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

(11) EP 3 415 648 A1

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

(43) Date of publication:
19.12.2018 Bulletin 2018/51

(21) Application number: **17778878.3**

(22) Date of filing: **21.02.2017**

(51) Int Cl.:
C22C 1/04 *(2006.01)* ***B22F 3/02*** *(2006.01)*
B22F 3/10 *(2006.01)* ***C22C 1/00*** *(2006.01)*
C22C 14/00 *(2006.01)* ***C22C 21/00*** *(2006.01)*

(86) International application number:
PCT/JP2017/006390

(87) International publication number:
WO 2017/175499 (12.10.2017 Gazette 2017/41)

(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:
MA MD

(30) Priority: **05.04.2016 JP 2016075932**

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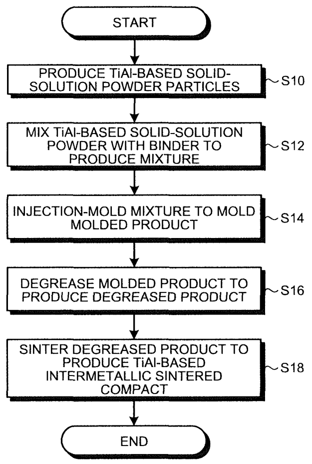
(54) **SINTERED BODY OF TiAl INTERMETALLIC COMPOUND AND METHOD FOR PRODUCING SINTERED BODY OF TiAl INTERMETALLIC COMPOUND**

(57) The sintered density of a TiAl-based intermetallic sintered compact is improved. A method for producing a TiAl-based intermetallic sintered compact includes sintering TiAl-based powder to produce the TiAl-based intermetallic sintered compact, the TiAl-based powder containing a TiAl-based intermetallic compound in which Ti and Al are bonded and an additional metal. The additional metal is Ni, or Ni and Fe.

FIG.4



Printed by Jouve, 75001 PARIS (FR)

Description

Field

[0001] The present invention relates to a TiAl-based intermetallic sintered compact and a method for producing a TiAl-based intermetallic sintered compact.

Background

[0002] A TiAl-based intermetallic compound is an intermetallic compound (alloy) in which Ti (titanium) and Al (aluminum) are bonded and is applied to structures for high-temperature use, such as engines and aerospace instruments, because of its light weight and high strength at high temperatures. The TiAl-based intermetallic compound is difficult to be shaped by forging or casting for its low ductility and other reasons and is sometimes shaped by sintering. A sintered compact of a TiAl-based intermetallic compound is formed by sintering a TiAl-based intermetallic compound powder, for example, as described in

Patent Literature 1.

Citation List

Patent Literature

[0003] Patent Literature 1: Japanese Patent Application Laid-open No. 3-243741

Summary

Technical Problem

[0004] The strength of a sintered compact of a TiAl-based intermetallic compound can be increased by increasing the sintered density in sintering. There is therefore a demand for increasing the sintered density.

[0005] The present invention is then aimed to provide a TiAl-based intermetallic sintered compact with high sintered density and high strength and a method for producing a TiAl-based intermetallic sintered compact with high sintered density and high strength.

Solution to Problem

[0006] To solve the problem described above and achieve the object, a method for producing a TiAl-based intermetallic sintered compact of the present disclosure includes sintering TiAl-based powder to produce a TiAl-based intermetallic sintered compact, the TiAl-based powder containing a TiAl-based intermetallic compound in which Ti and Al are bonded and an additional metal. The additional metal is Ni, or Ni and Fe. This method for producing a TiAl-based intermetallic sintered compact allows the TiAl-based intermetallic sintered compact to exhibit a metal structure in which the additional metal phase exists at the grain boundary between adjacent TiAl phases. Accordingly, this method for producing a TiAl-based intermetallic sintered compact can increase the sintered density and increase the strength.

[0007] It is preferable that the method for producing a TiAl-based intermetallic sintered compact includes a mixing step of mixing the TiAl-based powder with a binder to yield a mixture; an injection molding step of molding the mixture into a molded product with a metal-powder injection molder; a degreasing step of degreasing the molded product to produce a degreased product; and a sintering step of sintering the degreased product to produce the TiAl-based intermetallic sintered compact. This method for producing a TiAl-based intermetallic sintered compact uses a metal-powder injection molding method and therefore can improve the shape accuracy while improving the sintered density.

[0008] It is preferable that in the method for producing a TiAl-based intermetallic sintered compact, the TiAl-based powder has a Ni content of 0.01% by weight to 1% by weight. This method for producing a TiAl-based intermetallic sintered compact allows the additional metal phase to exist appropriately at the grain boundary between adjacent TiAl phases, thereby appropriately improving the sintered density.

[0009] It is preferable that in the method for producing a TiAl-based intermetallic sintered compact, the TiAl-based powder has a total amount of Ni and Fe of 0.01% by weight to 2% by weight. This method for producing a TiAl-based intermetallic sintered compact allows the additional metal phase to exist appropriately at the grain boundary between adjacent TiAl phases, thereby appropriately improving the sintered density.

[0010] It is preferable that in the method for producing a TiAl-based intermetallic sintered compact, the TiAl-based powder is formed by mixing a plurality of TiAl-based solid-solution powder particles containing the TiAl-based intermetallic compound and the additional metal. This method for producing a TiAl-based intermetallic sintered compact allows the additional metal phase to exist appropriately at the grain boundary between adjacent TiAl phases, thereby appropriately improving the sintered density.

[0011] It is preferable that in the method for producing a TiAl-based intermetallic sintered compact, the TiAl-based powder is formed by mixing a plurality of TiAl-based powder particles and a plurality of additional metal powder particles, the TiAl-based powder particles being powder particles of the TiAl-based intermetallic compound, the additional metal powder particles containing the additional metal. This method for producing a TiAl-based intermetallic sintered compact allows the additional metal phase to exist appropriately at the grain boundary between adjacent TiAl phases, thereby appropriately improving the sintered density.

[0012] To solve the problem described above and achieve the object, a TiAl-based intermetallic sintered compact of the present disclosure contains a TiAl-based intermetallic compound in which Ti and Al are bonded and an additional metal that is Ni. A Ni content is 0.01% by weight to 1% by weight of total content. Since this TiAl-based intermetallic sintered compact contains Ni in this proportion with respect to the TiAl-based intermetallic compound, the Ni phase can exist at the grain boundary of TiAl phases of the sintered compact. Accordingly, this TiAl-based intermetallic sintered compact improves in sintered density.

[0013] To solve the problem described above and achieve the object, a TiAl-based intermetallic sintered compact of the present disclosure contains a TiAl-based intermetallic compound in which Ti and Al are bonded and an additional metal that is Ni and Fe. A total content of Ni and Fe is 0.01% by weight to 2% by weight of total content. Since this TiAl-based intermetallic sintered compact contains Ni and Fe in this proportion with respect to the TiAl-based intermetallic compound, the NiFe phase can exist at the grain boundary of TiAl phases of the sintered compact. Accordingly, this TiAl-based intermetallic sintered compact improves in sintered density.

[0014] It is preferable that in the TiAl-based intermetallic sintered compact, the TiAl-based intermetallic compound contains 20 to 80% by weight of Ti, 20 to 80% by weight of Al, and 0 to 30% by weight of mixed metal, and the mixed metal contains at least one of Nb, Cr, and Mn. This TiAl-based intermetallic sintered compact contains the TiAl-based intermetallic compound in this proportion and therefore improves in strength.

[0015] It is preferable that in the TiAl-based intermetallic sintered compact, a plurality of TiAl-based sintered powder particles containing the TiAl-based intermetallic compound and the additional metal are bonded, and an additional metal phase that is a metal phase of the additional metal exists between the TiAl-based sintered powder particles adjacent to each other. The TiAl-based intermetallic sintered compact improves in sintered density more appropriately because the additional metal phase exists at the grain boundary of TiAl phases of the sintered compact.

Advantageous Effects of Invention

[0016] The present invention can increase the sintered density of a TiAl-based intermetallic sintered compact and increase the strength.

Brief Description of Drawings

[0017]

FIG. 1 is a block diagram illustrating a configuration of a sintered compact production system according to a first embodiment.

FIG. 2 is a diagram schematically illustrating a configuration of a powder production apparatus according to the first embodiment.

FIG. 3 is a schematic diagram illustrating phases of a TiAl-based intermetallic sintered compact according to the first embodiment.

FIG. 4 is a flowchart illustrating the production flow of the TiAl-based intermetallic sintered compact with the sintered compact production system according to the first embodiment.

FIG. 5 is a table illustrating the sintered density in examples and comparative examples.

FIG. 6 is a diagram illustrating the metal structure of the TiAl-based intermetallic sintered compact in a comparative example.

FIG. 7 is a diagram illustrating the metal structure of the TiAl-based intermetallic sintered compact in a comparative example.

FIG. 8 is a diagram of the metal structure of the TiAl-based intermetallic sintered compact in an example.

FIG. 9 is a diagram of the metal structure of the TiAl-based intermetallic sintered compact in an example.

FIG. 10 is a graph illustrating the relation between the Ni content and the sintered density.

FIG. 11 is a table illustrating the sintered density in examples and a comparative example.

FIG. 12 is a diagram of the metal structure of the TiAl-based intermetallic sintered compact in a comparative example.

FIG. 13 is a diagram of the metal structure of the TiAl-based intermetallic sintered compact in an example.

FIG. 14 is a diagram of the metal structure of the TiAl-based intermetallic sintered compact in an example.

FIG. 15 is a graph illustrating the relation between the Ni and Fe content and the sintered density.

FIG. 16 is a table illustrating the sintered density in an example and a comparative example.

FIG. 17 is a diagram of the metal structure of the TiAl-based intermetallic sintered compact in a comparative example.

FIG. 18 is a diagram of the metal structure of the TiAl-based intermetallic sintered compact in an example. Description of Embodiments

[0018] Preferred embodiments of the present invention will be described in detail below with reference to the accompanying drawings. It should be noted that the present invention is not limited by those embodiments and when a plurality of embodiments are provided, the embodiments may be combined.

First Embodiment

[0019] FIG. 1 is a block diagram illustrating a configuration of a sintered compact production system according to a first embodiment. The sintered compact production system 1 according to the first embodiment is a system for performing a method for producing a sintered compact of a TiAl-based intermetallic compound. The TiAl-based intermetallic sintered compact refers to a sintered compact mainly composed of a TiAl-based intermetallic compound (TiAl-based alloy). The TiAl-based intermetallic compound in the present embodiment is a compound (TiAl, Ti_3Al, Al_3Ti, and the like) in which Ti (titanium) and Al (aluminum) are bonded. However, the TiAl-based intermetallic compound may be a solid-solution of a mixed metal M as described later in a TiAl phase, which is a phase in which Ti and Al are bonded.

[0020] As illustrated in FIG. 1, the sintered compact production system 1 includes a powder production apparatus 10, a metal-powder injection molding apparatus 20, a degreasing apparatus 30, and a sintering apparatus 40. The sintered compact production system 1 produces a sintered compact of a TiAl-based intermetallic compound (TiAl-based intermetallic sintered compact) by producing powder particles of a TiAl-based intermetallic compound with the powder production apparatus 10, injection-molding the powder particles together with a binder with the metal-powder injection molding apparatus 20, and sintering the molded product subjected to metal-powder injection molding with the sintering apparatus 40.

[0021] The powder production apparatus 10 produces TiAl-based solid-solution powder particles B_1 from a TiAl-based ingot A_1. The TiAl-based ingot A_1 is an ingot of the above-noted TiAl-based intermetallic compound. The TiAl-based ingot A_1 in the present embodiment is a solid-solution of an additional metal in the TiAl phase of the TiAl-based intermetallic compound. The additional metal in the first embodiment is Ni (nickel). The TiAl-based ingot A_1 contains 99% by weight to 99.99% by weight of the TiAl-based intermetallic compound and 0.01% by weight to 1% by weight of Ni as an additional metal. More preferably, the Ni content as an additional metal is 0.2% by weight to 0.6% by weight.

[0022] The TiAl-based intermetallic compound in the TiAl-based ingot A_1 contains 20 to 80% by weight of Ti, 20 to 80% by weight of Al, and 0 to 30% by weight of a mixed metal M. That is, in terms of all components including the additional metal, the TiAl-based ingot A_1 contains 19.8% by weight to 79.992% by weight of Ti, 19.8% by weight to 79.992% by weight of Al, and 0% by weight to 29.997% by weight of a mixed metal M. When the TiAl-based intermetallic compound in the TiAl-based ingot A_1 contains a mixed metal M, the mixed metal M is in a solid-solution state in the TiAl phase. The mixed metal M is a metal other than Ti and Al and contains, for example, at least one of Nb (niobium), Cr (chromium), and Mn (manganese).

[0023] As described above, the TiAl-based ingot A_1 is a mass of an alloy that is a solid solution of Ni as an additional metal and the mixed metal M in the TiAl phase of the TiAl-based intermetallic compound. The TiAl-based ingot A_1 is produced by melting and mixing pure metals of the components (Ti, Al, Ni, mixed metal M), followed by cooling.

[0024] FIG. 2 is a diagram schematically illustrating a configuration of the powder production apparatus according to the first embodiment. As illustrated in FIG. 2, the powder production apparatus 10 includes a heater 12 and a gas injector 14. The heater 12 is a heating wire wound around the TiAl-based ingot A_1 into a coil shape. Current is fed through the heater 12 to generate heat, which melts the TiAl-based ingot A_1. The melted TiAl-based ingot A_1 drops as liquid TiAl-based melt A_2 vertically downward of the TiAl-based ingot A_1.

[0025] The gas injector 14 is an injection pipe into which an inert gas G (in the present embodiment, argon) is introduced and jetted from an opening. The opening of the gas injector 14 is positioned vertically below the TiAl-based ingot A_1 and jets the inert gas G toward the TiAl-based melt A_2 dropped vertically downward of the TiAl-based ingot A_1. The TiAl-based melt A_2 to which the inert gas G is jetted is split and cooled to be solidified into a plurality of TiAl-based solid-solution powder particles B_1. In the present embodiment, a plurality of gas injectors 14 are provided. However, one gas injector 14 may be provided or more than one gas injector 14 may be provided.

[0026] The TiAl-based solid-solution powder particles B_1 are produced by melting the TiAl-based ingot A_1 and thereafter solidifying the melt and therefore contain the same metal components as the TiAl-based ingot A_1. That is, the TiAl-based solid-solution powder particles B_1 are powder (particles) of an alloy that is a solid-solution of Ni as an additional metal and a mixed metal M in the TiAl phase of the TiAl-based intermetallic compound. The ratio of each metal component contained in the TiAl-based solid-solution powder particle B_1 is the same as the TiAl-based ingot A_1. The particle size of the TiAl-based solid-solution powder particle B_1 is 1 μm to 50 μm, more preferably 1 μm to 20 μm. In the description of the present embodiment, one particle of powder is referred to as powder particle, and an aggregate of powder particles is referred to as powder. The TiAl-based solid-solution powder particle B_1 is one particle, and an aggregate of TiAl-based solid-solution powder particles B_1 is referred to as TiAl-based powder B_2.

[0027] The metal-powder injection molding apparatus 20 illustrated in FIG. 1 is an apparatus that performs metal-powder injection molding (MIM). The metal-powder injection molding apparatus 20 produces a molded product D from a mixture C. The mixture C is a mixture of TiAl-based powder B_2 produced by the powder production apparatus 10 and a binder. The binder bonds the TiAl-based solid-solution powder particles B_1 in the TiAl-based powder B_2 and is a resin having flowability. The addition of a binder imparts flowability and moldability to the mixture C.

[0028] The metal-powder injection molding apparatus 20 injects the mixture C into a mold. The mixture C injected into the mold forms a molded product D. The molded product D has flowability because of the addition of a binder and is kept in a shape defined by the mold even after being released from the mold.

[0029] The degreasing apparatus 30 is an apparatus that degreases the molded product D. Specifically, the degreasing apparatus 30 accommodates the molded product D released from the mold and heats the inside to a degreasing temperature to remove (degrease) the binder from the molded product D, thereby producing a degreased product E. The degreasing temperature is a temperature equal to or higher than the temperature at which the binder is thermally decomposed.

[0030] The sintering apparatus 40 accommodates the degreased product E and heats the inside to a sintering temperature to sinter the degreased product E (sinter the TiAl-based solid-solution powder particles B_1 in the degreased product E), thereby producing a TiAl-based intermetallic sintered compact F. The sintering temperature is a temperature that allows the TiAl-based solid-solution powder particles B_1 to be sintered and, for example, is in a range from 1400°C to 1500°C. The sintering apparatus 40 keeps the inside at a sintering temperature for a predetermined time (for example, one hour) to accelerate sintering. The sintering apparatus 40 may be an apparatus independent of the degreasing apparatus 30 or may be the same apparatus as the degreasing apparatus 30. When the sintering apparatus 40 is the same apparatus as the degreasing apparatus 30, the temperature is not lowered from the degreasing temperature and is continuously increased to the sintering temperature.

[0031] The TiAl-based intermetallic sintered compact F is formed by sintering the TiAl-based solid-solution powder particles B_1 in the degreased product E and therefore has the same components as the TiAl-based solid-solution powder particles B_1 in the same ratios. That is, the TiAl-based intermetallic sintered compact F contains 99% by weight to 99.99% by weight of the TiAl-based intermetallic compound and contains 0.01% by weight to 1% by weight of Ni as an additional metal. More preferably, the Ni content as an additional metal is 0.2% by weight to 0.6% by weight. The TiAl-based intermetallic compound in the TiAl-based intermetallic sintered compact F contains 20 to 80% by weight of Ti, 20 to 80% by weight of Al, and 0 to 30% by weight of the mixed metal M. That is, in terms of all components including the additional metal, the TiAl-based intermetallic sintered compact F contains 19.8% by weight to 79.992% by weight of Ti, 19.8% by weight to 79.992% by weight of Al, and 0% by weight to 29.997% by weight of the mixed metal M.

[0032] Here, the TiAl-based solid-solution powder particles B_1 bonded by sintering are referred to as TiAl-based sintered powder particles F1. The TiAl-based intermetallic sintered compact F is formed such that a plurality of TiAl-based sintered powder particles F1 form necks to be bonded (fused). The TiAl-based solid-solution powder particles B_1 are a solid solution of Ni as an additional metal in the TiAl-based intermetallic compound (in the TiAl phase). On the other hand, the TiAl-based sintered powder particles F1 are not a solid solution of Ni as an additional metal in the TiAl-based intermetallic compound (in the TiAl phase) but the TiAl phase is separate from the additional metal phase (Ni phase). In other words, the TiAl-based intermetallic compound (TiAl phase) in the TiAl-based intermetallic sintered compact F contains Ti, Al, and the mixed metal M and does not contain Ni.

[0033] FIG. 3 is a schematic diagram illustrating the phases of the TiAl-based intermetallic sintered compact according to the first embodiment. In the following, the TiAl phase in the TiAl-based sintered powder particle F1 is referred to as TiAl phase F2 and the additional metal phase (Ni phase) is referred to as additional metal phase F3. As illustrated in FIG. 3, the Ni phase (additional metal phase F3) is present between adjacent TiAl-based sintered powder particles F1 (grain boundary), that is, between the TiAl phase F2 of one TiAl-based sintered powder particle F1 and the TiAl phase F2 of the adjacent TiAl-based sintered powder particle F1. To put it another way, the Ni phase (additional metal phase F3) is present on the periphery of each of a plurality of TiAl-based intermetallic compounds (TiAl phase F2).

[0034] The TiAl-based intermetallic sintered compact F improves in sintered density because the additional metal phase F3 is present at the grain boundary between adjacent TiAl phases F2.

[0035] The production flow of the TiAl-based intermetallic sintered compact F with the sintered compact production system 1 will be described below. FIG. 4 is a flowchart illustrating the production flow of the TiAl-based intermetallic sintered compact with the sintered compact production system according to the first embodiment. As illustrated in FIG. 4, first of all, the sintered compact production system 1 generates a plurality of TiAl-based solid-solution powder particles B_1 (TiAl-based powder B_2) from the TiAl-based ingot A_1 with the powder production apparatus 10 (step S10). After generating the TiAl-based solid-solution powder particles B_1, the sintered compact production system 1 mixes the TiAl-based powder B_2 with a binder to produce a mixture C (step S12) and injection-molds the mixture C with the metal-powder injection molding apparatus 20 to mold a molded product D (step S14). After molding the molded product D, the sintered compact production system 1 degreases the molded product D with the degreasing apparatus 30 to produce a degreased product E (step S16) and sinters the degreased product E with the sintering apparatus 40 to produce a TiAl-based intermetallic sintered compact F (step S18). At step S18, the production method for the TiAl-based intermetallic sintered compact is finished.

[0036] As described above, the method for producing the TiAl-based intermetallic sintered compact F by the sintered compact production system 1 in the present embodiment sinters the TiAl-based powder B_2 to produce the TiAl-based intermetallic sintered compact F. The TiAl-based powder B_2 contains a TiAl-based intermetallic compound in which Ti and Al are bonded and an additional metal. The additional metal is Ni in the first embodiment. Since this method for producing the TiAl-based intermetallic sintered compact F sinters the TiAl-based powder B_2 containing a TiAl-based intermetallic compound and an additional metal, the TiAl-based intermetallic sintered compact F exhibits a metal structure in which the additional metal phase F3 exists at the grain boundary between adjacent TiAl phases F2. Therefore, this method for producing the TiAl-based intermetallic sintered compact F can increase the sintered density and increase the strength.

[0037] The method for producing the TiAl-based intermetallic sintered compact F by the sintered compact production system 1 includes a mixing step, an injection molding step, a degreasing step, and a sintering step. The mixing step mixes the TiAl-based powder B_2 with a binder to yield a mixture C. The injection molding step molds the mixture C into a molded product D with a metal-powder injection molder (metal-powder injection molding apparatus 20). The degreasing step degreases the molded product D to produce a degreased product E. The sintering step sinters the degreased product E to produce a TiAl-based intermetallic sintered compact F. This method for producing the TiAl-based intermetallic sintered compact F produces the TiAl-based intermetallic sintered compact F using a metal-powder injection molding method. When a metal-powder injection molding method is used, it is necessary to perform sintering with the molded shape being kept. In particular, when a sintered compact of a TiAl-based intermetallic compound is produced by a metal-powder injection molding method, the sintering condition for sintering while keeping the molded shape is strict, such as a narrow range of sintering temperatures. For this reason, when a sintered compact of a TiAl-based intermetallic compound is produced by a metal-powder injection molding method, it may be difficult to improve the sintered density while keeping the molded shape because of a failure to set the sintering condition appropriately. However, according to the present embodiment, the TiAl-based intermetallic sintered compact F has a metal structure in which the additional metal phase F3 exists at the grain boundary between adjacent TiAl phases F2. Thus, this method for producing the TiAl-based intermetallic sintered compact F can improve the shape accuracy with the metal-powder injection molding method while keeping the sintered density high.

[0038] The TiAl-based powder B_2 has a Ni content of 0.01% by weight to 1% by weight. Thus, the sintering apparatus 40 allows the additional metal phase F3 to exist appropriately at the grain boundary between adjacent TiAl phases F2. Accordingly, this method for producing the TiAl-based intermetallic sintered compact F can improve the sintered density more appropriately.

[0039] The TiAl-based powder B_2 is a mixture of a plurality of TiAl-based solid-solution powder particles B_1 containing a TiAl-based intermetallic compound and an additional metal. In this method for producing the TiAl-based intermetallic sintered compact F, since the TiAl-based solid-solution powder particle B_1 used in sintering is a particle containing a TiAl-based intermetallic compound and an additional metal, the additional metal phase F3 can exist appropriately at the grain boundary between the TiAl phases F2 of the sintered compact. Therefore, this method for producing the TiAl-based intermetallic sintered compact F can improve the sintered density more appropriately.

[0040] The TiAl-based intermetallic sintered compact F according to the present embodiment contains a TiAl-based intermetallic compound in which Ti and Al are bonded and an additional metal that is Ni, and the Ni content is 0.01% by weight to 1% by weight of the total content. Since this TiAl-based intermetallic sintered compact F contains Ni in this proportion with respect to the TiAl-based intermetallic compound, the additional metal phase F3 can exist at the grain boundary of the TiAl phase F2 of the sintered compact. Therefore, the sintered density of this TiAl-based intermetallic sintered compact F can be improved more appropriately.

[0041] In the TiAl-based intermetallic sintered compact F, the TiAl-based intermetallic compound contains 20 to 80% by weight of Ti, 20 to 80% by weight of Al, and 0 to 30% by weight of a mixed metal M, and the mixed metal M contains at least one of Nb, Cr, and Mn. This TiAl-based intermetallic sintered compact F improves in strength because the TiAl-based intermetallic compound has such a proportion.

[0042] In the TiAl-based intermetallic sintered compact F, a plurality of TiAl-based sintered powder particles F1 containing a TiAl-based intermetallic compound and an additional metal are bonded to each other, and the additional metal phase, which is the metal phase of the additional metal, exists between the adjacent TiAl-based sintered powder particles F1. In this TiAl-based intermetallic sintered compact F, since the additional metal phase F3 exists at the grain boundary of the TiAl phase F2 of the sintered compact, the sintered density can be improved more appropriately.

Second Embodiment

[0043] A second embodiment will now be described. The second embodiment differs from the first embodiment in that Ni and Fe (iron) are used as additional metal. In the second embodiment, the parts having a configuration common to that of the first embodiment are not further elaborated.

[0044] The additional metal according to the second embodiment is Ni and Fe. A TiAl-based ingot A_1 according to the second embodiment contains 98% by weight to 99.99% by weight of a TiAl-based intermetallic compound and contains 0.01% by weight to 2% by weight of Ni and Fe in total as the additional metal. The Ni content is equal to or greater than 0.01% by weight and less than 2% by weight with respect to the total amount of Ni and Fe, more preferably 0.01% by weight to 1% by weight.

[0045] In the second embodiment, a TiAl-based intermetallic sintered compact F is produced using the TiAl-based ingot A_1 containing Ni and Fe as additional metal by a method similar as in the first embodiment. The TiAl-based intermetallic sintered compact F according to the second embodiment contains 98% by weight to 99.99% by weight of a TiAl-based intermetallic compound and 0.01% by weight to 2% by weight of Ni and Fe in total.

[0046] The TiAl-based intermetallic sintered compact F according to the second embodiment forms phases similar as in the first embodiment. That is, in the TiAl-based intermetallic sintered compact F according to the second embodiment, the alloy phase of Ni and Fe (additional metal phase F3) exists between adjacent TiAl-based sintered powder particles F1 (grain boundary), that is, between the TiAl phase F2 of one TiAl-based sintered powder particle F1 and the TiAl phase F2 of the adjacent TiAl-based sintered powder particle F1. Thus, the TiAl-based intermetallic sintered compact F according to the second embodiment also improves in sintered density, because the additional metal phase F3 is present at the grain boundary between adjacent TiAl phases F2.

[0047] The TiAl-based powder B_2 according to the second embodiment contains 0.01% by weight to 2% by weight of Ni and Fe in total. Thus, the sintering apparatus 40 allows the additional metal phase F3 to exist at the grain boundary between adjacent TiAl phases F2 appropriately. The method for producing the TiAl-based intermetallic sintered compact F according to the second embodiment therefore also can improve the sintered density more appropriately.

[0048] The TiAl-based intermetallic sintered compact F according to the second embodiment contains a TiAl-based intermetallic compound in which Ti and Al are bonded and additional metal that is Fe and Ni, and the total content of Fe and Ni is 0.01% by weight to 2% by weight of the total content. Since this TiAl-based intermetallic sintered compact F contains Fe and Ni in this proportion with respect to the TiAl-based intermetallic compound, the additional metal phase F3 can exist at the grain boundary of the TiAl phase F2 of the sintered compact. Therefore, the sintered density of this TiAl-based intermetallic sintered compact F can be improved more appropriately.

[0049] As illustrated in the first embodiment and the second embodiment, the use of Ni, or Ni and Fe as the additional metal can improve the sintered density of the TiAl-based intermetallic sintered compact F more appropriately.

Third Embodiment

[0050] A third embodiment will now be described. The third embodiment differs from the first embodiment in that a mixture of a plurality of TiAl-based powder particles that are powder particles of a TiAl-based intermetallic compound and a plurality of additional metal powder particles containing Ni as an additional metal is used as a TiAl-based powder. In the third embodiment, the parts having a configuration common to that in the first embodiment are not further elaborated.

[0051] The powder production apparatus 10 according to the third embodiment produces TiAl-based powder particles B_1a from a TiAl-based ingot A_1a. The TiAl-based ingot A_1a does not contain Ni as an additional metal and contains a TiAl-based intermetallic compound alone. The TiAl-based intermetallic compound here contains Ti, Al and a mixed metal M similar to the first embodiment, and the proportion is also the same as in the first embodiment. The TiAl-based powder particle B_1a is a powder particle containing Ti, Al, and a mixed metal M and has the same content ratios as the TiAl-based ingot A_1a. The particle size of the TiAl-based powder particle B_1a is the same as the TiAl-based solid-solution powder particle B_1 of the first embodiment.

[0052] In the third embodiment, a plurality of TiAl-based powder particles B_1a and a plurality of additional metal powder particles B_3a are mixed to produce a TiAl-based powder B_2a. The additional metal powder particles B_3a are powder particles of Ni. That is, the TiAl-based powder B_2a includes powder particles of different two components, namely, powder particles of a TiAl-based intermetallic compound and powder particles of Ni that are additional metal powder particles. The content ratio between the TiAl-based intermetallic compound and Ni in the TiAl-based powder B_2a is the same as the TiAl-based powder B_2 according to the first embodiment.

[0053] The particle size of the additional metal powder particle B_3a is in the same range as the TiAl-based powder particle B_1a, more preferably smaller than the TiAl-based powder particle B_1a. For example, the particle size of the additional metal powder particle B_3a is preferably 0.01 time to 0.2 time the TiAl-based powder particle B_1a.

[0054] The sintered compact production system 1 according to the third embodiment mixes this TiAl-based powder B_2a with a binder to produce a mixture C, and the subsequent process of the sintered compact production system 1 according to the third embodiment is similar as in the first embodiment and produces the same TiAl-based intermetallic sintered compact F as in the first embodiment.

[0055] In this way, the TiAl-based powder B_2a according to the third embodiment is a mixture of TiAl-based powder particles B_1a that are powder particles of a TiAl-based intermetallic compound and additional metal powder particles B_3a containing Ni as an additional metal. Also in such a case, the TiAl-based intermetallic sintered compact F similar to the first embodiment can be produced, and the sintered compact production system 1 according to the third embodiment can improve the sintered density appropriately as in the first embodiment.

[0056] The production method according to the third embodiment is applicable to the second embodiment. That is, the additional metal powder particles B_3a may be powder particles of Ni and Fe. In this case, the additional metal powder particles B_3a may be powder particles of Ni and powder particles of Fe or may be powder particles of the alloy of Ni and Fe. In this case, the content ratio between the TiAl-based intermetallic compound and Ni and Fe in the TiAl-based powder B_2a is similar to that of the TiAl-based powder B_2 according to the second embodiment. The content ratio between Ni and Fe in the additional metal powder B_2a is also the same as in the first embodiment.

[0057] In the foregoing description, the additional metal is Ni, or Ni and Fe. However, the additional metal of Fe alone can increase the sintered density similarly if the Fe content is equal to or greater than 2% by weight. In this case, it is preferable that the Fe content is equal to or less than 5% by weight of the total content in order to suppress reduction in strength of the sintered compact (creep strength) and to suppress reduction in oxidation resistance.

Examples

[0058] Examples will now be described. FIG. 5 is a table illustrating the sintered density in examples and comparative examples. FIG. 6 and FIG. 7 are diagrams illustrating the metal structure of the TiAl-based intermetallic sintered compact in a comparative example. FIG. 8 and FIG. 9 are diagrams of the metal structure of the TiAl-based intermetallic sintered compact in an example. FIG. 10 is a graph illustrating the relation between the Ni content and the sintered density. In examples described below, the molded product molded with a metal-powder injection molder is degreased and then sintered at a sintering temperature of 1450°C for two hours to produce a TiAl-based intermetallic sintered compact F. In comparative examples described below, the molded product molded with a metal-powder injection molder is degreased and then sintered at a sintering temperature of 1450°C for two hours in the same manner as in the examples to produce a TiAl-based intermetallic sintered compact Fx. The TiAl-based intermetallic sintered compact F in the examples contains 30% by weight of Al, 14% by weight of Nb as a mixed metal M, and 0.7% by weight of Cr as a mixed metal M. This is the same in the TiAl-based intermetallic sintered compact Fx in the comparative examples.

[0059] The TiAl-based intermetallic sintered compact Fx according to Comparative Example 1 contains neither Fe nor Ni. More specifically, the TiAl-based intermetallic sintered compact Fx according to Comparative Example 1 has a Fe content less than 0.05% by weight and a Ni content less than 0.01% by weight. As illustrated in FIG. 5, the TiAl-based intermetallic sintered compact Fx according to Comparative Example 2 has a Fe content of less than 0.05% by weight and a Ni content of 1.05% by weight. As illustrated in FIG. 5, the TiAl-based intermetallic sintered compact F according to Example 1 contains Ni alone as an additional metal, in which the Ni content is 0.2% by weight of the total content, and the Fe content is less than 0.05% by weight of the total content. The TiAl-based intermetallic sintered compact F according to Example 2 contains Ni alone as an additional metal, in which the Ni content is 0.6% by weight of the total content, and the Fe content is equal to or less than 0.05% by weight of the total content. In Comparative Example 1 and Examples 1 and 2, the method in the third embodiment, that is, the production method of mixing the TiAl-based powder particles B_1a and the additional metal powder particles B_3a was employed.

[0060] The TiAl-based intermetallic sintered compact Fx according to Comparative Example 1 has a sintered density of 91% as illustrated in FIG. 5 and has many pores V as illustrated in FIG. 6. The TiAl-based intermetallic sintered compact Fx according to Comparative Example 2 has a sintered density of 97% as illustrated in FIG. 5 and has many pores V as illustrated in FIG. 7, and a γ-phase colony occurs at the grain boundary. The γ-phase colony is a mass of single γ-phase and deteriorates the performance of the TiAl-based intermetallic sintered compact having a lamellar structure.

[0061] On the other hand, the TiAl-based intermetallic sintered compact F according to Example 1 has a sintered density of 98% as illustrated in FIG. 5 and has fewer pores V as illustrated in FIG. 8, and a γ-phase colony does not occur. The TiAl-based intermetallic sintered compact F according to the Example 2 has a sintered density of 97% as illustrated in FIG. 5 and has fewer pores V as illustrated in FIG. 9, and a γ-phase colony does not occur.

[0062] The horizontal axis in FIG. 10 represents the Ni content and the vertical axis represents the sintered density. FIG. 10 is a plot of results of Comparative Examples 1 and 2 and Examples 1 and 2. As illustrated in FIG. 10, when the TiAl-based intermetallic sintered compact F containing Ni alone as an additional metal has a Ni content of 0.1% by weight to 1% by weight of the total content, the sintered density is high and occurrence of a γ-phase colony is suppressed.

[0063] FIG. 11 is a table illustrating the sintered density in examples and a comparative example. FIG. 12 is a diagram of the metal structure of the TiAl-based intermetallic sintered compact in a comparative example. FIG. 13 and FIG. 14 are diagrams of the metal structure of the TiAl-based intermetallic sintered compact in an example. FIG. 15 is a graph illustrating the relation between the Ni and Fe content and the sintered density.

[0064] As illustrated in FIG. 11, the TiAl-based intermetallic sintered compact Fx according to Comparative Example 3 has a Ni content of 0.34% by weight and a Fe content of 1.79% by weight. That is, the TiAl-based intermetallic sintered compact Fx according to Comparative Example 3 has a total content of Ni and Fe of 2.13% by weight. The TiAl-based intermetallic sintered compact F according to Examples 3 and 4 has a Ni content of 0.17% by weight and a Fe content of 0.92% by weight. That is, the TiAl-based intermetallic sintered compact F according to Examples 3 and 4 has a total content of Ni and Fe of 1.09% by weight. For the TiAl-based intermetallic sintered compact Fx according to Comparative Example 3, a similar method as in the third embodiment was employed, and in Example 4, the method in the third embodiment, that is, the production method of mixing the

TiAl-based powder particles B_1a and the additional metal powder particles B_3a was employed. On the other hand, in the Example 3, the method in the first embodiment, that is, the production method using the TiAl-based solid-solution powder particles B_1 containing a TiAl-based intermetallic compound and an additional metal was employed.

[0065] The TiAl-based intermetallic sintered compact Fx according to Comparative Example 3 has a sintered density of 97% as illustrated in FIG. 11 and has many pores V as illustrated in FIG. 12, and a γ-phase colony occurs at the grain boundary. On the other hand, the TiAl-based intermetallic sintered compact F according to Example 3 has a sintered density of 99% as illustrated in FIG. 11 and has fewer pores V as illustrated in FIG. 13, and a γ-phase colony does not occur. The TiAl-based intermetallic sintered compact F according to Example 4 has a sintered density of 97% as illustrated in FIG. 11 and has fewer pores V as illustrated in FIG. 14, and a γ-phase colony does not occur.

[0066] The horizontal axis in FIG. 15 represents the total content of Ni and Fe and the vertical axis represents the sintered density. FIG. 15 is a plot of the results of Comparative Examples 1 and 3 and Examples 3 and 4. As illustrated in FIG. 15, when the TiAl-based intermetallic sintered compact F containing Ni and Fe as additional metal has a total content of Ni and Fe of 0.1% by weight to 2% by weight of the total content, the sintered density is high and occurrence of a γ-phase colony is suppressed. Referring to Example 3 and Example 4, it is understood that the sintered density can be increased either by the method in the third embodiment, that is, the production method of mixing the TiAl-based powder particles B_1a and the additional metal powder particles B_3a or by the method in the first embodiment, that is, the production method using the TiAl-based solid-solution powder particles B_1 containing a TiAl-based intermetallic compound and an additional metal.

[0067] FIG. 16 is a table illustrating the sintered density in an example and a comparative example. FIG. 17 is a diagram of the metal structure of the TiAl-based intermetallic sintered compact in a comparative example. FIG. 18 is a diagram of the metal structure of the TiAl-based intermetallic sintered compact in an example. As illustrated in FIG. 16, the TiAl-based intermetallic sintered compact Fx according to Comparative Example 4 has a Fe content of 1.08% by weight and a Ni content of less than 0.01% by weight. The TiAl-based intermetallic sintered compact F according to Example 5 has a Fe content of 2.13% by weight and a Ni content of less than 0.01% by weight. In Comparative Example 4 and Example 5, the sintering temperature is 1420°C. The other conditions are the same in Comparative Example 4 and Comparative Example 1 and are the same in Example 5 and Example 1.

[0068] The TiAl-based intermetallic sintered compact Fx according to Comparative Example 4 has a sintered density of 93% as illustrated in FIG. 16 and has many pores V as illustrated in FIG. 17. On the other hand, the TiAl-based intermetallic sintered compact F according to Example 5 has a sintered density of 98% as illustrated in FIG. 16 and has fewer pores V as illustrated in FIG. 18, and a γ-phase colony does not occur.

[0069] In this way, the TiAl-based intermetallic sintered compact F achieves a high sintered density when Fe alone is an additional metal and the Fe content is equal to or greater than 2% by weight.

[0070] Although embodiments of the present invention have been described above, embodiments are not intended to be limited by the specifics of these embodiments. The components above include those easily conceived by those skilled in the art, those substantially identical, and equivalents. Furthermore, the components above can be combined as appropriate. The components can be omitted, replaced, or modified in various ways without departing from the spirit of the foregoing embodiments.

Reference Signs List

[0071]

1	Sintered compact production system
10	Powder production apparatus
20	Metal-powder injection molding apparatus
30	Degreasing apparatus
40	Sintering apparatus
A_1	TiAl-based ingot
A_2	TiAl-based melt
B_1	TiAl-based solid-solution powder particle
B_1a	TiAl-based powder particle
B_2	TiAl-based powder
B_3a	Additional metal powder particle
C	Mixture
D	Molded product
E	Degreased product
F	TiAl-based intermetallic sintered compact
F1	TiAl-based sintered powder particle
F2	TiAl phase
F3	Additional metal phase

Claims

1. A method for producing a TiAl-based intermetallic sintered compact, comprising:

sintering TiAl-based powder to produce a TiAl-based intermetallic sintered compact, the TiAl-based powder containing a TiAl-based intermetallic compound in which Ti and Al are bonded and an additional metal, wherein
the additional metal is Ni, or Ni and Fe.

2. The method for producing a TiAl-based intermetallic sintered compact according to claim 1, the method comprising:

a mixing step of mixing the TiAl-based powder with a binder to yield a mixture;
an injection molding step of molding the mixture into a molded product with a metal-powder injection molder;
a degreasing step of degreasing the molded product to produce a degreased product; and
a sintering step of sintering the degreased product to produce the TiAl-based intermetallic sintered compact.

3. The method for producing a TiAl-based intermetallic sintered compact according to claim 1 or 2, wherein the TiAl-based powder has a Ni content of 0.01% by weight to 1% by weight.

4. The method for producing a TiAl-based intermetallic sintered compact according to any one of claims 1 to 3, wherein the TiAl-based powder has a total amount of Ni and Fe of 0.01% by weight to 2% by weight.

5. The method for producing a TiAl-based intermetallic sintered compact according to any one of claims 1 to 4, wherein the TiAl-based powder is formed by mixing a plurality of TiAl-based solid-solution powder particles containing the TiAl-based intermetallic compound and the additional metal.

6. The method for producing a TiAl-based intermetallic sintered compact according to any one of claims 1 to 4, wherein the TiAl-based powder is formed by mixing a plurality of TiAl-based powder particles and a plurality of additional metal powder particles, the TiAl-based powder particles being powder particles of the TiAl-based intermetallic compound, the additional metal powder particles containing the additional metal.

7. A TiAl-based intermetallic sintered compact containing a TiAl-based intermetallic compound in which Ti and Al are bonded and an additional metal that is Ni, wherein
a Ni content is 0.01% by weight to 1% by weight of total content.

8. A TiAl-based intermetallic sintered compact containing a TiAl-based intermetallic compound in which Ti and Al are bonded and an additional metal that is Ni and Fe, wherein
a total content of Ni and Fe is 0.01% by weight to 2% by weight of total content.

9. The TiAl-based intermetallic sintered compact according to claim 7 or 8, wherein the TiAl-based intermetallic compound contains 20 to 80% by weight of Ti, 20 to 80% by weight of Al, and 0 to 30% by weight of mixed metal, and the mixed metal contains at least one of Nb, Cr, and Mn.

10. The TiAl-based intermetallic sintered compact according to any one of claims 7 to 9, wherein a plurality of TiAl-based sintered powder particles containing the TiAl-based intermetallic compound and the additional metal are bonded, and an additional metal phase that is a metal phase of the additional metal exists between the TiAl-based sintered powder particles adjacent to each other.

FIG.1

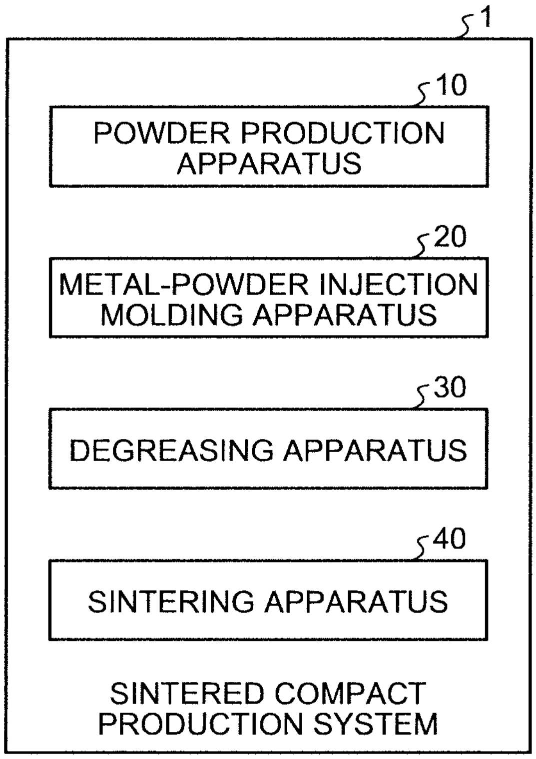

1
10
POWDER PRODUCTION APPARATUS
20
METAL-POWDER INJECTION MOLDING APPARATUS
30
DEGREASING APPARATUS
40
SINTERING APPARATUS
SINTERED COMPACT PRODUCTION SYSTEM

FIG.2

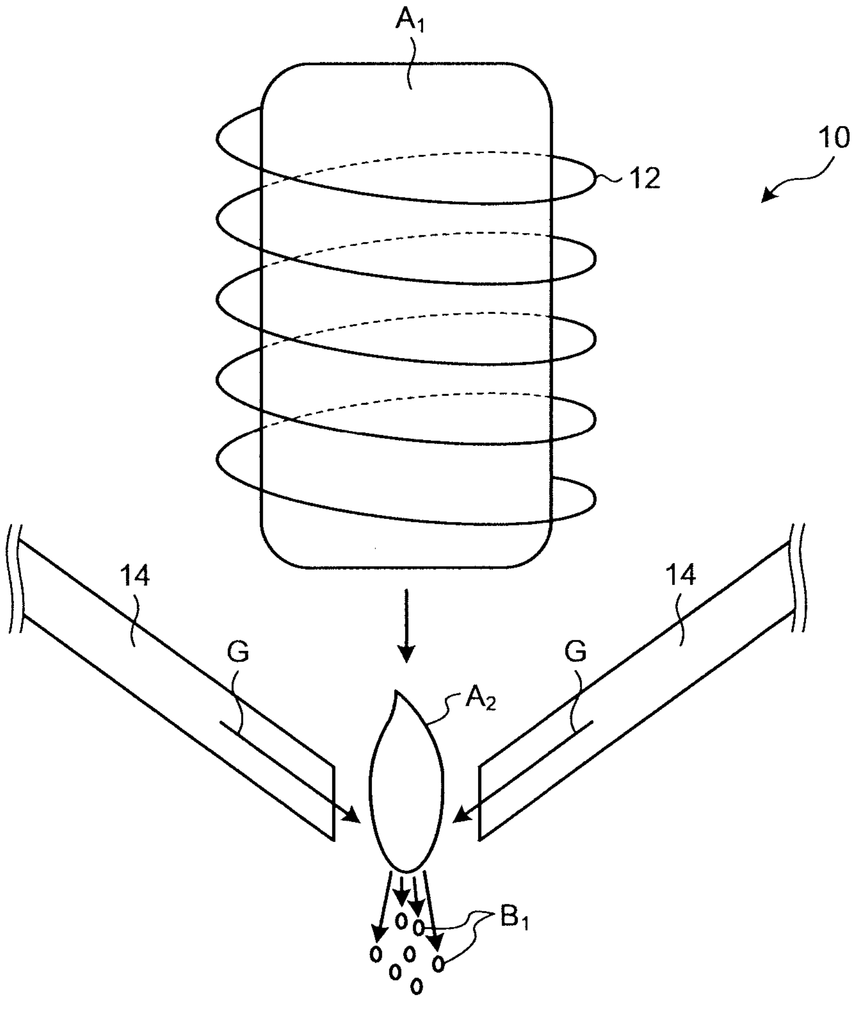


FIG.3

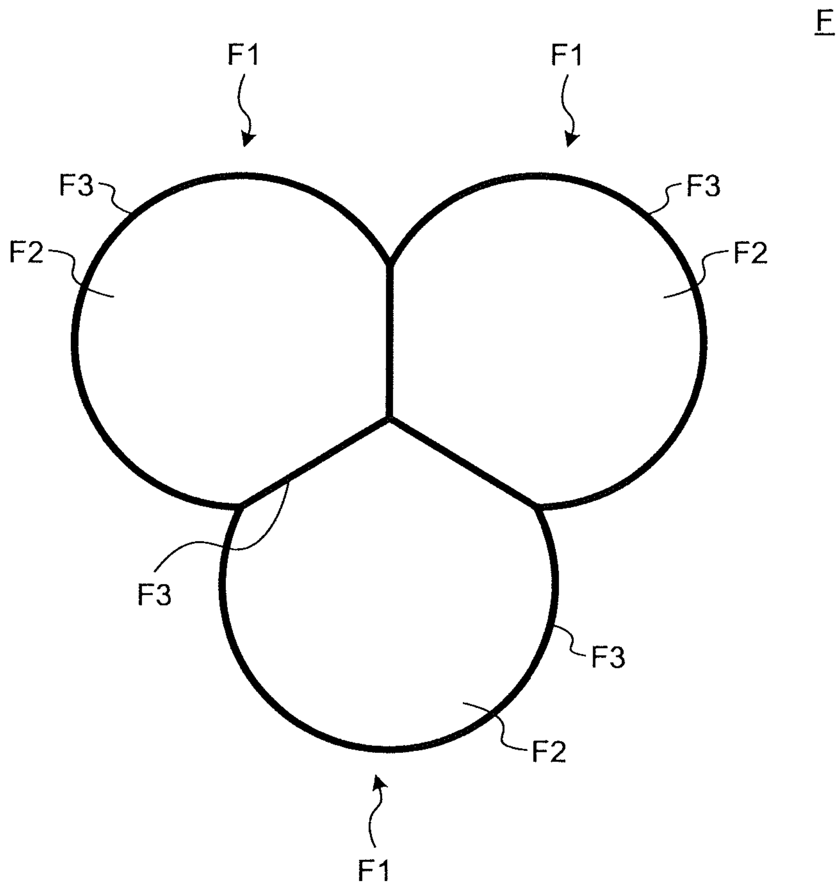


FIG.4

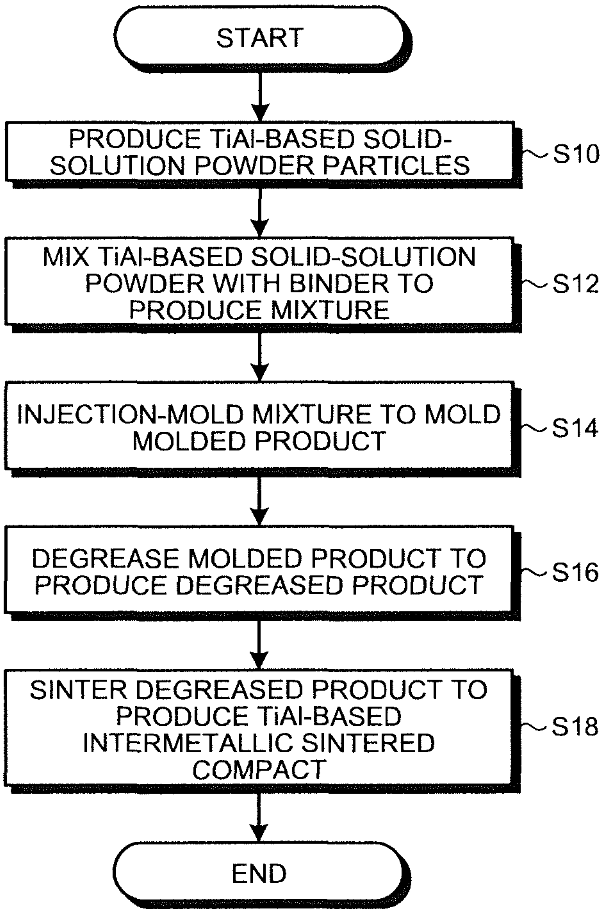
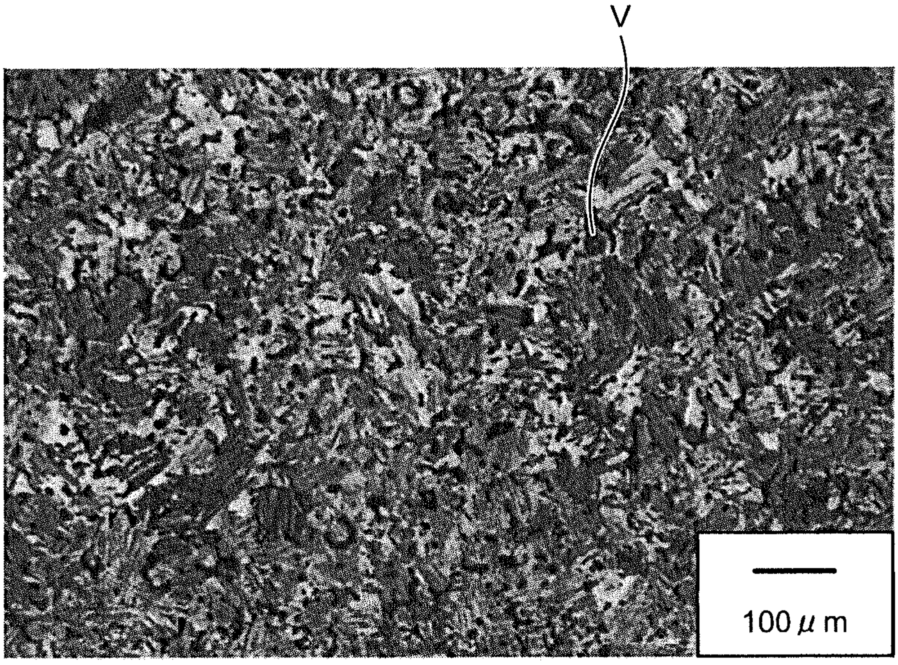


FIG.5

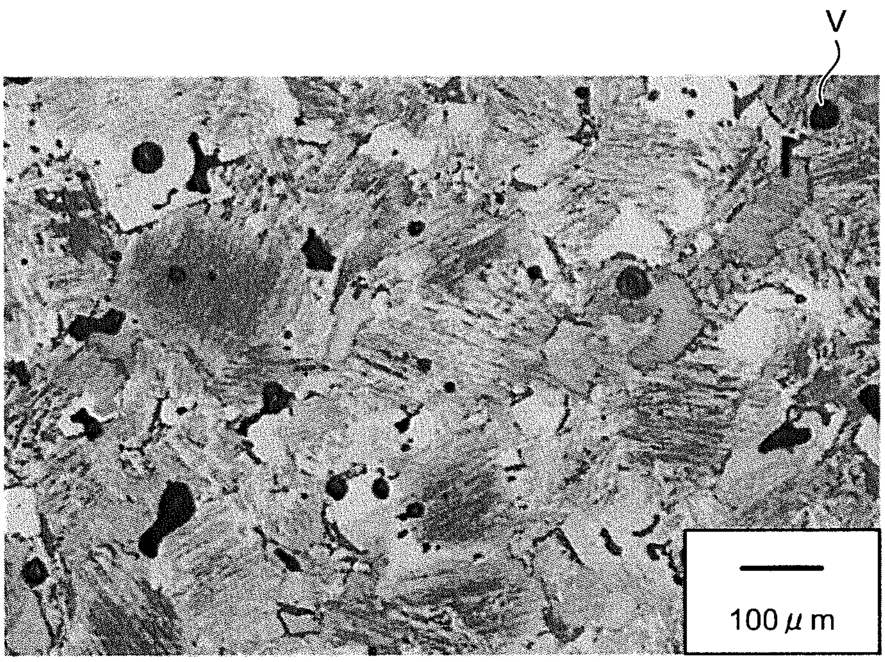
	AMOUNT OF Fe (wt%)	AMOUNT OF Ni (wt%)	SINTERED DENSITY (%)	γ PHASE OF GRAIN BOUNDARY
COMPARATIVE EXAMPLE 1	<0.05	<0.01	91	
COMPARATIVE EXAMPLE 2	<0.05	1.05	97	PRESENT
EXAMPLE 1	<0.05	0.2	98	ABSENT
EXAMPLE 2	<0.05	0.6	97	ABSENT

FIG.6



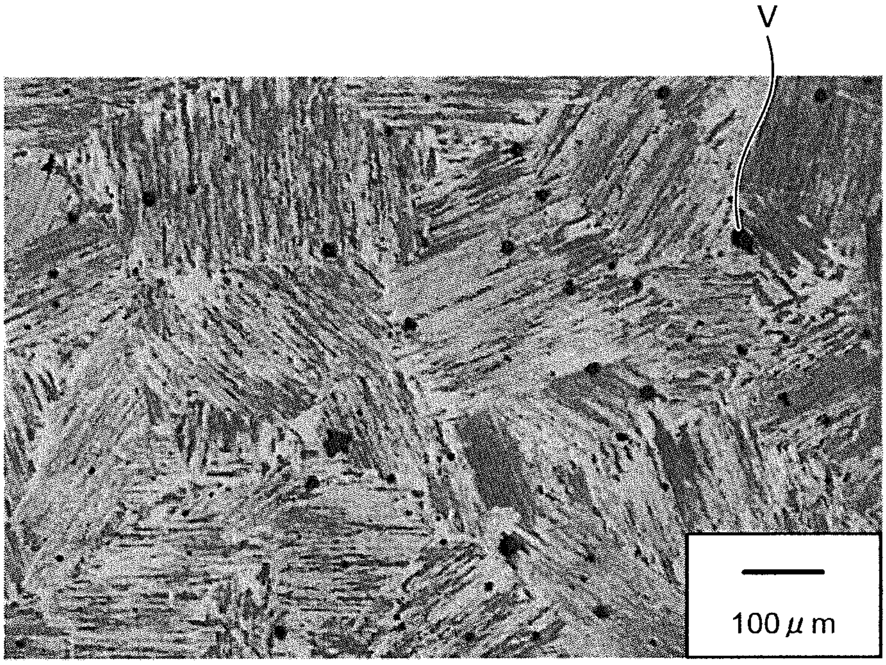
COMPARATIVE EXAMPLE 1

FIG.7



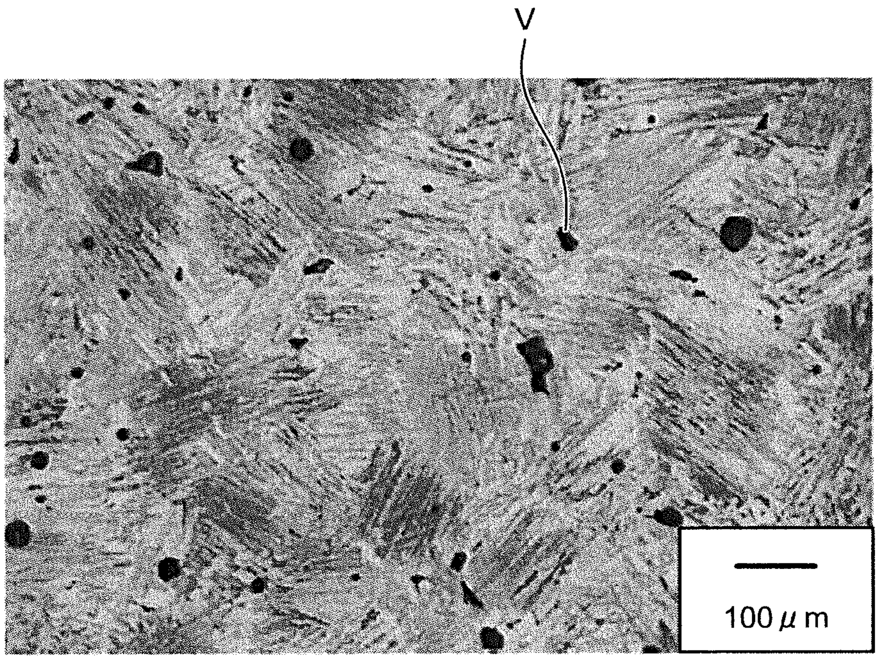
COMPARATIVE EXAMPLE 2

FIG.8



EXAMPLE 1

FIG.9



EXAMPLE 2

FIG.10

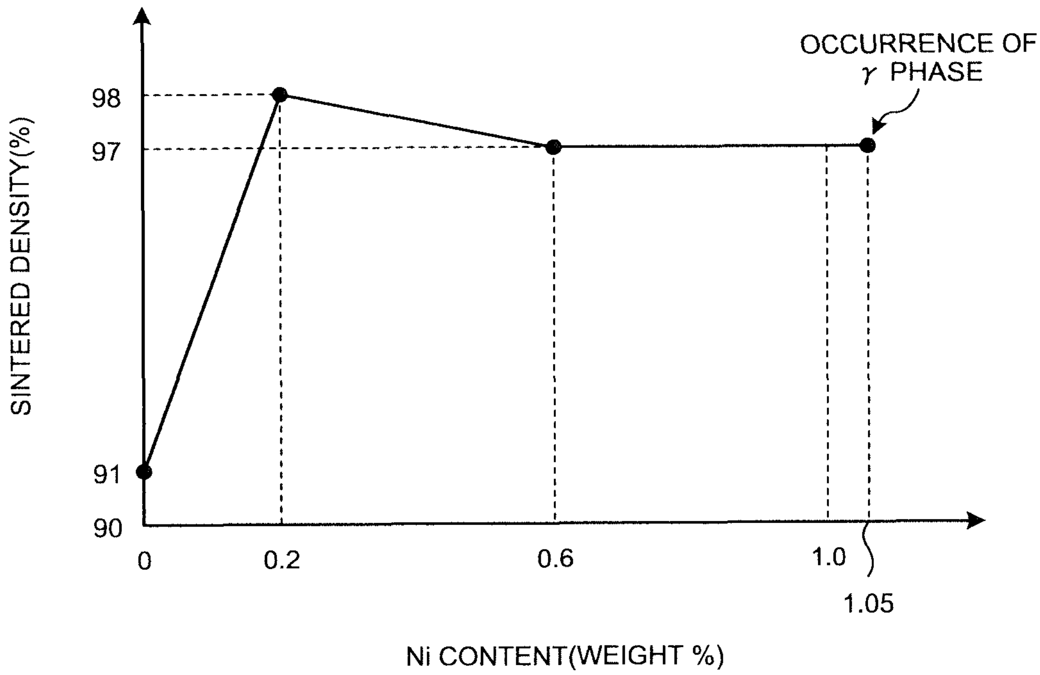
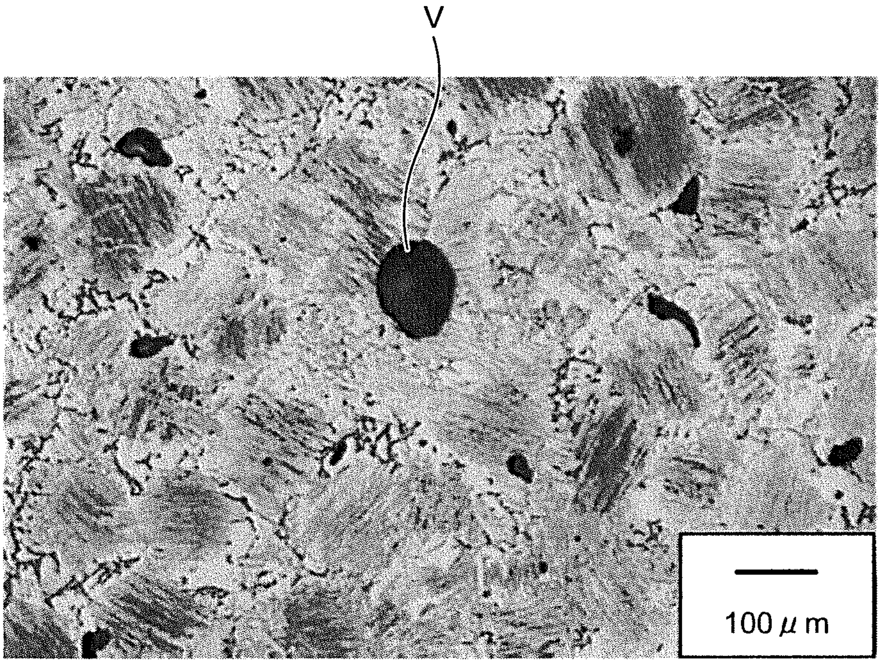


FIG.11

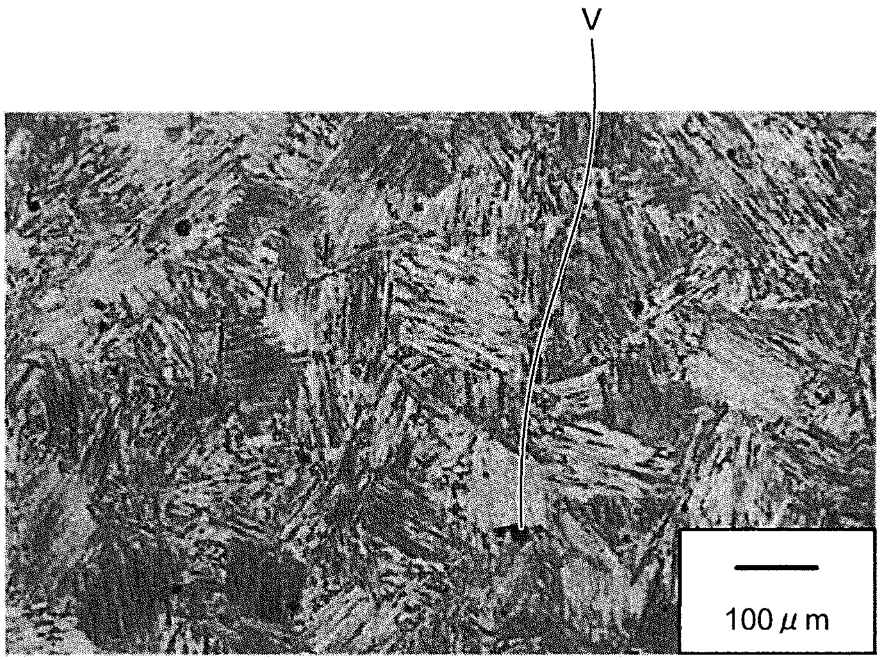
	AMOUNT OF Ni (wt%)	AMOUNT OF Fe (wt%)	PRODUCTION PROCESS	SINTERED DENSITY (%)	γ PHASE OF GRAIN BOUNDARY
COMPARATIVE EXAMPLE 3	0.34	1.79	THIRD EMBODIMENT	97	PRESENT
EXAMPLE 3	0.17	0.92	FIRST EMBODIMENT	99	ABSENT
EXAMPLE 4	0.17	0.92	THIRD EMBODIMENT	97	ABSENT

FIG.12



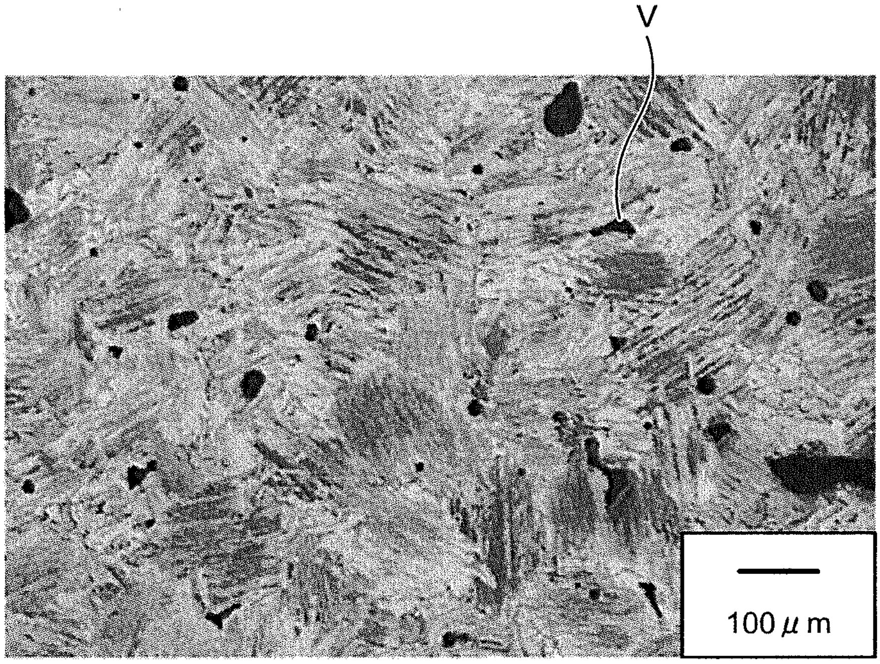
COMPARATIVE EXAMPLE 3

FIG.13



EXAMPLE 3

FIG.14



EXAMPLE 4

FIG.15

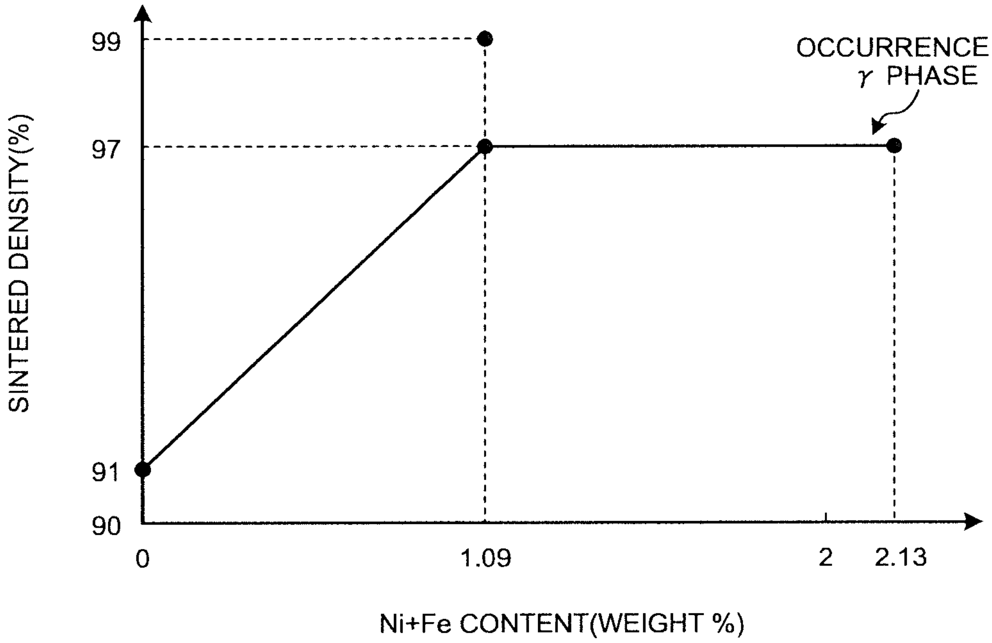
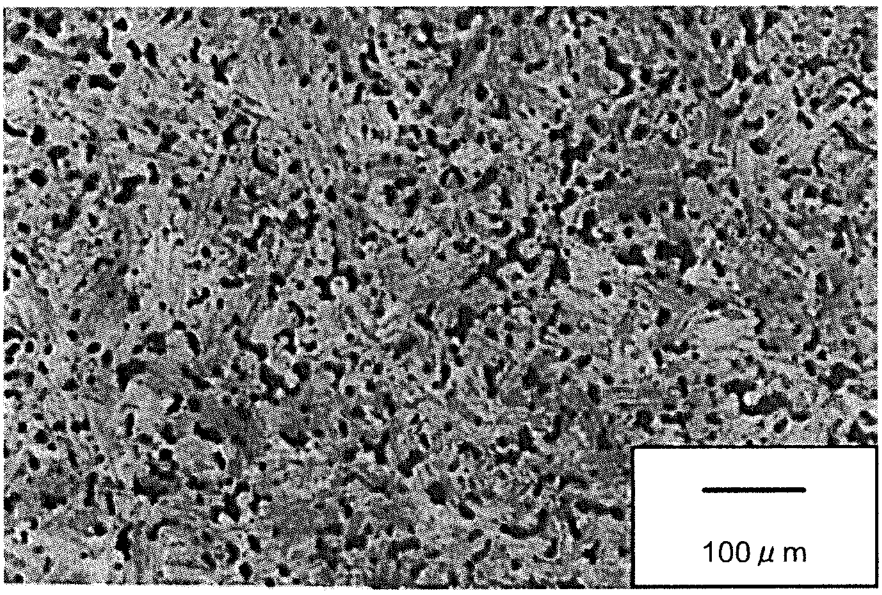


FIG.16

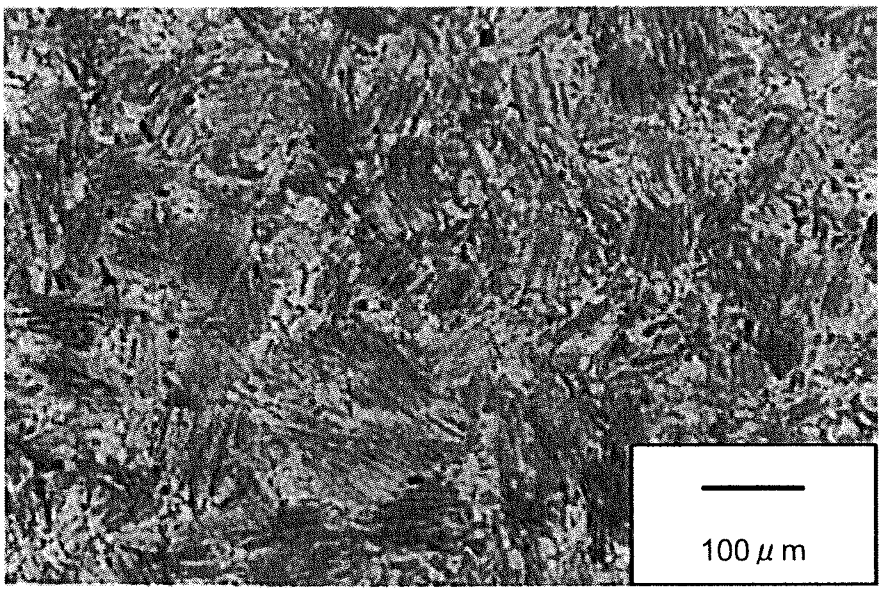
	AMOUNT OF Fe (wt%)	AMOUNT OF Ni (wt%)	SINTERED DENSITY (%)
COMPARATIVE EXAMPLE 4	1.08	<0.01	93
EXAMPLE 5	2.13	<0.01	98

FIG.17



COMPARATIVE EXAMPLE 4

FIG.18



EXAMPLE 5

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2017/006390

A. CLASSIFICATION OF SUBJECT MATTER
C22C1/04(2006.01)i, *B22F3/02*(2006.01)i, *B22F3/10*(2006.01)i, *C22C1/00*(2006.01)i, *C22C14/00*(2006.01)i, *C22C21/00*(2006.01)i

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)
C22C1/04, B22F3/00-B22F3/26, C22C14/00

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2017
Kokai Jitsuyo Shinan Koho	1971-2017	Toroku Jitsuyo Shinan Koho	1994-2017

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.
X Y	JP 3-243741 A (Nippon Tungsten Co., Ltd.), 30 October 1991 (30.10.1991), page 2, upper right column, line 14 to page 3, upper right column, the last line; fig. 1 to 4 (Family: none)	1,3,6-7,10 2,9
Y	JP 3-193801 A (Nippon Steel Corp.), 23 August 1991 (23.08.1991), page 3, upper left column, line 10 to upper right column, the last line; table 1 (Family: none)	2
Y	JP 2000-355704 A (Osaka Yakin Kogyo Co., Ltd.), 26 December 2000 (26.12.2000), paragraphs [0010] to [0025]; fig. 1 to 3 (Family: none)	2

☒ 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
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"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 11 April 2017 (11.04.17)	Date of mailing of the international search report 25 April 2017 (25.04.17)
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

International application No.
PCT/JP2017/006390

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 8-92602 A (Toyo Aluminium Kabushiki Kaisha), 09 April 1996 (09.04.1996), claims; paragraphs [0036] to [0039] (Family: none)	9
Y	JP 2-200743 A (Sumitomo Light Metal Industries, Ltd.), 09 August 1990 (09.08.1990), page 5, upper right column, line 18 to lower right column, line 15; tables (Family: none)	9
A	JP 2004-76095 A (National Institute of Advanced Industrial Science and Technology), 11 March 2004 (11.03.2004), paragraphs [0021] to [0028]; fig. 1 to 2 (Family: none)	1-10

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

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 3243741 A **[0003]**