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(54) **TIAL ALLOY FOR FORGING, TIAL ALLOY MATERIAL, AND METHOD FOR PRODUCING TIAL ALLOY MATERIAL**

(57) To provide a TiAl alloy for forging from which a TiAl alloy material having excellent oxidation resistance and high-temperature creep strength can be obtained and which has excellent hot forgeability and can be subjected to die forging. The TiAl alloy for forging contains

Al: 42.0 atomic% or more and 43.6 atomic% or less, Cu: 0.5 atomic% or more and 2.0 atomic% or less; and, Nb: 3.0 atomic% or more and 7.0 atomic% or less, with the balance being Ti and unavoidable impurities.

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Description

TECHNICAL FIELD

[0001] The present invention relates to a TiAl alloy for forging, a TiAl alloy material, and a method for manufacturing a TiAl alloy material, and particularly to a TiAl alloy material having excellent oxidation resistance and creep strength, a TiAl alloy for forging with which such a TiAl alloy material can be obtained and which has excellent hot forgeability and can be subjected to die forging, and a method for manufacturing a TiAl alloy material.

BACKGROUND ART

[0002] Turbochargers for obtaining high combustion energy are employed in engines for transportation machines, industrial machines, and the like. In recent years, in order to improve the fuel efficiency of engines and improve the response speed, the use of a TiAl alloy, which has excellent high-temperature resistance and is light weight, has been put to practical use as turbocharger members.

[0003] Among various TiAl alloys, a related-art TiAl alloy such as a casting TiAl alloy is composed of a γ phase having a face centered cubic lattice (FCC) structure as a crystal structure and an α phase having a hexagonal close-packed lattice (HCP) structure as a crystal structure. The material structure of such a TiAl alloy is characterized in that a thin plate-like γ phase precipitates in the α phase during a cooling process after a heat treatment, and a lamellar phase is formed.

[0004] Since hot forged products are superior in both strength and toughness compared to cast products, in particular, the development of TiAl alloy for hot forgings is underway for the purpose of applying them to members requiring these properties. The TiAl alloy for hot forging is added with a component that stabilizes a β phase having a body centered cubic lattice (BCC) structure that is easily deformed at a high temperature, and the β phase is responsible for most of the deformation, so that hot forging is possible.

[0005] As a TiAl alloy that enables hot forging, for example, Patent Literature 1 discloses a forging TiAl alloy in which Nb, V, and B are added to Ti and Al and a grain size of a boride is specified. In addition, Patent Literature 2 discloses a TiAl-based alloy containing Al and Nb in which relative amounts of additive components are adjusted, and a TiAl-based alloy in which Nb, V, Cr, and Mo are co-added to Ti and Al.

[0006] Further, Patent Literature 3 discloses a titanium-aluminum-based alloy material containing Ti, Al, Nb, Mo and/or Mn, and B and/or C and/or Si and having a specified β /B2-Ti phase ratio. Further, Patent Literature 4 discloses a titanium aluminide alloy composed of titanium, aluminum, and niobium and having a predetermined lamellar structure.

[0007] As shown in Patent Literatures 1 to 4, Nb is an important element for improving oxidation resistance of the TiAl alloy, and Nb is added to many TiAl alloys for hot forging. However, assuming the formation of a γ phase including a lamellar phase, when Nb is added alone to a material set to a high concentration of Al, the β phase cannot be sufficiently stabilized in a practical forging heating temperature range of lower than 1300°C. Therefore, in most of the related art, either "isothermal forging", which is a low-manufacturability working process, or "co-addition" of Nb and other β -stabilizing elements is used to form a sufficient β phase in the forging heating temperature range, and to ensure good hot forgeability.

[0008] In addition, the TiAl alloy for forging requires a heat treatment for adjusting the material structure after forging. Examples of such a heat treatment include two heat treatments including a high-temperature heat treatment for recrystallizing an α phase of a forged material and promoting an α single phase, and thereafter, a lower-temperature heat treatment for precipitating a γ plate in the α phase and introducing a lamellar structure. Then, the material structure after the second heat treatment becomes the material structure of a TiAl product.

[0009] The α phase maintains the α phase at a high temperature, but becomes more ordered at around room temperature, and is sometimes referred to as a " α_2 phase". In addition, the β phase becomes a "B2 structure" at around room temperature. However, the description of the α phase and the β phase in the description of the present application does not particularly limit the temperature.

CITATION LIST

PATENT LITERATURE

[0010]

Patent Literature 1: JP6687118B
 Patent Literature 2: JP2009-215631A
 Patent Literature 3: JP5926886B
 Patent Literature 4: JP5512964B

SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0011] However, when Nb and other β -stabilizing elements are co-added as described above, there are problems that a large amount of β phase remains even after the heat treatment for the TiAl alloy, and high-temperature creep strength, which is one of mechanical properties, decreases.

[0012] In addition, when a component having a small amount of β -stabilizing elements is selected such that the β phase does not remain after the heat treatment, there is a problem that the β phase at a high temperature is insufficient, resulting in insufficient hot forgeability.

[0013] In this way, it can be said that the hot forgeability and the high-temperature creep strength are in a trade-off relationship.

[0014] Examples of the hot forging for the TiAl alloy include general die forging in which a die is preheated to room temperature or several hundred Celsius degrees, and isothermal forging in which a die is heated to a temperature same as that of a forging material, such as 1200°C, and forged over time under conditions where a strain rate is slow, such as 10⁻³/sec. Of these hot forging methods, when isothermal forging is used, it is often possible to work even when the β phase is insufficient, but since the isothermal forging takes a very long time per stroke, the productivity decreases.

[0015] That is, when using general die forging instead of the isothermal forging for the TiAl alloy to ensure excellent oxidation resistance, it is necessary to co-add Nb, which is a β -stabilizing element and contributes to improving the oxidation resistance, and another β -stabilizing element.

[0016] However, even when Nb and other β -stabilizing elements are co-added using the methods described in Patent Literatures 1 to 4, the β phase remains after the heat treatment, resulting in insufficient high-temperature creep strength.

[0017] On the other hand, when the amount of the β -stabilizing element added is reduced to reduce the amount of the β phase after the heat treatment, the β phase at a high temperature is insufficient, resulting in poor hot forgeability.

[0018] The present invention has been made in view of such problems, and an object thereof is to provide a TiAl alloy for forging which has excellent hot forgeability and can be subjected to die forging, a TiAl alloy material obtained using the TiAl alloy for forging and having excellent oxidation resistance and high-temperature creep strength due to addition of Nb, and a method for manufacturing a TiAl alloy material for obtaining the TiAl alloy material.

SOLUTION TO PROBLEM

[0019] The above object of the present invention is achieved by the following configuration [1] related to a TiAl alloy for forging.

[1] A TiAl alloy for forging comprising:

Al: 42.0 atomic% or more and 43.6 atomic% or less;
Cu: 0.5 atomic% or more and 2.0 atomic% or less; and
Nb: 3.0 atomic% or more and 7.0 atomic% or less, with
the balance being Ti and unavoidable impurities.

In addition, the above object of the present invention is achieved by the following configuration [2] related to a TiAl alloy material.

[2] A TiAl alloy material comprising:

Al: 42.0 atomic% or more and 43.6 atomic% or less;
Cu: 0.5 atomic% or more and 2.0 atomic% or less; and
Nb: 3.0 atomic% or more and 7.0 atomic% or less, with
the balance being Ti and unavoidable impurities, wherein
an area ratio of a β phase is 0.5% or more and 15.0% or less.

Further, the above object of the present invention is achieved by the following configuration [3] related to a method for manufacturing a TiAl alloy material.

[3] A method for manufacturing a TiAl alloy material including:

a step of forging a TiAl alloy for forging to obtain a forged material, the TiAl alloy comprising Al: 42.0 atomic%

or more and 43.6 atomic% or less, Cu: 0.5 atomic% or more and 2.0 atomic% or less, and Nb: 3.0 atomic% or more and 7.0 atomic% or less, with the balance being Ti and unavoidable impurities; and a step of subjecting the forged material to a heat treatment, wherein the step of subjecting the forged material to a heat treatment includes

a first heat treatment step of performing a heat treatment at a temperature of 1200°C or higher and 1350°C or lower, and
a second heat treatment step of performing a heat treatment at a temperature of 850°C or higher and 1000°C or lower after the first heat treatment step.

ADVANTAGEOUS EFFECTS OF INVENTION

[0020] According to the present invention, it is possible to provide a TiAl alloy for forging which has excellent hot forgeability and can be subjected to die forging, a TiAl alloy material obtained by forging the TiAl alloy for forging and having excellent oxidation resistance and high-temperature creep strength, and a method for manufacturing a TiAl alloy material for obtaining the TiAl alloy material.

BRIEF DESCRIPTION OF DRAWINGS

[0021]

[Fig. 1] Fig. 1 is a graph showing a relationship between Examples and Comparative Examples, where the vertical axis represents a concentration of Cu and the horizontal axis represents a concentration of Al.

[Fig. 2] Fig. 2 is a graph showing a relationship between Examples and Comparative Examples, where the vertical axis represents a minimum creep rate and the horizontal axis represents a β phase fraction.

DESCRIPTION OF EMBODIMENTS

[0022] Hereinafter, embodiments for carrying out the present invention (hereinafter, referred to as "the present embodiment") will be described in detail. The present invention is not limited to the embodiments described below, and can be optionally modified and implemented without departing from the scope of the present invention.

[1. TiAl alloy for forging]

[0023] In a related-art TiAl alloy, when the formation of a β phase at a high temperature is promoted in order to improve the hot forgeability, there are problems that the β phase remains even after a heat treatment and the high-temperature creep strength decreases.

[0024] Therefore, the inventors of the present invention have found that by co-adding Nb and Cu at a specified concentration, deformability of an α phase during hot forging can be improved, and the amount of a β phase after a heat treatment can be reduced while sufficiently ensuring the β phase during forging.

[0025] Accordingly, good high-temperature creep strength can be obtained, and as a result, both the hot forgeability and the high-temperature creep strength can be achieved.

[0026] Hereinafter, components contained in the TiAl alloy for forging according to the present invention, and reasons for limiting upper limit values and lower limit values of concentrations of the components will be described in more detail.

<Al: 42.0 atomic% or more and 43.6 atomic% or less>

[0027] Al is an element that promotes the formation of an Al_2O_3 protective film on the surface of the TiAl alloy. By appropriately containing a predetermined amount of Al in the alloy, base oxidation resistance is improved, a γ phase is stabilized, and a large amount of γ plate is formed in the α phase to form a lamellar structure. Accordingly, creep strength of the TiAl alloy can be improved.

[0028] When a concentration of Al in the TiAl alloy is less than 42.0 atomic%, the desired creep strength cannot be obtained. Therefore, the concentration of Al is 42.0 atomic% or more, and preferably 42.5 atomic% or more.

[0029] On the other hand, when the concentration of Al in the TiAl alloy is more than 43.6 atomic%, the γ phase is excessively stabilized and γ grains are formed, making it impossible to obtain the desired creep strength, and decreasing the hot forgeability. Therefore, the concentration of Al is 43.6 atomic% or less, and preferably 43.5 atomic% or less.

<Cu: 0.5 atomic% or more and 2.0 atomic% or less>

[0030] Cu is an element that has an effect of stabilizing the β phase at a high temperature, and appropriately controlling a content of Cu in the TiAl alloy is the most important requirement in the present embodiment. In addition, Cu is an element that has an effect of improving the deformability of the α phase during hot forging and forming the β phase only at a hot forging temperature.

[0031] When a concentration of Cu in the TiAl alloy is less than 0.5 atomic%, the desired hot forgeability cannot be obtained. Therefore, the concentration of Cu is 0.5 atomic% or more, and preferably 0.7 atomic% or more.

[0032] On the other hand, when the concentration of Cu in the TiAl alloy is more than 2.0 atomic%, the β phase remains after the heat treatment, and the desired creep strength cannot be obtained. Therefore, the concentration of Cu is 2.0 atomic% or less, and preferably 1.2 atomic% or less.

<Nb: 3.0 atomic% or more and 7.0 atomic% or less>

[0033] Nb is an element that has an effect of improving the oxidation resistance of the TiAl alloy.

[0034] When a concentration of Nb in the TiAl alloy is less than 3.0 atomic%, the oxidation resistance of the obtained alloy material decreases. Therefore, the concentration of Nb is 3.0 atomic% or more, and preferably 4.5 atomic% or more.

[0035] On the other hand, when the concentration of Nb in the TiAl alloy is more than 7.0 atomic%, the α phase is unstable, the formation of lamellar grains cannot be ensured, and the high-temperature creep strength decreases. Therefore, the concentration of Nb is 7.0 atomic% or less, and preferably 6.0 atomic% or less.

<Balance>

[0036] The balance of the TiAl alloy for forging according to the present embodiment, excluding the above components, is Ti and unavoidable impurities. Examples of the unavoidable impurities include C, N, O, H, Cl, Fe, Si, Mg, Ca, Mn, Cr, V, Sn, Bi, Ni, Zr, Na, Be, and Zn.

[2. TiAl Alloy Material]

[0037] A TiAl alloy material according to the present embodiment is obtained by forging the above [1. TiAl alloy for forging] and performing a predetermined heat treatment. A composition of the TiAl alloy material is the same as the composition of the above TiAl alloy for forging. Hereinafter, features of the TiAl alloy material according to the present embodiment will be described in detail.

< β phase fraction (area ratio of β phase): 0.5% or more and 15.0% or less>

[0038] The TiAl alloy material according to the present invention has a β phase fraction controlled within a predetermined range. When the β phase fraction is less than 0.5%, grain boundary cracking occurs due to growth of the α phase. Therefore, the β phase fraction is 0.5% or more, and preferably 1.0% or more.

[0039] On the other hand, when the β phase fraction is more than 15.0%, the desired high-temperature creep strength cannot be ensured. Therefore, the β phase fraction is 15.0% or less, preferably 10.0% or less, and more preferably 5.0% or less.

[0040] The β phase fraction can be obtained, for example, by taking a backscattered electron image of a cross section of the TiAl material using a scanning electron microscope (SEM) and calculating an area ratio of a β phase region with respect to the entire field of view. It is preferable that the backscattered electron image is photographed at a plurality of any cross sections, and the area ratio of the β phase in each cross section is obtained, and as the β phase fraction, it is preferable to adopt an average area ratio obtained by averaging these area ratios.

[3. Method for Manufacturing TiAl Alloy Material]

[0041] A method for manufacturing a TiAl alloy material according to the present embodiment includes a step of forging the TiAl alloy for forging according to the present embodiment described in the above [1. TiAl alloy for forging] to obtain a forged material, and a step of subjecting the forged material to a heat treatment at a predetermined temperature. Hereinafter, the method for manufacturing a TiAl alloy material according to the present embodiment will be described in detail.

<Step of Forging TiAl alloy for forging>

[0042] In the present embodiment, forging conditions for forging the TiAl alloy for forging are not particularly limited. The forging step includes, for example, a step of heating an ingot of TiAl alloy for forging to a predetermined temperature and a step of applying a pressure to the heated ingot.

[0043] It is preferable to select an appropriate range for the heating temperature, the pressure, and the like depending on the desired shape and the like.

<Step of Subjecting Forged Material to Heat Treatment>

[0044] In the present embodiment, the forged material obtained by the above forging step is subjected to two heat treatments.

[0045] The purpose of a first heat treatment step is to bring the metal structure closer to an α single phase structure. When the temperature in the first heat treatment step is lower than 1200°C, the metal structure may not be brought close to a single α phase. Therefore, the temperature in the first heat treatment step is 1200°C or higher, and preferably 1250°C or higher.

[0046] On the other hand, when the temperature in the first heat treatment step is higher than 1350°C, the amount of the β phase of the obtained TiAl alloy material increases and the β phase fraction is more than 15.0%, resulting in a decrease in creep strength. Therefore, the temperature in the first heat treatment step is 1350°C or lower, and preferably 1300°C or lower.

[0047] The purpose of a second heat treatment step after the first heat treatment step is to form a γ phase to form a lamellar structure [$\alpha_2 + \gamma$]. When the temperature in the second heat treatment step is lower than 850°C, the formation of the γ phase is insufficient, or the heat treatment time is longer, resulting in poor industrial productivity. Therefore, the temperature in the second heat treatment step is 850°C or higher, and preferably 875°C or higher.

[0048] On the other hand, when the temperature in the second heat treatment step is higher than 1000°C, the formation amount of the γ phase is reduced, and the desired lamellar structure necessary for providing strength cannot be obtained. Therefore, the temperature in the second heat treatment step is 1000°C or lower, and preferably 975°C or lower.

[0049] In this way, in the present embodiment, a TiAl alloy material having the β phase fraction described in the above [2. TiAl Alloy Material] can be obtained by forging a TiAl alloy having the composition specified in the above [1. TiAl alloy for forging] and subjecting the obtained forged material to the above first heat treatment step and second heat treatment step.

[0050] The TiAl alloy material according to the present embodiment can be subjected to die forging, is obtained from a TiAl alloy for forging having excellent hot forgeability, has excellent high-temperature resistance, is lightweight, and has excellent creep strength, and is thus preferably used as a member that requires such material properties. Therefore, the TiAl alloy material according to the present embodiment can be suitably used, for example, as a member for an internal combustion engine such as a turbine for transportation machines and industrial machines.

Examples

[0051] Hereinafter, Examples and Comparative Examples of the TiAl alloy for forging according to the present embodiment will be described.

[Hot Forgeability Evaluation]

(Preparation of Forged Material)

[0052] First, raw materials having the compositions shown in Table 1 below were prepared, and TiAl alloy ingots each weighing about 9 kg were prepared by a cold crucible induction melting (CCIM) method. Each of the TiAl alloy ingots had a tapered cylinder shape, and had an axial diameter of 110 mm at one end face, an axial diameter of 85 mm at the other end face, and an axial length of 300 mm.

[0053] Next, a cylindrical test piece having a diameter of 80 mm and an axial length of 120 mm was prepared from the obtained TiAl alloy ingot and was held at a temperature of 1250°C or higher for 0.5 hours or longer, and then uniaxial compression processing was performed with respect to the axial direction of the test piece by using a pressing machine at a rolling reduction of 70% to 80%, to prepare a disc-shaped forged material. Even when the rolling reduction is changed by about 10%, it is considered that the evaluation results for the hot forgeability and the creep strength are not greatly influenced.

(Hot Forgeability Evaluation Test)

[0054] Thereafter, the obtained forged material was cut at an approximate center position of the disc shape in the radial direction, and was divided into two semilunar forged materials. Then, for each member, cracks in a cross section region having a length of at least 120 mm in the radial direction were observed and the number of cracks with a depth of 2 mm or more was counted. Then, a crack number density was calculated by dividing the number of cracks by the total length (24 cm to 26 cm) in the longitudinal direction in the cross section of the two forged materials obtained by cutting.

[0055] As evaluation criteria for the hot forgeability, those with a crack number density of 0.45 (/cm) or less were acceptable as having good hot forgeability, and those with a crack number density of more than 0.45 (/cm) were unacceptable.

[Creep Strength Evaluation]

(Preparation of Test Material)

[0056] Six rectangular materials each having a width of 14 mm, a length of 130 mm, and a thickness of 24 mm were taken from the approximate center position of the disc-shaped forged material obtained as described above in the radial direction, and any one of these was used as a test material for a creep strength evaluation test.

(Heat Treatment)

[0057] The above test material was subjected to two heat treatments under various conditions also shown in Table 1 below. The purpose of the first heat treatment is to bring the structure close to an α single phase structure, and the purpose of the second heat treatment is to form a γ phase to form a lamellar structure [$\alpha 2 + \gamma$].

[0058] As conditions in the first heat treatment, the heat treatment was performed by changing the post-heat treatment temperature every about 30°C, the material structure was observed for all test pieces, and the lowest temperature among the test pieces that underwent the α single phase was adopted.

[0059] The second heat treatment was performed at conditions including a temperature of 950°C for 1 hour or at a temperature of 900°C for 3 hours to obtain a heat-treated material.

(Creep Strength Evaluation Test)

[0060] A flanged creep test piece having a total length of 80 mm, a parallel portion diameter of 6 mm, a length of 30 mm, and a screw portion (both ends of the test piece in the longitudinal direction) M12 was prepared from the obtained heat-treated material, and a creep rate test was performed with a single type creep tester. The test conditions were a temperature of 800°C and a stress of 150 MPa, and a minimum creep rate was obtained based on test data. The minimum creep rate is an index of how much deformation occurs at a high temperature, and is a value generally used as one of indices for the creep strength.

[0061] As evaluation criteria for the creep strength, those with a minimum creep rate of 3.0×10^{-1} (sec⁻¹) or less were acceptable, and those with a minimum creep rate of more than 3.0×10^{-1} (sec⁻¹) were unacceptable.

[Structure Observation on TiAl Alloy Material]

(Preparation of Test Piece)

[0062] A creep test piece was taken from the heat-treated material obtained by the above heat treatment, and then the surface of the remaining material at the end in the longitudinal direction was mirror-finished by mechanical and chemical polishing to prepare a test piece for structure observation.

(Measurement of Area Ratio of β Phase)

[0063] A backscattered electron image of the above test piece was taken using a scanning electron microscope (SEM) at a magnification of 400 times. The photographing was performed near the center of the plate thickness of the test piece, and three photographs were obtained for each test piece. Then, for each SEM photograph, the presence of the β phase was identified based on a bright contrast (Z contrast reflecting composition information) peculiar to the β phase, and the β phase region was colored separately using image processing software. Thereafter, the area ratio of the β phase in the entire field of view was obtained using image analysis software "Image Pro Plus" (manufactured by Media Cybernetics), and an average area ratio of the β phase in the three photographs was calculated.

[0064] The average area ratio of the β phase and the evaluation results are shown in Table 1 below.

[Table 1]

[0065]

Table 1

No.		Composition (atomic%) Balance: Ti and unavoidable impurities			Condition in heat treatment Temperature × time		Average area ratio (%) of β phase	Hot forgeability	Creep strength
		Al	Nb	Cu	First heat treatment step	Second heat treatment step		Crack number density (/cm at depth of 2 mm or more)	Minimum creep rate (sec ⁻¹)
Invention Example	1	43.47	4.94	1.02	1280°C × 1 hr	950° C × 1 hr	1.58	0.35	6.96 × 10 ⁻⁰⁸
	2	43.47	4.94	1.02	1300°C × 1 hr	900° C × 3 hr	2.55	0.35	9.85 × 10 ⁻⁰⁸
	3	43.14	3.92	1.57	1280°C × 1 hr	950° C × 1 hr	6.85	0.15	1.85 × 10 ⁻⁰⁷
	4	42.56	5.00	1.42	1280°C × 1 hr	950° C × 1 hr	9.85	0.27	2.13 × 10 ⁻⁰⁷
	5	42.76	4.92	0.97	1280°C × 1 hr	950° C × 1 hr	2.23	0.17	2.48 × 10 ⁻⁰⁷
Comparative Example W	6	43.83	4.98	1.05	1280°C × 1 hr	950° C × 1 hr	1.25	0.50	4.59 × 10 ⁻⁰⁸
	7	43.69	4.07	0.84	1280°C × 1 hr	950° C × 1 hr	0	0.62	> 1.00 × 10 ⁻¹
	8	41.97	0	2.01	1250°C × 1 hr	950° C × 1 hr	5.63	0.23	1.24 × 10 ⁻⁰⁶
	9	43.08	0	2.09	1280°C × 1 hr	950° C × 1 hr	6.95	0.12	5.75 × 10 ⁻⁰⁷
	10	43.31	5.09	2.11	1280°C × 1 hr	950° C × 1 hr	19.05	0.19	3.71 × 10 ⁻⁰⁷

[0066] As shown in the above Table 1, in Examples Nos. 1 to 5, the composition of the TiAl alloy satisfies the requirements specified in the present invention, and the area ratio of the β phase of the TiAl alloy material also satisfies the requirements specified in the present invention, so that both good hot forgeability and high-temperature creep strength can be achieved.

[0067] On the other hand, in Comparative Example No. 6, the concentration of Al is more than the upper limit of the range of the present invention, so that the hot forgeability decreases. In Comparative Example No. 7, the concentration of Al is more than the upper limit of the range of the present invention, so that the hot forgeability is poor, and brittle fracture is exhibited at a high temperature, so that brittle rupture occurs immediately after the creep test, and the creep strength remarkably decreases. In Comparative Example No. 8, the concentration of Al and the concentration of Nb are less than the lower limits of the range of the present invention and the concentration of Cu is more than the upper limit of the range of the present invention, so that the creep strength decreases. In Comparative Example No. 9, the concentration of Nb is less than the lower limit of the range of the present invention and the concentration of Cu is more than the upper limit of the range of the present invention, so that the creep strength decreases. In Comparative Example No. 10, the concentration of Cu is more than the upper limit of the range of the present invention, so that the β phase remains after the first and second heat treatment steps, and the average area ratio of the β phase is more than the range specified in the present invention, and as a result, the creep strength decreases.

[0068] Fig. 1 is a graph showing a relationship between Examples and Comparative Examples, where the vertical

axis represents the concentration of Cu and the horizontal axis represents the concentration of Al. In Fig. 1, white one indicates good creep strength, and black one indicates poor creep strength. In addition, "o" indicates good hot forgeability, and "0" indicates poor hot forgeability. That is, "o" indicates that the hot forgeability and the creep strength are good, and represents Examples Nos. 1 to 5. "•" indicates that the hot forgeability is good but the creep strength decreases, and represents Comparative Examples Nos. 8, 9 and 10. In addition, "0" indicates that the creep strength is good but the hot forgeability decreases, and represents Comparative Example No. 6. "♦" indicates that the hot forgeability and the creep strength decrease, and represents Comparative Example No. 7. A range indicated by the dashed line in the drawing is a region in which the concentration of Cu and the concentration of Al are within the ranges of the present invention.

[0069] As shown in Fig. 1, when the concentration of Cu and the concentration of Al in the TiAl alloy are within the ranges specified in the present invention, it is possible to obtain a TiAl alloy material having excellent hot forgeability and particularly excellent creep strength.

[0070] Fig. 2 is a graph showing a relationship between Examples and Comparative Examples, where the vertical axis represents the minimum creep rate and the horizontal axis represents the β phase fraction. In Fig. 2, "o", "•", "0" and "♦" are the same as in Fig. 1. In Comparative Example 7 indicated by "♦", rupture occurs instantaneously immediately after the start of the test, so that "↑" is indicated in the figure, indicating that the creep rate is extremely high. In addition, a range indicated by the dashed line in the figure is a region in which the β phase fraction is within the range of the present invention and the minimum creep rate is acceptable.

[0071] As shown in Fig. 2, the TiAl alloy material obtained by the manufacturing method according to the present invention using the TiAl alloy for forging according to the present invention shows a tendency that the smaller the remaining β phase fraction, the better the minimum creep rate. If the β phase fraction is 5% or less, an even better minimum creep rate can be obtained in the present invention. If the β phase fraction is less than 0.5%, it is shown that the minimum creep rate increases (worsens) or the forgeability decreases.

[0072] Although various embodiments have been described above with reference to the drawings, it is needless to say that the present invention is not limited to such examples. It will be apparent to those skilled in the art that various alterations, modifications can be conceived within the scope of claims, and it should be understood that they also justifiably belong to the technical scope of the present invention. In addition, each component in the above embodiments may be combined freely in the range without departing from the spirit of the invention.

[0073] The present application is based on a Japanese Patent Application (No. 2021-070003) filed on April 16, 2021 and a Japanese Patent Application (No. 2022-008171) filed on January 21, 2022, the contents of which are incorporated by reference into the present application.

Claims

1. A TiAl alloy for forging comprising:

Al: 42.0 atomic% or more and 43.6 atomic% or less;
Cu: 0.5 atomic% or more and 2.0 atomic% or less; and
Nb: 3.0 atomic% or more and 7.0 atomic% or less, with
the balance being Ti and unavoidable impurities.

2. A TiAl alloy material comprising:

Al: 42.0 atomic% or more and 43.6 atomic% or less;
Cu: 0.5 atomic% or more and 2.0 atomic% or less; and
Nb: 3.0 atomic% or more and 7.0 atomic% or less, with
the balance being Ti and unavoidable impurities, wherein
an area ratio of a β phase is 0.5% or more and 15.0% or less.

3. A method for manufacturing a TiAl alloy material comprising:

a step of forging a TiAl alloy for forging to obtain a forged material, the TiAl alloy comprising Al: 42.0 atomic% or more and 43.6 atomic% or less, Cu: 0.5 atomic% or more and 2.0 atomic% or less, and Nb: 3.0 atomic% or more and 7.0 atomic% or less, with the balance being Ti and unavoidable impurities; and
a step of subjecting the forged material to a heat treatment, wherein
the step of subjecting the forged material to a heat treatment includes

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a first heat treatment step of performing a heat treatment at a temperature of 1200°C or higher and 1350°C or lower, and
a second heat treatment step of performing a heat treatment at a temperature of 850°C or higher and 1000°C or lower after the first heat treatment step.

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FIG. 1

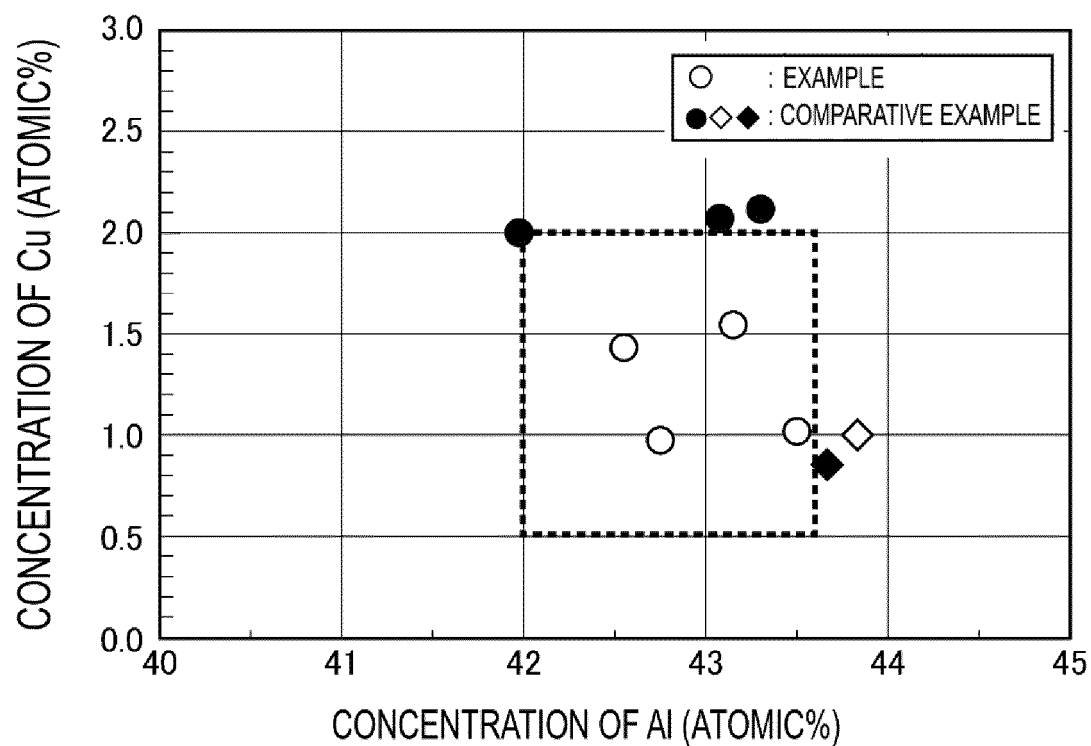
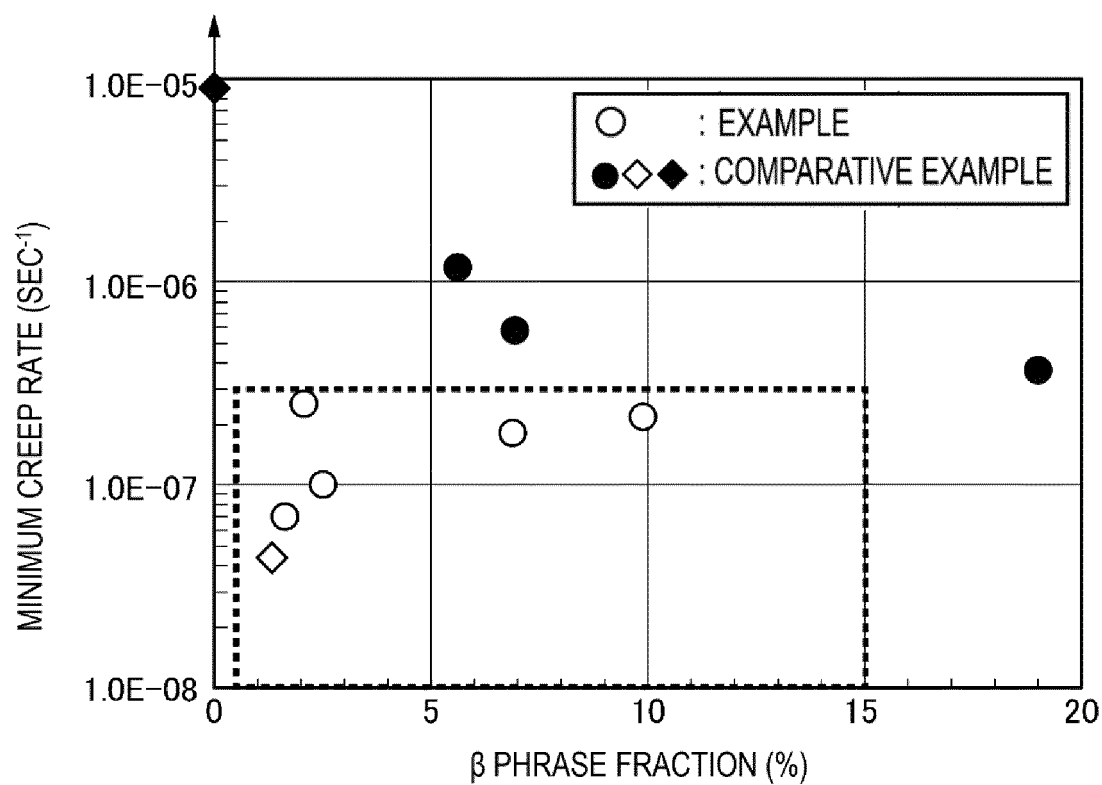


FIG. 2



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2022/011450

A. CLASSIFICATION OF SUBJECT MATTER

C22C 14/00(2006.01)i; **C22F 1/00**(2006.01)n; **C22F 1/18**(2006.01)i
 FI: C22C14/00 Z; C22F1/18 H; C22F1/00 691B; C22F1/00 691C; C22F1/00 694A; C22F1/00 682; C22F1/00 624;
 C22F1/00 684C; C22F1/00 640B; C22F1/00 650A; C22F1/00 630K; C22F1/00 651B; C22F1/00 683

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)

C22C14/00; C22F1/00; C22F1/18

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 1971-2022
 Registered utility model specifications of Japan 1996-2022
 Published registered utility model applications of Japan 1994-2022

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 2016-166418 A (LEISTRITZ TURBINENTECHNIK GMBH) 15 September 2016 (2016-09-15)	1-3
A	JP 04-235262 A (MITSUBISHI MATERIALS CORP.) 24 August 1992 (1992-08-24)	1-3
A	JP 03-226538 A (NIPPON KOKAN LTD.) 07 October 1991 (1991-10-07)	1-3

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

* Special categories of cited documents:	"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
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
"E" earlier application or patent but published on or after the international filing date	"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
"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)	"&" document member of the same patent family
"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	

Date of the actual completion of the international search

13 May 2022

Date of mailing of the international search report

24 May 2022

Name and mailing address of the ISA/JP

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Telephone No.

PCT/JP2022/011450

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 6687118 B [0010]
- JP 2009215631 A [0010]
- JP 5926886 B [0010]
- JP 5512964 B [0010]
- JP 2021070003 A [0073]
- JP 2022008171 A [0073]