applied stress was 150 MPa.

[0049] As shown in Figs. 5 and 6, it was found that the TiAl alloy of Example 1 had excellent mechanical strength and ductility, and the mechanical strength and the ductility were improved in a good balance. On the other hand, the TiAl alloy of Comparative Example 1 had more degraded room temperature mechanical characteristics and high temperature mechanical characteristics than the TiAl alloy of Example 1. The reason of the above degradation is considered to be caused by the influence or the like of Cr contained in the TiAl alloy of Comparative Example 1.

[0050] The oxidation resistance of the TiAl alloy was evaluated. Oxidation tests were performed for the TiAl alloys of Example 1 and Comparative Example 1. The oxidation tests were performed in air atmosphere by continuous oxidization at 750 °C for 200 hours. After performing the oxidation tests, cross-sectional areas were observed to evaluate the thickness of oxide layers. Fig. 7 is photographs showing results of the observation of the cross-sectional areas after the oxidation tests, that is, Fig. 7(a) is a photograph of Example 1, and Fig. 7(b) is a photograph of Comparative Example 1. The thickness of the oxide layer of Example 1 was 2.1 μm. The thickness of the oxide layer of Comparative Example 1 was 4.3 μm. From this result, it was found that Example 1 had more excellent oxidation resistance than Comparative Example 1.

[0051] The castability of the TiAl alloy was evaluated. Solid-liquid coexistent temperature regions of the TiAl alloys of Example 1 and Comparative Example 1 were evaluated. The solid-liquid coexistent temperature regions were evaluated based on differential thermal analysis (DTA). Fig. 8 is a graph showing results of differential thermal analysis. Fig. 8 shows the solid-liquid coexistent temperature regions of the individual TiAl alloys with squares, with a horizontal axis representing each TiAl alloy and a vertical axis representing temperatures. From the graph shown in Fig. 8, it was found that Example 1 had a lower solidification temperature than Comparative Example 1. More specifically, the solid-liquid coexistent temperature region of the TiAl alloy of Example 1 was in a range from 1440 °C to 1510 °C, when the solid-liquid coexistent temperature region was measured based on differential thermal analysis (DTA). This enables setting of a casting temperature of Example 1 to be lower than that of Comparative Example 1, and accordingly, it became clear that mold reaction defects can be suppressed.

[Industrial Applicability]

[0052] The present disclosure enables the improvement of the mechanical strength and the ductility of the TiAl alloy in a good balance, and thus, is applicable to turbine blades and the like of aircraft engine components.

Claims

1. A TiAl alloy, comprising:

48 at% or more and 50 at% or less of Al;
1 at% or more and 3 at% or less of Nb;
0.3 at% or more and 1 at% or less of Zr;
0.05 at% or more and 0.3 at% or less of B; and
the balance being Ti and inevitable impurities.

2. The TiAl alloy according to claim 1, wherein
a content of Al is 49 at% or more and 50 at% or less.

3. The TiAl alloy according to claim 1 or 2, wherein
a metal structure is formed of a lamellar grain and a γ grain, and is free of a segregation of Zr.

4. The TiAl alloy according to claim 3, wherein
a volume fraction of the lamellar grain is 50 volume % or more, relative to a total of the volume fraction of the lamellar

grain and the volume fraction of the γ grain being 100 volume %.

5. The TiAl alloy according to any one of claims 1 to 4, wherein
a room temperature ultimate tensile strength is 400 MPa or more, and a room temperature tensile fracture strain is 1.0 % or more.

6. The TiAl alloy according to any one of claims 1 to 5, wherein
a creep strain after an elapse of 200 hours is 2% or less, when a temperature is 800 °C and applied stress is 150 MPa.

7. A method of manufacturing a TiAl alloy, comprising:
a casting step of casting a TiAl alloy raw material which contains 48 at% or more and 50 at% or less of Al, 1 at% or more and 3 at% or less of Nb, 0.3 at% or more and 1 at% or less of Zr, 0.05 at% or more and 0.3 at% or less of B, and the balance being Ti and inevitable impurities.

8. The method of manufacturing the TiAl alloy according to claim 7, comprising:
a hot isostatic pressing process step for performing a hot isostatic pressing process of applying hot isostatic pressing to the cast TiAl alloy at a temperature range from 1250 °C or higher to 1350 °C or lower, for a hour range from 1 hour or more to 5 hours or less, at an applied stress range from 158 MPa or higher to 186 MPa or lower, and then furnace cooling the cast TiAl alloy subjected to the hot isostatic pressing to 900 °C, followed by rapid cooling of the cast TiAl alloy subjected to the hot isostatic pressing from 900 °C.

9. The method of manufacturing the TiAl alloy according to claim 8, comprising:
a stress relieving step of relieving stress by holding the TiAl alloy subjected to the hot isostatic pressing process at a temperature range from 800 °C or higher to 950 °C or lower for a hour range from 1 hour or more to 5 hours or less

FIG. 1

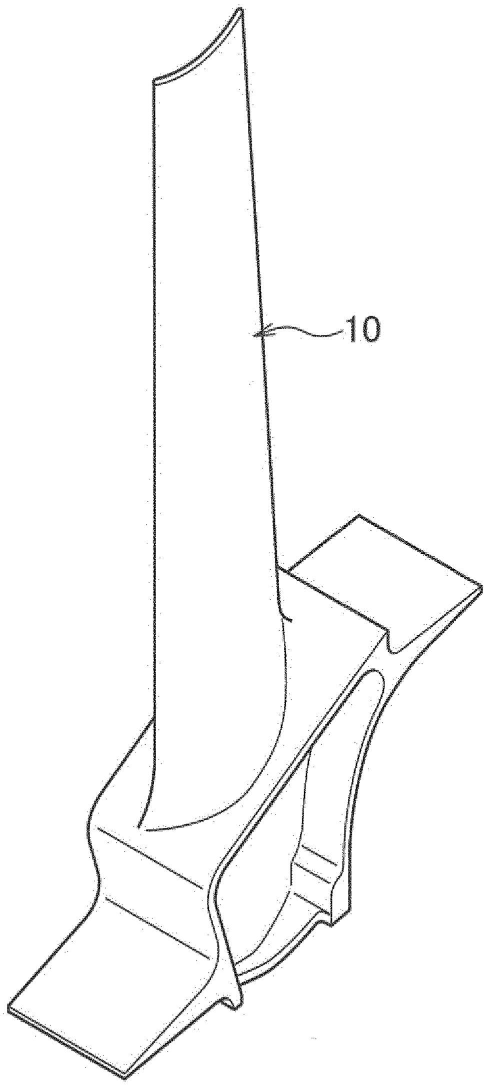


FIG. 2

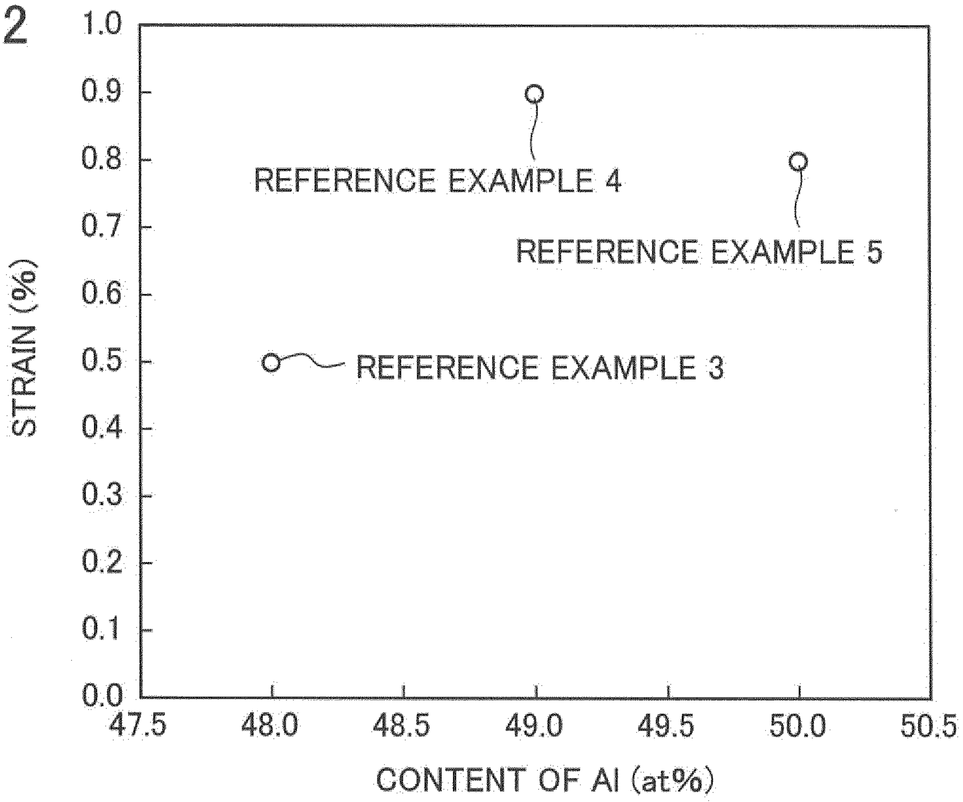

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
STRAIN (%)
REFERENCE EXAMPLE 4
REFERENCE EXAMPLE 5
REFERENCE EXAMPLE 3
47.5
48.0
48.5
49.0
49.5
50.0
50.5
CONTENT OF Al (at%)

FIG. 3

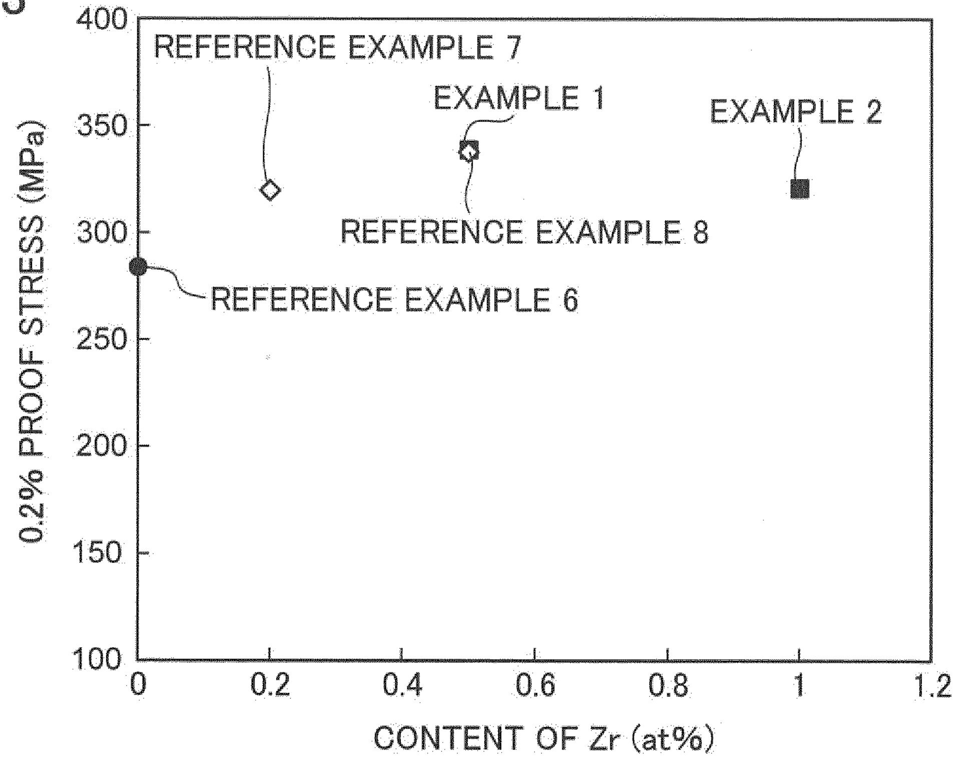

400
350
300
250
200
150
100
0.2% PROOF STRESS (MPa)
REFERENCE EXAMPLE 7
EXAMPLE 1
EXAMPLE 2
REFERENCE EXAMPLE 8
REFERENCE EXAMPLE 6
0
0.2
0.4
0.6
0.8
1
1.2
CONTENT OF Zr (at%)

FIG. 4

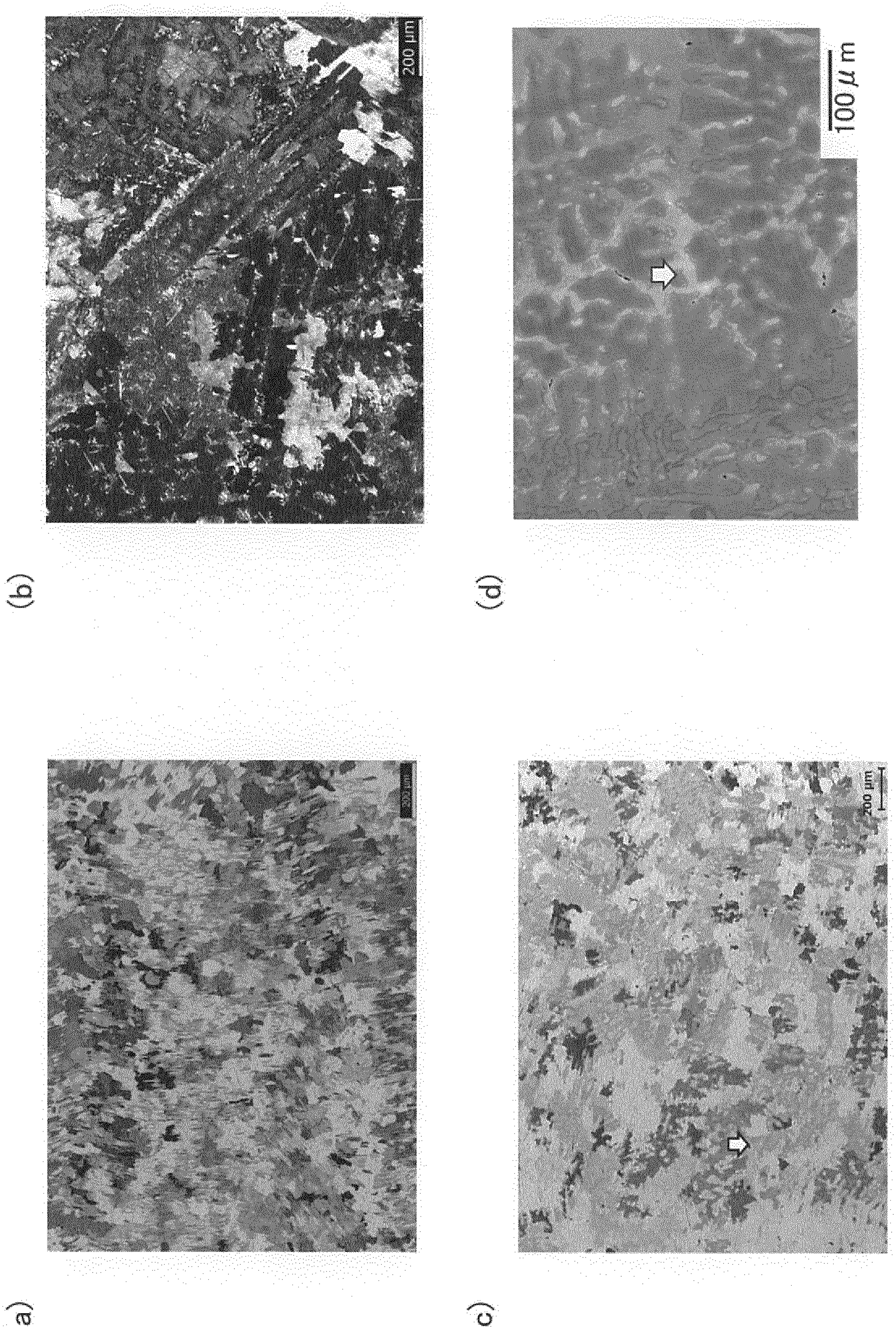


FIG. 5

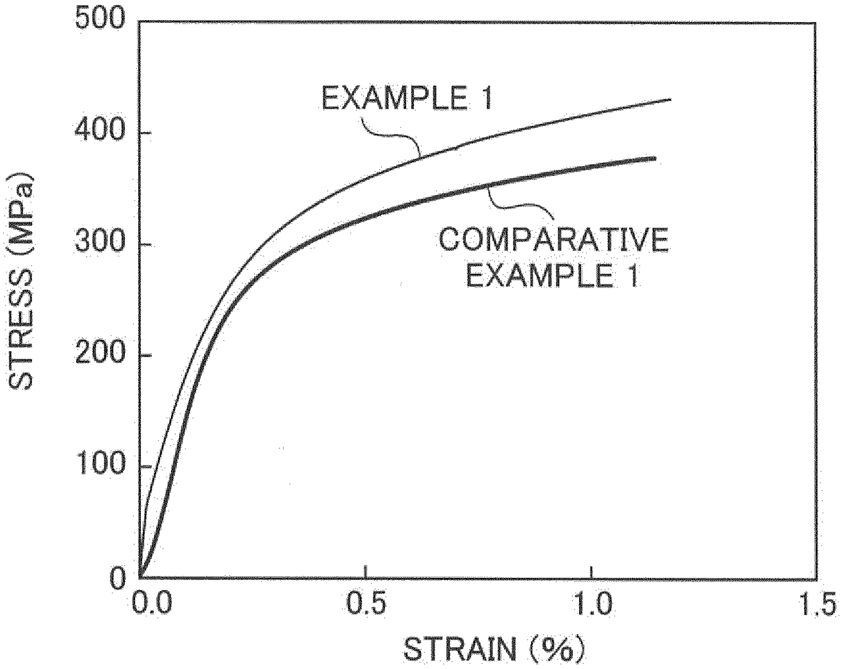

STRESS (MPa)
500
400
300
200
100
0
EXAMPLE 1
COMPARATIVE EXAMPLE 1
0.0
0.5
1.0
1.5
STRAIN (%)

FIG. 6

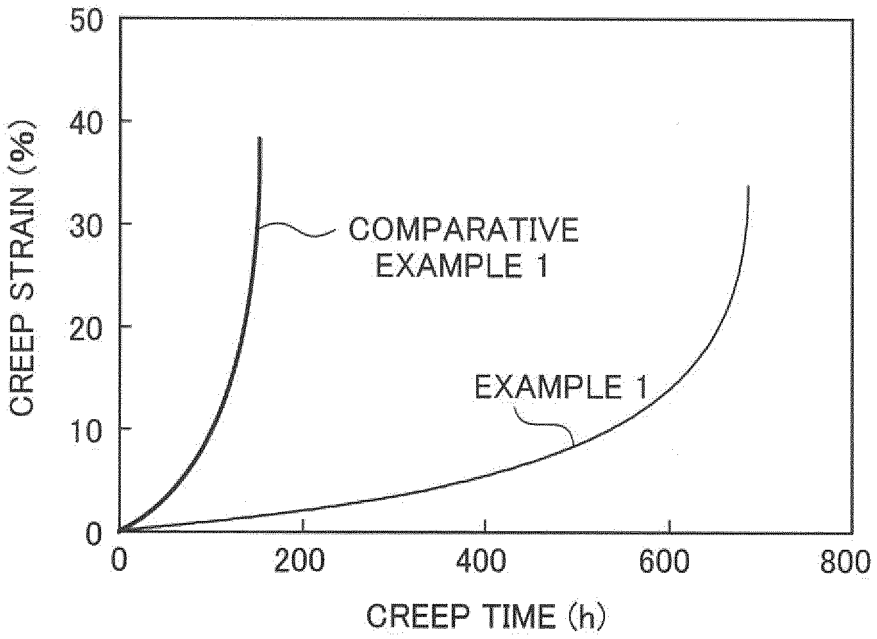

CREEP STRAIN (%)
50
40
30
20
10
0
COMPARATIVE EXAMPLE 1
EXAMPLE 1
0
200
400
600
800
CREEP TIME (h)

FIG. 7

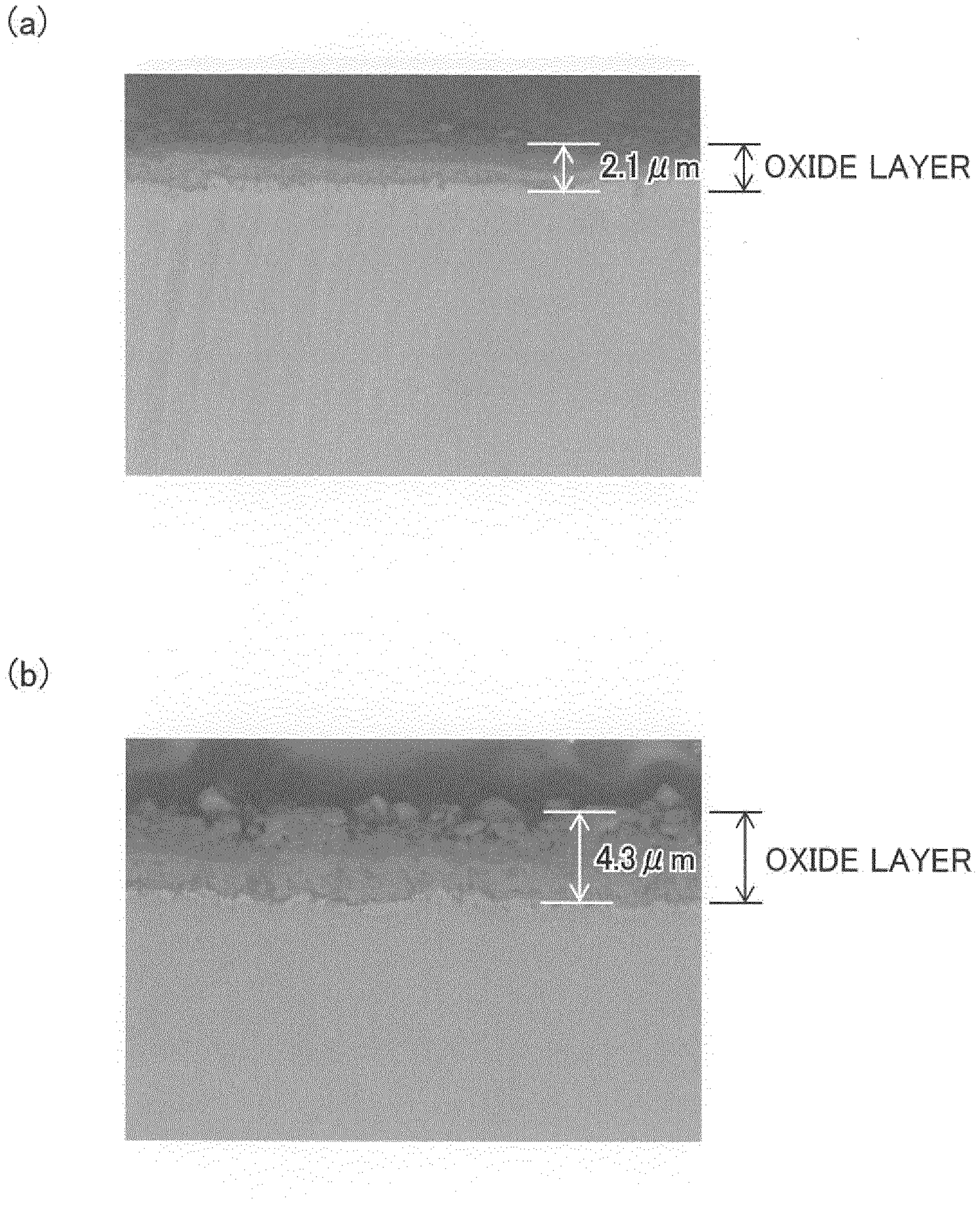
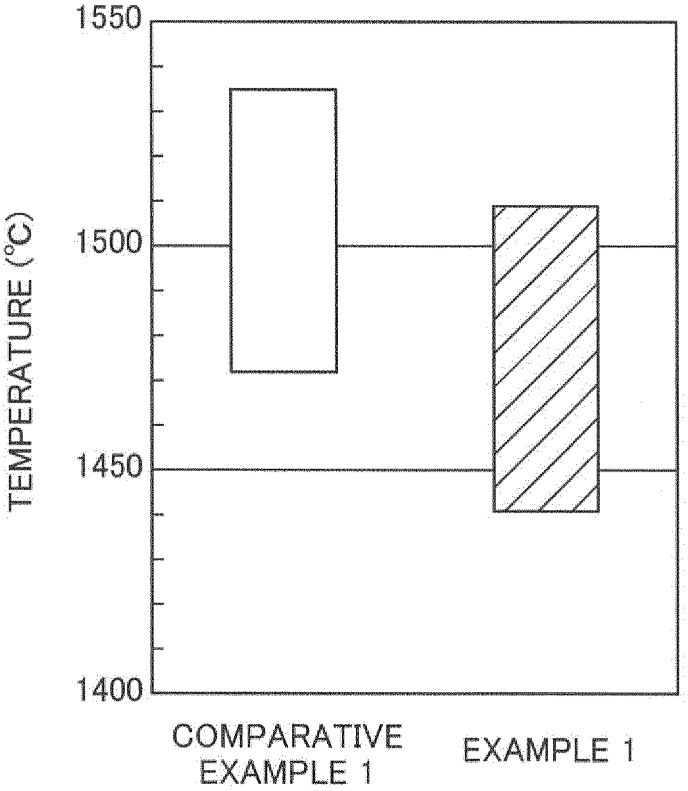


FIG. 8


1550
1500
1450
1400
TEMPERATURE (°C)
COMPARATIVE EXAMPLE 1
EXAMPLE 1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2020/011935

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. C22C14/00(2006.01)i, B21J5/00(2006.01)i, C22F1/18(2006.01)i, C22F1/00(2006.01)n
FI: C22C14/00Z, C22F1/18H, B21J5/00G, C22F1/00611, C22F1/00692A, C22F1/00604, C22F1/00691C, C22F1/00694B, C22F1/00691B, C22F1/00694Z, C22F1/00630A, C22F1/00630K, C22F1/00640B, C22F1/00651B, C22F1/00650A, C22F1/00692B
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl. C22C14/00, B21J5/00, C22F1/18, C22F1/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2020
Registered utility model specifications of Japan	1996-2020
Published registered utility model applications of Japan	1994-2020

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 6-17211 A (GENERAL ELECTRIC COMPANY) 25.01.1994 (1994-01-25)	1-9
A	US 5997808 A (ROLLS-ROYCE PLC) 07.12.1999 (1999-12-07)	1-9
A	JP 2001-316743 A (MITSUBISHI HEAVY INDUSTRIES, LTD.) 16.11.2001 (2001-11-16)	1-9
A	JP 3-226538 A (NKK CORP.) 07.10.1991 (1991-10-07)	1-9
A	JP 2003-533594 A (GFE METALLE UND MATERIALIEN GMBH) 11.11.2003 (2003-11-11)	1-9

☐ Further documents are listed in the continuation of Box C.
☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 09.06.2020	Date of mailing of the international search report 23.06.2020
Name and mailing address of the ISA/ Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2020/011935

JP 6-17211 A	25.01.1994	US 5204058 A US 5264054 A GB 2251000 A DE 4140679 A1 FR 2670804 A1 CA 2056465 A1 IT MI913446 A1
US 5997808 A	07.12.1999	GB 9714391 A0 EP 0889143 A1 DE 69805242 T2
JP 2001-316743 A	16.11.2001	US 2001/0022946 A1 US 2004/0055676 A1 EP 1127949 A2 DE 60110294 T2
JP 3-226538 A	07.10.1991	(Family: none)
JP 2003-533594 A	11.11.2003	US 2004/0045644 A1 WO 2001/088214 A1 EP 1287173 A1 AU 6229501 A AT 384146 T ES 2298238 T3 DE 10024343 T3

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2013209750 A **[0003]**