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(54) **METAL POWDER FOR POWDER METALLURGY, COMPOUND, GRANULATED POWDER, AND SINTERED BODY**

(57) A metal powder for powder metallurgy according to the invention contains Fe as a principal component, Cr in a proportion of 15 mass% or more and 26 mass% or less, Ni in a proportion of 7 mass% or more and 22 mass% or less, Si in a proportion of 0.3 mass% or more and 1.2 mass% or less, and C in a proportion of 0.005 mass% or more and 0.3 mass% or less, wherein when two elements selected from the group consisting of Ti, V, Y, Zr, Nb, Hf, and Ta are defined as a first element and a second element, the first element is contained in a proportion of 0.01 mass% or more and 0.5 mass% or less and the second element is contained in a proportion of 0.01 mass% or more and 0.5 mass% or less. Further, the metal powder for powder metallurgy preferably has an austenite crystal structure.

EP 3 042 974 A2

Description

BACKGROUND

1. Technical Field

[0001] The present invention relates to a metal powder for powder metallurgy, a compound, a granulated powder, and a sintered body.

2. Related Art

[0002] In a powder metallurgy method, a composition containing a metal powder and a binder is molded into a desired shape to obtain a molded body, and the obtained molded body is degreased and sintered, whereby a sintered body is produced. In such a process for producing a sintered body, an atomic diffusion phenomenon occurs among particles of the metal powder, whereby the molded body is gradually densified, resulting in sintering.

[0003] For example, JP-A-2012-87416 proposes a metal powder for powder metallurgy which contains Zr and Si, with the remainder including at least one element selected from the group consisting of Fe, Co, and Ni, and inevitable elements. According to such a metal powder for powder metallurgy, the sinterability is enhanced by the action of Zr, and a sintered body having a high density can be easily produced.

[0004] Further, for example, JP-A-6-279913 discloses a composition for metal injection molding which contains 100 parts by weight of a stainless steel powder containing 0.03% by weight or less of C, 8 to 32% by weight of Ni, 12 to 32% by weight of Cr, and 1 to 7% by weight of Mo, with the remainder including Fe and inevitable impurities, and 0.1 to 5.5 parts by weight of at least one powder containing Ti or/and Nb and having an average particle diameter of 10 to 60 μm. By using such a composition obtained by mixing two types of powders, a sintered body having a high sintered density and excellent corrosion resistance is obtained.

[0005] Further, for example, JP-A-2007-177675 discloses a needle seal for a needle valve, which has a composition containing 0.95 to 1.4% by mass of C, 1.0% by mass or less of Si, 1.0% by mass or less of Mn, 16 to 18% by mass of Cr, and 0.02 to 3% by mass of Nb, with the remainder including Fe and inevitable impurities, has a density after sintering of 7.65 to 7.75 g/cm^3, and is obtained by molding using a metal injection molding method. According to this, a needle seal having a high density is obtained.

[0006] The thus obtained sintered body has become widely used recently for a variety of machine parts, structural parts, and the like.

[0007] However, depending on the use of the sintered body, further densification is needed in some cases. In such a case, a sintered body is further subjected to an additional treatment such as a hot isostatic pressing treatment (HIP treatment) to increase the density, however, the workload is significantly increased, and also an increase in the cost is inevitable.

[0008] Therefore, an expectation for realization of a metal powder capable of producing a sintered body having a high density without performing an additional treatment or the like has increased.

SUMMARY

[0009] An advantage of some aspects of the invention is to provide a metal powder for powder metallurgy, a compound, and a granulated powder, each of which is capable of producing a sintered body having a high density, and a sintered body having a high density produced by using the metal powder for powder metallurgy.

[0010] The advantage can be achieved by aspects of the invention described below.

[0011] A metal powder for powder metallurgy according to an aspect of the invention contains Fe as a principal component, Cr in a proportion of 15% by mass or more and 26% by mass or less, Ni in a proportion of 7% by mass or more and 22% by mass or less, Si in a proportion of 0.3% by mass or more and 1.2% by mass or less, and C in a proportion of 0.005% by mass or more and 0.3% by mass or less, wherein when one element selected from the group consisting of Ti, V, Y, Zr, Nb, Hf, and Ta is defined as a first element, and one element selected from the group consisting of Ti, V, Y, Zr, Nb, Hf, and Ta, and having a larger group number in the periodic table than that of the first element or having the same group number in the periodic table as that of the first element and a larger period number in the periodic table than that of the first element is defined as a second element, the first element is contained in a proportion of 0.01% by mass or more and 0.5% by mass or less, and the second element is contained in a proportion of 0.01% by mass or more and 0.5% by mass or less.

[0012] According to this, the alloy composition is optimized so that the densification during sintering of the metal powder for powder metallurgy can be enhanced. As a result, a metal powder for powder metallurgy capable of producing a sintered body having a high density is obtained without performing an additional treatment.

[0013] In the metal powder for powder metallurgy according to the aspect of the invention, it is preferred that the metal powder has an austenite crystal structure.

[0014] According to this, high corrosion resistance and large elongation can be provided to a sintered body to be produced. That is, a metal powder for powder metallurgy capable of producing a sintered body having high corrosion resistance and large elongation in spite of a high density is obtained.

[0015] In the metal powder for powder metallurgy according to the aspect of the invention, it is preferred that the ratio (X1/X2) of a value (X1) obtained by dividing the content (E1) of the first element by the mass number of the first element to a value (X2) obtained by dividing the content (E2) of the second element by the mass number of the second element is 0.3 or more and 3 or less.

[0016] According to this, when the metal powder for powder metallurgy is fired, a difference in timing between the deposition of a carbide or the like of the first element and the deposition of a carbide or the like of the second element can be optimized. As a result, pores remaining in a molded body can be eliminated as if they were swept out sequentially from the inside, and therefore, pores generated in the sintered body can be minimized. Accordingly, a metal powder for powder metallurgy capable of producing a sintered body having a high density and excellent sintered body properties is obtained.

[0017] In the metal powder for powder metallurgy according to the aspect of the invention, it is preferred that the sum of the content of the first element and the content of the second element is 0.05% by mass or more and 0.6% by mass or less.

[0018] According to this, the densification of a sintered body to be produced becomes necessary and sufficient.

[0019] In the metal powder for powder metallurgy according to the aspect of the invention, it is preferred that Mo is further contained in a proportion of 1% by mass or more and 5% by mass or less.

[0020] According to this, the corrosion resistance of a sintered body to be produced can be further enhanced without causing a significant decrease in the density of the sintered body.

[0021] In the metal powder for powder metallurgy according to the aspect of the invention, it is preferred that the metal powder has an average particle diameter of 0.5 μm or more and 30 μm or less.

[0022] According to this, pores remaining in a sintered body are extremely decreased, and therefore, a sintered body having a particularly high density and particularly excellent mechanical properties can be produced.

[0023] A compound according to an aspect of the invention includes the metal powder for powder metallurgy according to the aspect of the invention and a binder which binds the particles of the metal powder for powder metallurgy to one another.

[0024] According to this, a compound capable of producing a sintered body having a high density is obtained.

[0025] A granulated powder according to an aspect of the invention is obtained by granulating the metal powder for powder metallurgy according to the aspect of the invention.

[0026] According to this, a granulated powder capable of producing a sintered body having a high density is obtained.

[0027] A sintered body according to an aspect of the invention is produced by sintering a metal powder for powder metallurgy containing Fe as a principal component, Cr in a proportion of 15% by mass or more and 26% by mass or less, Ni in a proportion of 7% by mass or more and 22% by mass or less, Si in a proportion of 0.3% by mass or more and 1.2% by mass or less, and C in a proportion of 0.005% by mass or more and 0.3% by mass or less, wherein when one element selected from the group consisting of Ti, V, Y, Zr, Nb, Hf, and Ta is defined as a first element, and one element selected from the group consisting of Ti, V, Y, Zr, Nb, Hf, and Ta, and having a larger group number in the periodic table than that of the first element or having the same group number in the periodic table as that of the first element and a larger period number in the periodic table than that of the first element is defined as a second element, the first element is contained in a proportion of 0.01% by mass or more and 0.5% by mass or less, and the second element is contained in a proportion of 0.01% by mass or more and 0.5% by mass or less.

[0028] According to this, a sintered body having a high density is obtained without performing an additional treatment.

[0029] In the sintered body according to the aspect of the invention, it is preferred that a first region which is in the form of a particle and has a relatively high silicon oxide content and a second region which has a relatively lower silicon oxide content than the first region are included.

[0030] According to this, the concentration of oxides inside the crystal is decreased, and also the significant growth of crystal grains is suppressed, and thus, a sintered body having a high density and excellent mechanical properties is obtained.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0031] Hereinafter, a metal powder for powder metallurgy, a compound, a granulated powder, and a sintered body according to the invention will be described in detail.

Metal Powder for Powder Metallurgy

[0032] First, a metal powder for powder metallurgy according to the invention will be described.

[0033] In powder metallurgy, a sintered body having a desired shape can be obtained by molding a composition containing a metal powder for powder metallurgy and a binder into a desired shape, followed by degreasing and sintering. According to such a powder metallurgy technique, an advantage that a sintered body with a complicated and fine shape can be produced in a near-net shape (a shape close to a final shape) as compared with the other metallurgy techniques is obtained.

[0034] Heretofore, with respect to the metal powder for powder metallurgy to be used in the powder metallurgy, an attempt to increase the density of a sintered body to be produced by appropriately changing the composition thereof has been made. However, in the sintered body, pores are liable to be generated, and therefore, in order to obtain mechanical properties comparable to those of ingot materials, it was necessary to further increase the density of the sintered body.

[0035] Therefore, in the past, the obtained sintered body was further subjected to an additional treatment such as a hot isostatic pressing treatment (HIP treatment) to increase the density. However, such an additional treatment requires much time, labor and cost, and therefore becomes an obstacle to the expansion of the application of the sintered body.

[0036] In consideration of the above-mentioned problems, the present inventors have made extensive studies to find conditions for obtaining a sintered body having a high density without performing an additional treatment. As a result, they found that the density of a sintered body can be increased by optimizing the composition of an alloy which forms a metal powder, and thus completed the invention.

[0037] Specifically, the metal powder for powder metallurgy according to the invention is a metal powder which contains Cr in a proportion of 15% by mass or more and 26% by mass or less, Ni in a proportion of 7% by mass or more and 22% by mass or less, Si in a proportion of 0.3% by mass or more and 1. 2 % by mass or less, C in a proportion of 0.005% by mass or more and 0.3% by mass or less, the below-mentioned first element in a proportion of 0.01% by mass or more and 0.5% by mass or less, and the below-mentioned second element in a proportion of 0.01% by mass or more and 0.5% by mass or less, with the remainder including Fe and other elements. According to such a metal powder, as a result of optimizing the alloy composition, the densification during sintering can be particularly enhanced. As a result, a sintered body having a high density can be produced without performing an additional treatment.

[0038] By increasing the density of a sintered body, a sintered body having excellent mechanical properties is obtained. Such a sintered body can be widely applied also to, for example, machine parts, structural parts, and the like, to which an external force (load) is applied.

[0039] The first element is one element selected from the group consisting of the following seven elements: Ti, V, Y, Zr, Nb, Hf, and Ta, and the second element is one element selected from the group consisting of the above-mentioned seven elements and having a larger group number in the periodic table than that of the first element or one element selected from the group consisting of the above-mentioned seven elements and having the same group number in the periodic table as that of the first element and a larger period number in the periodic table than that of the first element.

[0040] Hereinafter, the alloy composition of the metal powder for powder metallurgy according to the invention will be described in further detail. In the following description, the "metal powder for powder metallurgy" is sometimes simply referred to as "metal powder".

[0041] Cr (chromium) is an element which provides corrosion resistance to a sintered body to be produced. By using the metal powder containing Cr, a sintered body capable of maintaining high mechanical properties over a long period of time is obtained.

[0042] The content of Cr in the metal powder is set to 15% by mass or more and 26% by mass or less, but is preferably 15.5% by mass or more and 25% by mass or less, more preferably 16% by mass or more and 21% by mass or less, further more preferably 16% by mass or more and 20% by mass or less. If the content of Cr is less than the above lower limit, the corrosion resistance of a sintered body to be produced is insufficient depending on the overall composition. On the other hand, if the content of Cr exceeds the above upper limit, the sinterability is deteriorated depending on the overall composition so that it becomes difficult to increase the density of the sintered body.

[0043] A more preferred range of the content of Cr is defined according to the contents of Ni and Mo described below. For example, in the case where the content of Ni is 7% by mass or more and 22% by mass or less and the content of Mo is less than 1.2% by mass, the content of Cr is more preferably 18% by mass or more and 20% by mass or less. On the other hand, in the case where the content of Ni is 10% by mass or more and 22% by mass or less and the content of Mo is 1.2% by mass or more and 5% by mass or less, the content of Cr is more preferably 16% by mass or more and less than 18% by mass.

[0044] Ni is an element which provides corrosion resistance and heat resistance to a sintered body to be produced as expected.

[0045] The content of Ni in the metal powder is preferably set to 7% by mass or more and 22% by mass or less, more preferably 7.5% by mass or more and 17% by mass or less, further more preferably 8% by mass or more and 15% by mass or less. By setting the content of Ni within the above range, a sintered body having excellent mechanical properties over a long period of time can be obtained.

[0046] If the content of Ni is less than the above lower limit, the corrosion resistance and the heat resistance of a sintered body to be produced may not be sufficiently enhanced depending on the overall composition. On the other hand, if the content of Ni exceeds the above upper limit, the corrosion resistance and the heat resistance may be deteriorated instead.

[0047] Si (silicon) is an element which provides corrosion resistance and high mechanical properties to a sintered body to be produced, and by using the metal powder containing Si, a sintered body capable of maintaining high mechanical properties over a long period of time is obtained.

[0048] The content of Si in the metal powder is set to 0.3% by mass or more and 1.2% by mass or less, but is preferably 0.4% by mass or more and 1.1% by mass or less, more preferably 0.5% by mass or more and 0.9% by mass or less. If the content of Si is less than the above lower limit, the effect of the addition of Si is weakened depending on the overall composition so that the corrosion resistance and the mechanical properties of a sintered body to be produced are deteriorated. On the other hand, if the content of Si exceeds the above upper limit, the amount of Si is too large depending on the overall composition so that the corrosion resistance and the mechanical properties are deteriorated instead.

[0049] C (carbon) can particularly enhance the sinterability when it is used in combination with the below-mentioned first element and second element. Specifically, the first element and the second element each form a carbide by binding to C. By dispersedly depositing this carbide, an effect of preventing the significant growth of crystal grains is exhibited. A clear reason for obtaining such an effect has not been known, but one of the reasons therefor is considered to be because the dispersed deposit serves as an obstacle to inhibit the significant growth of crystal grains, and therefore, a variation in the size of crystal grains is suppressed. Accordingly, it becomes difficult to generate pores in a sintered body, and also the increase in the size of crystal grains is prevented, and thus, a sintered body having a high density and excellent mechanical properties is obtained.

[0050] The content of C in the metal powder is set to 0.005% by mass or more and 0.3% by mass or less, but is preferably 0.008% by mass or more and 0.15% by mass or less, more preferably 0.01% by mass or more and 0.08% by mass or less. If the content of C is less than the above lower limit, crystal grains are liable to grow depending on the overall composition so that the mechanical properties of the sintered body are insufficient. On the other hand, if the content of C exceeds the above upper limit, the amount of C is too large depending on the overall composition so that the sinterability is deteriorated instead.

[0051] The first element and the second element each deposit a carbide or an oxide (hereinafter also collectively referred to as "carbide or the like"). It is considered that this deposited carbide or the like inhibits the significant growth of crystal grains when the metal powder is sintered. As a result, as described above, it becomes difficult to generate pores in a sintered body, and also the increase in the size of crystal grains is prevented, and thus, a sintered body having a high density and excellent mechanical properties is obtained.

[0052] In addition, although a detailed description will be given later, the deposited carbide or the like promotes the accumulation of silicon oxide at a crystal grain boundary, and as a result, the sintering is promoted and the density is increased while preventing the increase in the size of crystal grains.

[0053] The first element and the second element are two elements selected from the group consisting of Ti, V, Y, Zr, Nb, Hf, and Ta, but preferably include an element belonging to group III A or group IV A in the long periodic table (Ti, Y, Zr, or Hf). By including an element belonging to group III A or group IV A as at least one of the first element and the second element, oxygen contained as an oxide in the metal powder is removed and the sinterability of the metal powder can be particularly enhanced.

[0054] The first element is only required to be one element selected from the group consisting of Ti, V, Y, Zr, Nb, Hf, and Ta as described above, but is preferably an element belonging to group III A or group IV A in the long periodic table in the above-mentioned group. An element belonging to group III A or group I VA in the above-mentioned group removes oxygen contained as an oxide in the metal powder and therefore can particularly enhance the sinterability of the metal powder. According to this, the concentration of oxygen remaining in the crystal grains after sintering can be decreased. As a result, the content of oxygen in the sintered body can be decreased, and the density can be increased. Further, these elements are elements having high activity, and therefore are considered to cause rapid atomic diffusion. Accordingly, this atomic diffusion acts as a driving force, and thereby a distance between particles of the metal powder is efficiently decreased and a neck is formed between the particles, so that the densification of a molded body is promoted. As a result, the density of the sintered body can be further increased.

[0055] On the other hand, the second element is only required to be one element selected from the group consisting of Ti, V, Y, Zr, Nb, Hf, and Ta and different from the first element as described above, but is preferably an element belonging to group V A in the long periodic table in the above-mentioned group. An element belonging to group V A in the above-mentioned group particularly efficiently deposits the above-mentioned carbide or the like, and therefore, can efficiently inhibit the significant growth of crystal grains during sintering. As a result, the production of fine crystal grains is promoted, and thus, the density of the sintered body can be increased and also the mechanical properties of the sintered body can be enhanced.

[0056] Incidentally, by the combination of the first element with the second element composed of the elements as described above, the effects of the respective elements are exhibited without inhibiting each other. Due to this, the metal powder containing such a first element and a second element enables the production of a sintered body having a particularly high density.

[0057] More preferably, a combination of an element belonging to group IV A as the first element with Nb as the second element is adopted.

[0058] Further more preferably, a combination of Zr or Hf as the first element with Nb as the second element is adopted.

[0059] By adopting such a combination, the above-mentioned effect becomes more prominent.

[0060] Among these elements, Zr is a ferrite forming element, and therefore deposits a body-centered cubic lattice phase. This body-centered cubic lattice phase has more excellent sinterability than the other crystal lattice phases, and therefore contributes to the densification of a sintered body.

[0061] The content of the first element in the metal powder is set to 0.01% by mass or more and 0.5% by mass or less, but is set to preferably 0.03% by mass or more and 0.2% by mass or less, more preferably 0.05% by mass or more and 0.1% by mass or less. If the content of the first element is less than the above lower limit, the effect of the addition of the first element is weakened depending on the overall composition so that the density of a sintered body to be produced is not sufficiently increased. On the other hand, if the content of the first element exceeds the above upper limit, the amount of the first element is too large depending on the overall composition so that the ratio of the above-mentioned carbide or the like is too high, and therefore, the densification is deteriorated instead.

[0062] The content of the second element in the metal powder is set to 0.01% by mass or more and 0.5% by mass or less, but is set to preferably 0.03% by mass or more and 0.2% by mass or less, more preferably 0.05% by mass or more and 0.1% by mass or less. If the content of the second element is less than the above lower limit, the effect of the addition of the second element is weakened depending on the overall composition so that the density of a sintered body to be produced is not sufficiently increased. On the other hand, if the content of the second element exceeds the above upper limit, the amount of the second element is too large depending on the overall composition so that the ratio of the above-mentioned carbide or the like is too high, and therefore, the densification is deteriorated instead.

[0063] As described above, each of the first element and the second element deposits a carbide or the like, however, in the case where an element belonging to group III A or group IV A is selected as the first element as described above and an element belonging to group V A is selected as the second element as described above, it is presumed that when the metal powder is sintered, the timing when a carbide or the like of the first element is deposited and the timing when a carbide or the like of the second element is deposited differ from each other. It is considered that due to the difference in timing when a carbide or the like is deposited in this manner, sintering gradually proceeds so that the generation of pores is prevented, and thus, a dense sintered body is obtained. That is, it is considered that by the existence of both of the carbide or the like of the first element and the carbide or the like of the second element, the increase in the size of crystal grains can be suppressed while increasing the density of the sintered body.

[0064] It is preferred to set the ratio of the content of the first element to the content of the second element in consideration of the mass number of the element selected as the first element and the mass number of the element selected as the second element.

[0065] Specifically, when a value obtained by dividing the content E1 (mass%) of the first element by the mass number of the first element is represented by an index X1 and a value obtained by dividing the content E2 (mass%) of the second element by the mass number of the second element is represented by an index X2, the ratio X1/X2 of the index X1 to the index X2 is preferably 0.3 or more and 3 or less, more preferably 0.5 or more and 2 or less, further more preferably 0.75 or more and 1.3 or less. By setting the ratio X1/X2 within the above range, a difference between the timing when a carbide or the like of the first element is deposited and the timing when a carbide or the like of the second element is deposited can be optimized. According to this, pores remaining in a molded body can be eliminated as if they were swept out sequentially from the inside, and therefore, pores generated in a sintered body can be minimized. Therefore, by setting the ratio X1/X2 within the above range, a metal powder capable of producing a sintered body having a high density and excellent mechanical properties can be obtained. Further, the balance between the number of atoms of the first element and the number of atoms of the second element is optimized, and therefore, an effect brought about by the first element and an effect brought about by the second element are synergistically exhibited, and thus, a sintered body having a particularly high density can be obtained.

[0066] Here, with respect to a specific example of the combination of the first element with the second element, based on the above-mentioned range of the ratio X1/X2, the ratio (E1/E2) of the content E1 (mass%) to the content E2 (mass%) is also calculated.

[0067] For example, in the case where the first element is Zr and the second element is Nb, since the mass number of Zr is 91.2 and the mass number of Nb is 92.9, E1/E2 is preferably 0.29 or more and 2.95 or less, more preferably 0.49 or more and 1.96 or less.

[0068] In the case where the first element is Hf and the second element is Nb, since the mass number of Hf is 178.5

and the mass number of Nb is 92.9, E1/E2 is preferably 0.58 or more and 5.76 or less, more preferably 0.96 or more and 3.84 or less.

[0069] In the case where the first element is Ti and the second element is Nb, since the mass number of Ti is 47.9 and the mass number of Nb is 92.9, E1/E2 is preferably 0.15 or more and 1.55 or less, more preferably 0.26 or more and 1.03 or less.

[0070] In the case where the first element is Nb and the second element is Ta, since the mass number of Nb is 92.9 and the mass number of Ta is 180.9, E1/E2 is preferably 0.15 or more and 1.54 or less, more preferably 0.26 or more and 1.03 or less.

[0071] In the case where the first element is Y and the second element is Nb, since the mass number of Y is 88.9 and the mass number of Nb is 92.9, E1/E2 is preferably 0.29 or more and 2.87 or less, more preferably 0.48 or more and 1.91 or less.

[0072] In the case where the first element is V and the second element is Nb, since the mass number of V is 50.9 and the mass number of Nb is 92.9, E1/E2 is preferably 0.16 or more and 1.64 or less, more preferably 0.27 or more and 1.10 or less.

[0073] In the case where the first element is Ti and the second element is Zr, since the mass number of Ti is 47.9 and the mass number of Zr is 91.2, E1/E2 is preferably 0.16 or more and 1.58 or less, more preferably 0.26 or more and 1.05 or less.

[0074] In the case where the first element is Zr and the second element is Ta, since the mass number of Zr is 91.2 and the mass number of Ta is 180.9, E1/E2 is preferably 0.15 or more and 1.51 or less, more preferably 0.25 or more and 1.01 or less.

[0075] In the case where the first element is Zr and the second element is V, since the mass number of Zr is 91.2 and the mass number of V is 50.9, E1/E2 is preferably 0.54 or more and 5.38 or less, more preferably 0.90 or more and 3.58 or less.

[0076] Also in the case of a combination other than the above-mentioned combinations, E1/E2 can be calculated in the same manner as described above.

[0077] The sum (E1+E2) of the content E1 of the first element and the content E2 of the second element is preferably 0.05% by mass or more and 0.6% by mass or less, more preferably 0.10% by mass or more and 0.48% by mass or less, further more preferably 0.12% by mass or more and 0.24% by mass or less. By setting the sum of the content of the first element and the content of the second element within the above range, the densification of a sintered body to be produced becomes necessary and sufficient.

[0078] When the ratio of the sum of the content of the first element and the content of the second element to the content of Si is represented by (E1+E2)/Si, (E1+E2)/Si is preferably 0.1 or more and 0.7 or less, more preferably 0.15 or more and 0.6 or less, further more preferably 0.2 or more and 0.5 or less. By setting the ratio (E1+E2)/Si within the above range, a decrease in the toughness or the like when Si is added is sufficiently compensated by the addition of the first element and the second element. As a result, a metal powder capable of producing a sintered body which has excellent mechanical properties such as toughness in spite of a high density and also has excellent corrosion resistance attributed to Si is obtained.

[0079] In addition, it is considered that by the addition of appropriate amounts of the first element and the second element, the carbide or the like of the first element and the carbide or the like of the second element act as "nuclei", and therefore, silicon oxide is accumulated at a crystal grain boundary in the sintered body. By the accumulation of silicon oxide at a crystal grain boundary, the concentration of oxides inside the crystal grain is decreased, and therefore, sintering is promoted. As a result, it is considered that the densification of the sintered body is further promoted.

[0080] The deposited silicon oxide easily moves to the triple point of a crystal grain boundary during the accumulation, and therefore, the crystal growth is suppressed at this point (a flux pinning effect). As a result, the significant growth of crystal grains is suppressed, and thus, a sintered body having finer crystals is obtained. Such a sintered body has particularly high mechanical properties.

[0081] The accumulated silicon oxide is easily located at the triple point of a crystal grain boundary as described above, and therefore tends to be shaped into a particle. Therefore, in the sintered body, a first region which is in the form of such a particle and has a relatively high silicon oxide content and a second region which has a relatively lower silicon oxide content than the first region are easily formed. By the existence of the first region, the concentration of oxides inside the crystal is decreased, and the significant growth of crystal grains is suppressed as described above.

[0082] When a qualitative and quantitative analysis is performed for the first region and the second region using an electron beam microanalyzer (EPMA), the first region contains O (oxygen) as a principal element, and the second region contains Fe as a principal element. As described above, the first region mainly exists at a crystal grain boundary, and the second region mainly exists inside the crystal grain. Therefore, in the first region, when the sum of the contents of the two elements, O and Si, and the content of Fe are compared, the sum of the contents of the two elements is higher than the content of Fe. On the other hand, in the second region, the sum of the contents of the two elements, O and Si, is much smaller than the content of Fe. Based on these analysis results, it is found that Si and O are accumulated in the first region. Specifically, the sum of the content of Si and the content of O is preferably 1.5 times or more and 10000 times or less the content of Fe in the first region. Further, the content of Si in the first region is preferably 3 times or more and 10000 times or less the content of Si in the second region.

[0083] Further, at least either of the content of the first element and the content of the second element satisfies the relationship that the content in the first region is larger than the content in the second region, which may vary depending on the compositional ratio. This indicates that in the first region, the carbide or the like of the first element and the carbide or the like of the second element act as nuclei when silicon oxide is accumulated as described above. Specifically, the content of the first element in the first region is preferably 3 times or more and 10000 times or less the content of the first element in the second region. Similarly, the content of Nb in the first region is preferably 3 times or more and 10000 times or less the content of Nb in the second region.

[0084] The accumulation of silicon oxide as described above is considered to be one of the causes for the densification of a sintered body. Therefore, it is considered that even in a sintered body having a density increased according to the invention, silicon oxide may not be accumulated depending on the compositional ratio in some cases.

[0085] The diameter of the first region in the form of a particle varies depending on the content of Si in the entire sintered body, but is set to about 0.5 μm or more and 15 μm or less, preferably about 1 μm or more and 10 μm or less. According to this, the densification of the sintered body can be sufficiently promoted while preventing the decrease in the mechanical properties of the sintered body accompanying the accumulation of silicon oxide.

[0086] The diameter of the first region can be obtained as the average of the diameter of a circle having the same area (circle equivalent diameter) as that of the first region determined by the color shade in an electron micrograph of the cross section of the sintered body. When the average is obtained, the measured values of 10 or more regions are used.

[0087] Further, when the ratio of the sum of the content of the first element and the content of the second element to the content of C is represented by (E1+E2) /C, (E1+E2) /C is preferably 1 or more and 16 or less, more preferably 2 or more and 13 or less, further more preferably 3 or more and 10 or less. By setting the ratio (E1+E2)/C within the above range, an increase in the hardness and a decrease in the toughness when C is added, and an increase in the density brought about by the addition of the first element and the second element can be achieved. As a result, a metal powder capable of producing a sintered body which has excellent mechanical properties such as tensile strength and toughness is obtained.

[0088] The metal powder is only required to contain two elements selected from the group consisting of Ti, V, Y, Zr, Nb, Hf, and Ta, but may further contain an element which is selected from this group and is different from these two elements. That is, the metal powder may contain three or more elements selected from the above-mentioned group. According to this, the above-mentioned effect can be further enhanced, which slightly varies depending on the combination of the elements to be contained.

[0089] The metal powder for powder metallurgy according to the invention may contain, other than these elements, at least one element of Mn, Mo, Cu, N, and S as needed. These elements may be inevitably contained in some cases.

[0090] Mn is an element which provides corrosion resistance and high mechanical properties to a sintered body to be produced in the same manner as Si.

[0091] The content of Mn in the metal powder is not particularly limited, but is preferably 0.01% by mass or more and 3% by mass or less, more preferably 0.05% by mass or more and 1% by mass or less. By setting the content of Mn within the above range, a sintered body having a high density and excellent mechanical properties is obtained.

[0092] If the content of Mn is less than the above lower limit, the corrosion resistance and the mechanical properties of a sintered body to be produced may not be sufficiently enhanced depending on the overall composition. On the other hand, if the content of Mn exceeds the above upper limit, the corrosion resistance and the mechanical properties may be deteriorated instead.

[0093] Mo is an element which enhances the corrosion resistance of a sintered body to be produced.

[0094] The content of Mo in the metal powder is not particularly limited, but is preferably 1% by mass or more and 5% by mass or less, more preferably 1.2% by mass or more and 4% by mass or less, further more preferably 2% by mass or more and 3% by mass or less. By setting the content of Mo within the above range, the corrosion resistance of a sintered body to be produced can be further enhanced without causing a large decrease in the density of the sintered body.

[0095] Cu is an element which enhances the corrosion resistance of a sintered body to be produced.

[0096] The content of Cu in the metal powder is not particularly limited, but is preferably 5% by mass or less, more preferably 1% by mass or more and 4% by mass or less. By setting the content of Cu within the above range, the corrosion resistance of a sintered body to be produced can be further enhanced without causing a large decrease in the density of the sintered body.

[0097] N is an element which enhances the mechanical properties such as proof stress of a sintered body to be produced.

[0098] The content of N in the metal powder is not particularly limited, but is preferably 0.03% by mass or more and 1% by mass or less, more preferably 0.08% by mass or more and 0.3% by mass or less, further more preferably 0.1% by mass or more and 0.25% by mass or less. By setting the content of N within the above range, the mechanical properties such as proof stress of a sintered body to be produced can be further enhanced without causing a large decrease in the density of the sintered body.

[0099] In order to produce the metal powder to which N is added, for example, a method using a nitrided starting material, a method of introducing nitrogen gas into a molten metal, a method of performing a nitriding treatment of the produced metal powder, or the like is used.

[0100] S is an element which enhances the machinability of a sintered body to be produced.

[0101] The content of S in the metal powder is not particularly limited, but is preferably 0.5% by mass or less, more preferably 0.01% by mass or more and 0.3% by mass or less. By setting the content of S within the above range, the machinability of a sintered body to be produced can be further enhanced without causing a large decrease in the density of the sintered body.

[0102] To the metal powder for powder metallurgy according to the invention, W, Co, B, Se, Te, Pd, Al, or the like may be added other than the above-mentioned elements. At this time, the contents of these elements are not particularly limited, but the content of each of these elements is preferably less than 0.1% by mass, and also the total content of these elements is preferably less than 0.2% by mass. These elements may be inevitably contained in some cases.

[0103] The metal powder for powder metallurgy according to the invention may contain impurities. Examples of the impurities include all elements other than the above-mentioned elements, and specific examples thereof include Li, Be, Na, Mg, P, K, Ca, Sc, Zn, Ga, Ge, Ag, In, Sn, Sb, Os, Ir, Pt, Au, and Bi. The incorporation amount of these impurity elements is preferably set such that the content of each of the impurity elements is less than the content of each of Fe, Cr, Ni, Si, the first element, and the second element. Further, the incorporation amounts of these impurity elements are preferably set such that the content of each of the impurity elements is less than 0.03% by mass, more preferably less than 0.02% by mass. Further, the total content of these impurity elements is set to preferably less than 0.3% by mass, more preferably less than 0.2% by mass. These elements do not inhibit the effect as described above as long as the content thereof is within the above range, and therefore may be intentionally added to the metal powder.

[0104] Meanwhile, O (oxygen) may also be intentionally added to or inevitably mixed in the metal powder, however, the amount thereof is preferably about 0.8% by mass or less, more preferably about 0.5% by mass or less. By controlling the amount of oxygen in the metal powder within the above range, the sinterability is enhanced, and thus, a sintered body having a high density and excellent mechanical properties is obtained. Incidentally, the lower limit thereof is not particularly set, but is preferably 0.03% by mass or more from the viewpoint of ease of mass production or the like.

[0105] Fe is a component (principal component) whose content is the highest in the alloy constituting the metal powder for powder metallurgy according to the invention and has a great influence on the properties of the sintered body. The content of Fe is not particularly limited, but is preferably 50% by mass or more.

[0106] The compositional ratio of the metal powder for powder metallurgy can be determined by, for example, Iron and steel - Atomic absorption spectrometric method specified in JIS G 1257 (2000), Iron and steel - ICP atomic emission spectrometric method specified in JIS G 1258 (2007), Iron and steel - Method for spark discharge atomic emission spectrometric analysis specified in JIS G 1253 (2002), Iron and steel - Method for X-ray fluorescence spectrometric analysis specified in JIS G 1256 (1997), gravimetric, titrimetric, and absorption spectrometric methods specified in JIS G 1211 to G 1237, or the like. Specifically, for example, an optical emission spectrometer for solids (spark optical emission spectrometer, model: SPECTROLAB, type: LAVMB08A) manufactured by SPECTRO Analytical Instruments GmbH or an ICP device (model: CIROS-120) manufactured by Rigaku Corporation can be used.

[0107] Incidentally, the methods specified in JIS G 1211 to G 1237 are as follows.

JIS G 1211 (2011) : Iron and steel - Methods for determination of carbon content
JIS G 1212 (1997) : Iron and steel - Methods for determination of silicon content
JIS G 1213 (2001) : Iron and steel - Methods for determination of manganese content
JIS G 1214 (1998) : Iron and steel - Methods for determination of phosphorus content
JIS G 1215 (2010) : Iron and steel - Methods for determination of sulfur content
JIS G 1216 (1997) : Iron and steel - Methods for determination of nickel content
JIS G 1217 (2005) : Iron and steel - Methods for determination of chromium content
JIS G 1218 (1999) : Iron and steel - Methods for determination of molybdenum content
JIS G 1219 (1997) : Iron and steel- Methods for determination of copper content
JIS G 1220 (1994) : Iron and steel - Methods for determination of tungsten content
JIS G 1221 (1998) : Iron and steel - Methods for determination of vanadium content
JIS G 1222 (1999) : Iron and steel - Methods for determination of cobalt content
JIS G 1223 (1997) : Iron and steel - Methods for determination of titanium content
JIS G 1224 (2001) : Iron and steel - Methods for determination of aluminum content
JIS G 1225 (2006) : Iron and steel - Methods for determination of arsenic content
JIS G 1226 (1994) : Iron and steel - Methods for determination of tin content
JIS G 1227 (1999) : Iron and steel - Methods for determination of boron content

JIS G 1228 (2006) : Iron and steel - Methods for determination of nitrogen content
JIS G 1229 (1994) : Steel - Methods for determination of lead content
JIS G 1232 (1980) : Methods for determination of zirconium in steel
JIS G 1233 (1994) : Steel - Method for determination of selenium content
JIS G 1234 (1981): Methods for determination of tellurium in steel
JIS G 1235 (1981): Methods for determination of antimony in iron and steel
JIS G 1236 (1992) : Method for determination of tantalum in steel JIS G 1237 (1997) : Iron and steel- Methods for determination of niobium content

[0108] Further, when C (carbon) and S (sulfur) are determined, particularly, an infrared absorption method after combustion in a current of oxygen (after combustion in a high-frequency induction heating furnace) specified in JIS G 1211 (2011) is also used. Specifically, a carbon-sulfur analyzer, CS-200 manufactured by LECO Corporation can be used.

[0109] Further, when N (nitrogen) and O (oxygen) are determined, particularly, a method for determination of nitrogen content in iron and steel specified in JIS G 1228 (2006) and a method for determination of oxygen content in metallic materials specified in JIS Z 2613 (2006) are also used. Specifically, an oxygen-nitrogen analyzer, TC-300/EF-300 manufactured by LECO Corporation can be used.

[0110] The metal powder for powder metallurgy according to the invention preferably has an austenite crystal structure. The austenite crystal structure provides high corrosion resistance and also large elongation to a sintered body. Due to this, the metal powder for powder metallurgy having such a crystal structure is capable of producing a sintered body having high corrosion resistance and large elongation in spite of a high density.

[0111] It can be determined whether or not the metal powder for powder metallurgy has an austenite crystal structure by, for example, X-ray diffractometry.

[0112] The average particle diameter of the metal powder for powder metallurgy according to the invention is preferably 0.5 μm or more and 30 μm or less, more preferably 1 μm or more and 20 μm or less, further more preferably 2 μm or more and 10 μm or less. By using the metal powder for powder metallurgy having such a particle diameter, pores remaining in a sintered body are extremely reduced, and therefore, a sintered body having a particularly high density and particularly excellent mechanical properties can be produced.

[0113] The average particle diameter can be obtained as a particle diameter when the cumulative amount obtained by cumulating the percentages of the particles from the smaller diameter side reaches 50% in a cumulative particle size distribution on a mass basis obtained by laser diffractometry.

[0114] If the average particle diameter of the metal powder for powder metallurgy is less than the above lower limit, the moldability is deteriorated in the case where the shape which is difficult to mold is formed, and therefore, the sintered density may be decreased. On the other hand, if the average particle diameter of the metal powder exceeds the above upper limit, spaces between the particles become larger during molding, and therefore, the sintered density may be decreased also in this case.

[0115] The particle size distribution of the metal powder for powder metallurgy is preferably as narrow as possible. Specifically, when the average particle diameter of the metal powder for powder metallurgy is within the above range, the maximum particle diameter of the metal powder is preferably 200 μm or less, more preferably 150 μm or less. By controlling the maximum particle diameter of the metal powder for powder metallurgy within the above range, the particle size distribution of the metal powder for powder metallurgy can be made narrower, and thus, the density of the sintered body can be further increased.

[0116] Here, the "maximum particle diameter" refers to a particle diameter when the cumulative amount obtained by cumulating the percentages of the particles from the smaller diameter side reaches 99.9% in a cumulative particle size distribution on a mass basis obtained by laser diffractometry.

[0117] When the minor axis of each particle of the metal powder for powder metallurgy is represented by S (μm) and the major axis thereof is represented by L (μm), the average of the aspect ratio defined by S/L is preferably about 0.4 or more and 1 or less, more preferably about 0.7 or more and 1 or less. The metal powder for powder metallurgy having an aspect ratio within this range has a shape relatively close to a spherical shape, and therefore, the packing factor when the metal powder is molded is increased. As a result, the density of the sintered body can be further increased.

[0118] Here, the "major axis" is the maximum length in the projected image of the particle, and the "minor axis" is the maximum length in the direction perpendicular to the major axis. Incidentally, the average of the aspect ratio can be obtained as the average of the measured aspect ratios of 100 or more particles.

[0119] The tap density of the metal powder for powder metallurgy according to the invention is preferably 3.5 g/cm^3 or more, more preferably 4 g/cm^3 or more. According to the metal powder for powder metallurgy having such a high tap density, when a molded body is obtained, the interparticle packing efficiency is particularly increased. Therefore, a particularly dense sintered body can be obtained in the end.

[0120] The specific surface area of the metal powder for powder metallurgy according to the invention is not particularly limited, but is preferably 0.1 m^2/g or more, more preferably 0.2 m^2/g or more. According to the metal powder for powder metallurgy having such a large specific surface area, a surface activity (surface energy) is increased so that it is possible to easily sinter the metal powder even if less energy is applied. Therefore, when a molded body is sintered, a difference in sintering rate hardly occurs between the inner side and the outer side of the molded body, and thus, the decrease in the sintered density due to the pores remaining inside the molded body can be suppressed.

Method for Producing Sintered Body

[0121] Next, a method for producing a sintered body using such a metal powder for powder metallurgy according to the invention will be described.

[0122] The method for producing a sintered body includes (A) a composition preparation step in which a composition for producing a sintered body is prepared, (B) a molding step in which a molded body is produced, (C) a degreasing step in which a degreasing treatment is performed, and (D) a firing step in which firing is performed. Hereinafter, the respective steps will be described sequentially.

(A) Composition Preparation Step

[0123] First, the metal powder for powder metallurgy according to the invention and a binder are prepared, and these materials are kneaded using a kneader, whereby a kneaded material is obtained.

[0124] In this kneaded material (an embodiment of the compound according to the invention), the metal powder for powder metallurgy is uniformly dispersed.

[0125] The metal powder for powder metallurgy according to the invention is produced by, for example, any of a variety of powdering methods such as an atomization method (such as a water atomization method, a gas atomization method, or a spinning water atomization method), a reducing method, a carbonyl method, and a pulverization method.

[0126] Among these, the metal powder for powder metallurgy according to the invention is preferably a metal powder produced by an atomization method, more preferably a metal powder produced by a water atomization method or a spinning water atomization method. The atomization method is a method in which a molten metal (metal melt) is caused to collide with a fluid (liquid or gas) sprayed at a high speed to atomize the metal melt into a fine powder and also to cool the fine powder, whereby a metal powder is produced. By producing the metal powder for powder metallurgy through such an atomization method, an extremely fine powder can be efficiently produced. Further, the shape of the particle of the obtained powder is closer to a spherical shape by the action of surface tension. Due to this, when the metal powder is molded, a molded body having a high packing factor is obtained. That is, a powder capable of producing a sintered body having a high density can be obtained.

[0127] In the case where a water atomization method is used as the atomization method, the pressure of water (hereinafter referred to as "atomization water") to be sprayed to the molten metal is not particularly limited, but is set to preferably about 75 MPa or more and 120 MPa or less (750 kgf/cm^2 or more and 1200 kgf/cm^2 or less), more preferably about 90 MPa or more and 120 MPa or less (900 kgf/cm^2 or more and 1200 kgf/cm^2 or less).

[0128] The temperature of the atomization water is also not particularly limited, but is preferably set to about 1°C or higher and 20°C or lower.

[0129] The atomization water is often sprayed in a cone shape such that it has a vertex on the falling path of the metal melt and the outer diameter gradually decreases downward. In this case, the vertex angle θ of the cone formed by the atomization water is preferably about 10° or more and 40° or less, more preferably about 15° or more and 35° or less. According to this, a metal powder for powder metallurgy having a composition as described above can be reliably produced.

[0130] Further, by using a water atomization method (particularly, a spinning water atomization method), the metal melt can be cooled particularly quickly. Due to this, a powder having high quality can be obtained in a wide alloy composition range.

[0131] The cooling rate when cooling the metal melt in the atomization method is preferably 1×10^4 °C/s or more, more preferably 1×10^5 °C/s or more. By the quick cooling in this manner, a homogeneous metal powder for powder metallurgy can be obtained. As a result, a sintered body having high quality can be obtained.

[0132] The thus obtained metal powder for powder metallurgy may be classified as needed. Examples of the classification method include dry classification such as sieving classification, inertial classification, and centrifugal classification, and wet classification such as sedimentation classification.

[0133] Examples of the binder include polyolefins such as polyethylene, polypropylene, and ethylene-vinyl acetate copolymers, acrylic resins such as polymethyl methacrylate and polybutyl methacrylate, styrenic resins such as polystyrene, polyesters such as polyvinyl chloride, polyvinylidene chloride, polyamide, polyethylene terephthalate, and polybutylene terephthalate, various resins such as polyether, polyvinyl alcohol, polyvinylpyrrolidone, and copolymers thereof, and various organic binders such as various waxes, paraffins, higher fatty acids (such as stearic acid), higher alcohols, higher fatty acid esters, and higher fatty acid amides. These can be used alone or by mixing two or more types thereof.

[0134] The content of the binder is preferably about 2% by mass or more and 20% by mass or less, more preferably about 5% by mass or more and 10% by mass or less with respect to the total amount of the kneaded material. By setting the content of the binder within the above range, a molded body can be formed with good moldability, and also the density is increased, whereby the stability of the shape of the molded body and the like can be particularly enhanced. Further, according to this, a difference in size between the molded body and the degreased body, that is, so-called a shrinkage ratio is optimized, whereby a decrease in the dimensional accuracy of the finally obtained sintered body can be prevented. That is, a sintered body having a high density and high dimensional accuracy can be obtained.

[0135] In the kneaded material, a plasticizer may be added as needed. Examples of the plasticizer include phthalate esters (such as DOP, DEP, and DBP), adipate esters, trimellitate esters, and sebacate esters. These can be used alone or by mixing two or more types thereof.

[0136] Further, in the kneaded material, other than the metal powder for powder metallurgy, the binder, and the plasticizer, for example, any of a variety of additives such as a lubricant, an antioxidant, a degreasing accelerator, and a surfactant can be added as needed.

[0137] The kneading conditions vary depending on the respective conditions such as the metal composition or the particle diameter of the metal powder for powder metallurgy to be used, the composition of the binder, and the blending amount thereof. However, for example, the kneading temperature can be set to about 50°C or higher and 200°C or lower, and the kneading time can be set to about 15 minutes or more and 210 minutes or less.

[0138] Further, the kneaded material is formed into a pellet (small particle) as needed. The particle diameter of the pellet is set to, for example, about 1 mm or more and 15 mm or less.

[0139] Incidentally, depending on the molding method described below, in place of the kneaded material, a granulated powder may be produced. The kneaded material, the granulated powder, and the like are examples of the composition to be subjected to the molding step described below.

[0140] The embodiment of the granulated powder according to the invention is directed to a granulated powder obtained by binding a plurality of metal particles to one another with a binder by subjecting the metal powder for powder metallurgy according to the invention to a granulation treatment.

[0141] Examples of the binder to be used for producing the granulated powder include polyolefins such as polyethylene, polypropylene, and ethylene-vinyl acetate copolymers, acrylic resins such as polymethyl methacrylate and polybutyl methacrylate, styrenic resins such as polystyrene, polyesters such as polyvinyl chloride, polyvinylidene chloride, polyamide, polyethylene terephthalate, and polybutylene terephthalate, various resins such as polyether, polyvinyl alcohol, polyvinylpyrrolidone, and copolymers thereof, and various organic binders such as various waxes, paraffins, higher fatty acids (such as stearic acid), higher alcohols, higher fatty acid esters, and higher fatty acid amides. These can be used alone or by mixing two or more types thereof.

[0142] Among these, as the binder, a binder containing a polyvinyl alcohol or polyvinylpyrrolidone is preferred. These binder components have a high binding ability, and therefore can efficiently form the granulated powder even in a relatively small amount. Further, the thermal decomposability thereof is also high, and therefore, the binder can be reliably decomposed and removed in a short time during degreasing and firing.

[0143] The content of the binder is preferably about 0.2% by mass or more and 10% by mass or less, more preferably about 0.3% by mass or more and 5% by mass or less, further more preferably about 0.3% by mass or more and 2% by mass or less with respect to the total amount of the granulated powder. By setting the content of the binder within the above range, the granulated powder can be efficiently formed while preventing significantly large particles from being formed or the metal particles which are not granulated from remaining in a large amount. Further, since the moldability is improved, the stability of the shape of the molded body and the like can be particularly enhanced. Further, by setting the content of the binder within the above range, a difference in size between the molded body and the degreased body, that is, so-called a shrinkage ratio is optimized, whereby a decrease in the dimensional accuracy of the finally obtained sintered body can be prevented.

[0144] Further, in the granulated powder, any of a variety of additives such as a plasticizer, a lubricant, an antioxidant, a degreasing accelerator, and a surfactant may be added as needed.

[0145] Examples of the granulation treatment include a spray drying method, a tumbling granulation method, a fluidized bed granulation method, and a tumbling fluidized bed granulation method.

[0146] In the granulation treatment, a solvent which dissolves the binder is used as needed. Examples of the solvent include inorganic solvents such as water and carbon tetrachloride, and organic solvents such as ketone-based solvents, alcohol-based solvents, ether-based solvents, cellosolve-based solvents, aliphatic hydrocarbon-based solvents, aromatic hydrocarbon-based solvents, aromatic heterocyclic compound-based solvents, amide-based solvents, halogen compound-based solvents, ester-based solvents, amine-based solvents, nitrile-based solvents, nitro-based solvents, and aldehyde-based solvents, and one type or a mixture of two or more types selected from these solvents is used.

[0147] The average particle diameter of the granulated powder is not particularly limited, and is preferably about 10 μm or more and 200 μm or less, more preferably about 20 μm or more and 100 μm or less, further more preferably about 25 μm or more and 60 μm or less. The granulated powder having such a particle diameter has favorable fluidity, and can more faithfully reflect the shape of a molding die.

[0148] The average particle diameter can be obtained as a particle diameter when the cumulative amount obtained by cumulating the percentages of the particles from the smaller diameter side reaches 50% in a cumulative particle size distribution on a mass basis obtained by laser diffractometry.

(B) Molding Step

[0149] Subsequently, the kneaded material or the granulated powder is molded, whereby a molded body having the same shape as that of a desired sintered body is produced.

[0150] The method for producing a molded body (molding method) is not particularly limited, and for example, any of a variety of molding methods such as a powder compacting (compression molding) method, a metal powder injection molding (MIM: Metal Injection Molding) method, and an extrusion molding method can be used.

[0151] The molding conditions in the case of a powder compacting method among these methods are preferably such that the molding pressure is about 200 MPa or more and 1000 MPa or less (2 t/cm^2 or more and 10 t/cm^2 or less), which vary depending on the respective conditions such as the composition and the particle diameter of the metal powder for powder metallurgy to be used, the composition of the binder, and the blending amount thereof.

[0152] The molding conditions in the case of a metal powder injection molding method are preferably such that the material temperature is about 80°C or higher and 210°C or lower, and the injection pressure is about 50 MPa or more and 500 MPa or less (0.5 t/cm^2 or more and 5 t/cm^2 or less), which vary depending on the respective conditions.

[0153] The molding conditions in the case of an extrusion molding method are preferably such that the material temperature is about 80°C or higher and 210°C or lower, and the extrusion pressure is about 50 MPa or more and 500 MPa or less (0.5 t/cm^2 or more and 5 t/cm^2 or less), which vary depending on the respective conditions.

[0154] The thus obtained molded body is in a state where the binder is uniformly distributed in spaces between the particles of the metal powder.

[0155] The shape and size of the molded body to be produced are determined in anticipation of shrinkage of the molded body in the subsequent degreasing step and firing step.

(C) Degreasing Step

[0156] Subsequently, the thus obtained molded body is subjected to a degreasing treatment (binder removal treatment), whereby a degreased body is obtained.

[0157] Specifically, the binder is decomposed by heating the molded body, whereby the binder is removed from the molded body. In this manner, the degreasing treatment is performed.

[0158] Examples of the degreasing treatment include a method of heating the molded body and a method of exposing the molded body to a gas capable of decomposing the binder.

[0159] In the case of using a method of heating the molded body, the conditions for heating the molded body are preferably such that the temperature is about 100°C or higher and 750°C or lower and the time is about 0.1 hours or more and 20 hours or less, and more preferably such that the temperature is about 150°C or higher and 600°C or lower and the time is about 0.5 hours or more and 15 hours or less, which slightly vary depending on the composition and the blending amount of the binder. According to this, the degreasing of the molded body can be necessarily and sufficiently performed without sintering the molded body. As a result, it is possible to reliably prevent the binder component from remaining inside the degreased body in a large amount.

[0160] The atmosphere when the molded body is heated is not particularly limited, and an atmosphere of a reducing gas such as hydrogen, an atmosphere of an inert gas such as nitrogen or argon, an atmosphere of an oxidative gas such as air, a reduced pressure atmosphere obtained by reducing the pressure of such an atmosphere, or the like can be used.

[0161] Examples of the gas capable of decomposing the binder include ozone gas.

[0162] Incidentally, by dividing this degreasing step into a plurality of steps in which the degreasing conditions are different, and performing the plurality of steps, the binder in the molded body can be more rapidly decomposed and removed so that the binder does not remain in the molded body.

[0163] Further, according to need, the degreased body may be subjected to a machining process such as grinding, polishing, or cutting. The degreased body has a relatively low hardness and relatively high plasticity, and therefore, the machining process can be easily performed while preventing the degreased body from losing its shape. According to such a machining process, a sintered body having high dimensional accuracy can be easily obtained in the end.

(D) Firing Step

[0164] The degreased body obtained in the above step (C) is fired in a firing furnace, whereby a sintered body is obtained.

[0165] By this firing, in the metal powder for powder metallurgy, diffusion occurs at the boundary surface between the particles, resulting in sintering. At this time, by the mechanism as described above, the degreased body is rapidly sintered. As a result, a sintered body which is dense and has a high density on the whole is obtained.

[0166] The firing temperature varies depending on the composition, the particle diameter, and the like of the metal powder for powder metallurgy used in the production of the molded body and the degreased body, but is set to, for example, about 980°C or higher and 1330°C or lower, and preferably set to about 1050°C or higher and 1260°C or lower.

[0167] Further, the firing time is set to 0.2 hours or more and 7 hours or less, but is preferably set to about 1 hour or more and 6 hours or less.

[0168] In the firing step, the firing temperature or the below-described firing atmosphere may be changed in the middle of the step.

[0169] By setting the firing conditions within such a range, it is possible to sufficiently sinter the entire degreased body while preventing the sintering from proceeding excessively to cause oversintering and increase the size of the crystal structure. As a result, a sintered body having a high density and particularly excellent mechanical properties can be obtained.

[0170] Further, since the firing temperature is a relatively low temperature, it is easy to control the heating temperature in the firing furnace to be constant, and therefore, it is also easy to maintain the temperature of the degreased body constant. As a result, a more homogeneous sintered body can be produced.

[0171] Further, since the firing temperature as described above is a temperature which can be sufficiently realized using a common firing furnace, and therefore, an inexpensive firing furnace can be used, and also the running cost can be kept low. In other words, in the case where the temperature exceeds the above-mentioned firing temperature, it is necessary to employ an expensive firing furnace using a special heat resistant material, and also the running cost may be increased.

[0172] The atmosphere when performing firing is not particularly limited, however, in consideration of prevention of significant oxidation of the metal powder, an atmosphere of a reducing gas such as hydrogen, an atmosphere of an inert gas such as argon, a reduced pressure atmosphere obtained by reducing the pressure of such an atmosphere, or the like is preferably used.

[0173] The thus obtained sintered body has a high density and excellent mechanical properties. That is, a sintered body produced by molding a composition containing the metal powder for powder metallurgy according to the invention and a binder, followed by degreasing and sintering has a higher relative density than a sintered body obtained by sintering a metal powder in the related art. Therefore, according to the invention, a sintered body having a high density which could not be obtained unless an additional treatment such as an HIP treatment is performed can be realized without performing an additional treatment.

[0174] Specifically, according to the invention, for example, the relative density can be expected to be increased by 2% or more as compared with the related art, which slightly varies depending on the composition of the metal powder for powder metallurgy.

[0175] As a result, the relative density of the obtained sintered body can be expected to be, for example, 97% or more (preferably 98% or more, more preferably 98.5% or more). The sintered body having a relative density within such a range has excellent mechanical properties comparable to those of ingot materials although it has a shape as close as possible to a desired shape by using a powder metallurgy technique, and therefore, the sintered body can be applied to a variety of machine parts, structural parts, and the like with virtually no post-processing.

[0176] Further, the tensile strength and the 0.2% proof stress of a sintered body produced by molding a composition containing the metal powder for powder metallurgy according to the invention and a binder, followed by degreasing and sintering are higher than those of a sintered body obtained by performing sintering in the same manner using a metal powder in the related art. This is considered to be because by optimizing the alloy composition, the sinterability of the metal powder is enhanced, and thus, the mechanical properties of a sintered body to be produced using the metal powder are enhanced.

[0177] Further, the sintered body produced as described above has a high surface hardness. Specifically, as one example, the Vickers hardness of the surface of the sintered body is expected to be 140 or more and 500 or less, which slightly varies depending on the composition of the metal powder for powder metallurgy, and further is expected to be preferably 150 or more and 400 or less. The sintered body having such a hardness has particularly high durability.

[0178] The sintered body has a sufficiently high density and mechanical properties even without performing an additional treatment, however, in order to further increase the density and enhance the mechanical properties, a variety of additional treatments may be performed.

[0179] As the additional treatment, for example, an additional treatment of increasing the density such as the HIP treatment described above may be performed, and also a variety of quenching treatments, a variety of sub-zero treatments, a variety of tempering treatments, and the like may be performed. These additional treatments may be performed alone or two or more treatments thereof may be performed in combination.

[0180] In the firing step and a variety of additional treatments described above, a light element in the metal powder (in the sintered body) is volatilized, and the composition of the finally obtained sintered body slightly changes from the composition of the metal powder in some cases.

[0181] For example, the content of C in the final sintered body may change within the range of 5% or more and 100% or less (preferably within the range of 30% or more and 100% or less) of the content of C in the metal powder for powder metallurgy, which varies depending on the conditions for the step or the conditions for the treatment.

[0182] Also the content of O in the final sintered body may change within the range of 1% or more and 50% or less (preferably within the range of 3% or more and 50% or less) of the content of O in the metal powder for powder metallurgy, which varies depending on the conditions for the step or the conditions for the treatment.

[0183] On the other hand, as described above, the produced sintered body may be subjected to an HIP treatment as part of the additional treatments to be performed as needed, however, even if the HIP treatment is performed, a sufficient effect is not exhibited in many cases. In the HIP treatment, the density of the sintered body can be further increased, however, the density of the sintered body obtained according to the invention has already been sufficiently increased at the end of the firing step in the first place. Therefore, even if the HIP treatment is further performed, densification hardly proceeds any further.

[0184] In addition, in the HIP treatment, it is necessary to apply pressure to a material to be treated through a pressure medium, and therefore, the material to be treated may be contaminated, the composition or the physical properties of the material to be treated may unintentionally change accompanying the contamination, or the color of the material to be treated may change accompanying the contamination. Further, by the application of pressure, residual stress is generated or increased in the material to be treated, and a problem such as a change in the shape or a decrease in the dimensional accuracy may occur as the residual stress is released over time.

[0185] On the other hand, according to the invention, a sintered body having a sufficiently high density can be produced without performing such an HIP treatment, and therefore, a sintered body having an increased density and also an increased strength can be obtained in the same manner as in the case of performing an HIP treatment. Such a sintered body is less contaminated and discolored, and also an unintended change in the composition or physical properties, or the like occurs less, and also a problem such as a change in the shape or a decrease in the dimensional accuracy occurs less. Therefore, according to the invention, a sintered body having high mechanical strength and dimensional accuracy, and excellent durability can be efficiently produced.

[0186] Further, the sintered body produced according to the invention requires almost no additional treatments for enhancing the mechanical properties, and therefore, the composition and the crystal structure tend to become uniform in the entire sintered body. Due to this, the sintered body has high structural anisotropy and therefore has excellent durability against a load from every direction regardless of its shape.

[0187] Incidentally, it is confirmed that in the thus produced sintered body, the porosity near the surface thereof is often relatively smaller than inside the sintered body. The reason therefor is not clear, however, one of the reasons is that by the addition of the first element and the second element, the sintering reaction more easily proceeds near the surface of the molded body than inside the molded body.

[0188] Specifically, when the porosity near the surface of the sintered body is represented by A1 and the porosity inside the sintered body is represented by A2, A2-A1 is preferably 0.1% or more and 3% or less, more preferably 0.2% or more and 2% or less. The sintered body showing the value of A2-A1 within the above range not only has necessary and sufficient mechanical strength, but also can easily flatten the surface. That is, by polishing the surface of such a sintered body, a surface having high specularity can be obtained.

[0189] Such a sintered body having high specularity not only has high mechanical strength, but also has excellent aesthetic properties. Therefore, such a sintered body is favorably used also for application requiring excellent aesthetic appearance.

[0190] Incidentally, the porosity A1 near the surface of the sintered body refers to a porosity in a 25-μm radius region centered on the position at a depth of 50 μm from the surface of the cross section of the sintered body. Further, the porosity A2 inside the sintered body refers to a porosity in a 25-μm radius region centered on the position at a depth of 300 μm from the surface of the cross section of the sintered body. These porosities are values obtained by observing the cross section of the sintered body with a scanning electron microscope and dividing the area of pores present in the region by the area of the region.

[0191] Hereinabove, the metal powder for powder metallurgy, the compound, the granulated powder, and the sintered body according to the invention have been described with reference to preferred embodiments, however, the invention is not limited thereto.

[0192] Further, the sintered body according to the invention is used for, for example, parts for transport machinery such as parts for automobiles, parts for bicycles, parts for railcars, parts for ships, parts for airplanes, and parts for space transport machinery (such as rockets); parts for electronic devices such as parts for personal computers and parts for mobile phone terminals; parts for electrical devices such as refrigerators, washing machines, and cooling and heating machines; parts for machines such as machine tools and semiconductor production devices; parts for plants such as atomic power plants, thermal power plants, hydroelectric power plants, oil refinery plants, and chemical complexes; parts for timepieces, metallic tableware, jewels, ornaments such as frames for glasses, and all other sorts of structural parts.

Examples

[0193] Next, Examples of the invention will be described.

1. Production of Sintered Body (Zr-Nb based)

Sample No. 1

[0194]

(1) First, a metal powder having a composition shown in Table 1 produced by a water atomization method was prepared. This metal powder had an average particle diameter of 4.12 μm, a tap density of 4.15 g/cm^3, and a specific surface area of 0.21 m^2/g.
The composition of the powder shown in Table 1 was identified and determined by an inductively coupled high-frequency plasma optical emission spectrometry (ICP analysis method). In the ICP analysis, an ICP device (model: CIROS-120) manufactured by Rigaku Corporation was used. Further, in the identification and determination of C, a carbon-sulfur analyzer (CS-200) manufactured by LECO Corporation was used. Further, in the identification and determination of O, an oxygen-nitrogen analyzer (TC-300/EF-300) manufactured by LECO Corporation was used.
(2) Subsequently, the metal powder and a mixture (organic binder) of polypropylene and a wax were weighed at a mass ratio of 9:1 and mixed with each other, whereby a mixed starting material was obtained.
(3) Subsequently, this mixed starting material was kneaded using a kneader, whereby a compound was obtained.
(4) Subsequently, this compound was molded using an injection molding device under the following molding conditions, whereby a molded body was produced. Molding Conditions

- Material temperature: 150°C
- Injection pressure: 11 MPa (110 kgf/cm^2)

(5) Subsequently, the obtained molded body was subjected to a heat treatment (degreasing treatment) under the following degreasing conditions, whereby a degreased body was obtained.
Degreasing Conditions

- Degreasing temperature: 500°C
- Degreasing time: 1 hour (retention time at the degreasing temperature)
- Degreasing atmosphere: nitrogen atmosphere

(6) Subsequently, the obtained degreased body was fired under the following firing conditions, whereby a sintered body was obtained. The shape of the sintered body was determined to be a cylinder with a diameter of 10 mm and a thickness of 5 mm.
Firing Conditions

- Firing temperature: 1200°C
- Firing time: 3 hours (retention time at the firing temperature)
- Firing atmosphere: argon atmosphere

Sample Nos. 2 to 30

[0195] Sintered bodies were obtained in the same manner as the method for producing the sintered body of sample No. 1 except that the composition and the like of the metal powder for powder metallurgy were changed as shown in Table 1, respectively. The sintered body of sample No. 30 was obtained by performing an HIP treatment under the following conditions after firing. Further, the sintered bodies of sample Nos. 18 to 20 were obtained by using the metal powder produced by a gas atomization method, respectively, and indicated by "gas" in the column of Remarks in Table 1.

HIP Treatment Conditions

[0196]

- Heating temperature: 1100°C
- Heating time: 2 hours
- Applied pressure: 100 MPa

Table 1

Sample No.	-	Metal powder for powder metallurgy														
		Alloy composition										E1/E2	E1+E2	(E1+E2)/Si	(E1+E2) /C	Remarks
		Cr	Ni	Si	C	E1 (Zr)	E2 (Nb)	Mo	Mn	O	Fe					
		mass%										-	mass%	-	-	-
No. 1	Example	16.43	12.48	0.73	0.018	0.09	0.07	2.11	0.06	0.28	remainder	1.29	0.16	0.22	8.89	
No. 2	Example	17.12	12.63	0.58	0.023	0.07	0.05	2.43	0.12	0.31	remainder	1.40	0.12	0.21	5.22	
No. 3	Example	17.87	13.24	0.65	0.029	0.05	0.09	2.04	0.07	0.42	remainder	0.56	0.14	0.22	4.83	
No. 4	Example	16.19	14.71	0.84	0.011	0.05	0.05	2.89	0.08	0.25	remainder	1.00	0.10	0.12	9.09	
No. 5	Example	17.55	13.88	0.75	0.026	0.09	0.10	2.61	0.11	0.36	remainder	0.90	0.19	0.25	7.31	
No. 6	Example	16.79	11.58	0.52	0.068	0.12	0.03	2.74	0.12	0.22	remainder	4.00	0.15	0.29	2.21	
No. 7	Example	17.49	13.21	0.69	0.054	0.03	0.12	2.15	0.79	0.41	remainder	0.25	0.15	0.22	2.78	
No. 8	Example	16.88	14.15	0.77	0.024	0.24	0.09	2.23	0.28	0.48	remainder	2.67	0.33	0.43	13.75	
No. 9	Example	17.32	12.65	0.48	0.021	0.08	0.26	2.81	0.17	0.29	remainder	0.31	0.34	0.71	16.19	
No. 10	Example	17.25	12.87	0.35	0.065	0.09	0.05	2.15	0.35	0.62	remainder	1.80	0.14	0.40	2.15	
No. 11	Example	17.66	12.55	0.96	0.017	0.07	0.07	2.24	0.05	0.25	remainder	1.00	0.14	0.15	8.24	
No. 12	Example	16.87	12.91	1.12	0.025	0.15	0.19	2.13	0.05	0.25	remainder	0.79	0.34	0.30	13.60	
No. 13	Example	16.78	12.19	0.54	0.019	0.36	0.42	2.25	0.07	0.58	remainder	0.86	0.78	1.44	41.05	
No. 14	Example	16.77	12.89	0.91	0.024	0.14	0.17	2.13	0.05	0.25	remainder	0.82	0.31	0.34	12.92	
No. 15	Example	16.47	12.57	0.87	0.023	0.13	0.15	2.04	0.05	0.25	remainder	0.87	0.28	0.32	12.17	
No. 16	Example	16.75	12.58	0.68	0.007	0.05	0.09	2.84	0.12	0.28	remainder	0.56	0.14	0.21	20.00	
No. 17	Example	17.22	13.54	0.84	0.152	0.08	0.05	2.84	0.12	0.28	remainder	1.60	0.13	0.15	0.86	
No. 18	Example	16.45	12.55	0.72	0.023	0.08	0.08	1.95	0.08	0.07	remainder	1.00	0.16	0.22	6.96	gas
No. 19	Example	17.26	12.57	0.59	0.032	0.07	0.06	2.64	0.02	0.08	remainder	1.17	0.13	0.22	4.06	gas
No. 20	Example	17.64	13.41	0.63	0.015	0.04	0.07	2.04	0.06	0.10	remainder	0.57	0.11	0.17	7.33	gas
No. 21	Comparative Example	16.34	12.84	0.75	0.025	0.00	0.07	2.36	0.11	0.29	remainder	0.00	0.07	0.09	2.80	

(continued)

		Metal powder for powder metallurgy														
		Alloy composition										E1/E2	E1+E2	(E1+E2)/Si	(E1+E2) /C	Remarks
Sample No.	-	Cr	Ni	Si	C	E1 (Zr)	E2 (Nb)	Mo	Mn	O	Fe					
		mass%										-	mass%	-	-	-
No. 22	Comparative Example	17.22	13.32	0.79	0.032	0.05	0.00	2.28	0.09	0.31	remainder	-	0.05	0.06	1.56	
No. 23	Comparative Example	16.75	14.23	0.75	0.015	0.00	0.00	2.33	0.12	0.33	remainder	-	0.00	0.00	0.00	
No. 24	Comparative Example	16.43	12.45	0.88	0.021	0.68	0.07	2.58	0.17	0.38	remainder	9.71	0.75	0.85	35.71	
No. 25	Comparative Example	16.35	13.04	0.66	0.035	0.06	0.71	2.36	0.05	0.41	remainder	0.08	0.77	1.17	22.00	
No. 26	Comparative Example	17.56	13.25	0.15	0.011	0.06	0.07	2.77	0.17	0.27	remainder	0.86	0.13	0.87	11.82	
No. 27	Comparative Example	17.63	13.54	0.95	0.061	0.04	0.08	2.89	0.32	0.45	remainder	0.50	0.12	0.06	1.97	
No. 28	Comparative Example	17.56	13.25	0.66	0.002	0.01	0.01	2.77	0.11	0.27	remainder	1.00	0.02	0.03	10.00	
No. 29	Comparative Example	17.56	13.25	0.35	0.380	0.22	0.07	2.68	0.24	0.45	remainder	3.14	0.29	0.83	0.76	
No. 30	Comparative Example	16.34	12.84	0.75	0.025	0.00	0.07	2.36	0.11	0.29	remainder	-	0.07	0.09	2.80	HIP treatment

[0197] In Table 1, among the sintered bodies of the respective sample Nos., those corresponding to the invention are indicated by "Example", and those not corresponding to the invention are indicated by "Comparative Example".

[0198] Each sintered body contained very small amounts of impurities, but the description thereof in Table 1 is omitted.

Sample Nos. 31 to 48

[0199] Sintered bodies were obtained in the same manner as the method for producing the sintered body of sample No. 1 except that the composition and the like of the metal powder for powder metallurgy were changed as shown in Table 2, respectively. The sintered body of sample No. 48 was obtained by performing an HIP treatment under the following conditions after firing. Further, the sintered bodies of sample Nos. 41 to 43 were obtained by using the metal powder produced by a gas atomization method, respectively, and indicated by "gas" in the column of Remarks in Table 2.

HIP Treatment Conditions

[0200]

- Heating temperature: 1100°C
    - Heating time: 2 hours
- Applied pressure: 100 MPa

Table 2

Sample No.	-	Metal powder for powder metallurgy														
		Alloy composition										E1/E2	E1+E2	(E1+E2)/Si	(E1+E2)/C	Remarks
		Cr	Ni	Si	C	E1 (Zr)	E2 (Nb)	Mo	Mn	O	Fe					
		mass%										-	mass%	-	-	-
No. 31	Example	18.94	13.59	0.77	0.048	0.11	0.09	3.48	0.08	0.48	remainder	1.22	0.20	0.26	4.17	
No. 32	Example	18.15	14.75	0.51	0.021	0.08	0.08	3.08	0.95	0.42	remainder	1.00	0.16	0.31	7.62	
No. 33	Example	19.63	11.39	0.32	0.074	0.09	0.05	3.92	0.35	0.62	remainder	1.80	0.14	0.44	1.89	
No. 34	Example	18.67	13.44	0.98	0.065	0.18	0.04	3.32	0.07	0.28	remainder	4.50	0.22	0.22	3.38	
No. 35	Example	18.03	14.87	0.51	0.005	0.04	0.08	3.15	0.02	0.35	remainder	0.50	0.12	0.24	24.00	
No. 36	Example	19.78	12.35	0.42	0.178	0.09	0.08	3.87	0.35	0.62	remainder	1.13	0.17	0.40	0.96	
No. 37	Example	18.65	13.42	0.87	0.061	0.17	0.04	3.29	0.07	0.28	remainder	4.25	0.21	0.24	3.44	
No. 38	Example	18.63	13.46	0.94	0.063	0.16	0.05	3.27	0.07	0.28	remainder	3.20	0.21	0.22	3.33	
No. 39	Example	22.54	13.59	0.86	0.066	0.08	0.08	0.00	0.09	0.26	remainder	1.00	0.16	0.19	2.42	
No. 40	Example	25.41	21.36	1.16	0.053	0.06	0.08	0.00	0.07	0.27	remainder	0.75	0.14	0.12	2.64	
No. 41	Example	18.88	13.54	0.87	0.056	0.12	0.11	3.52	0.11	0.12	remainder	1.09	0.23	0.26	4.11	gas
No. 42	Example	18.21	14.81	0.48	0.025	0.07	0.09	3.11	0.98	0.11	remainder	0.78	0.16	0.33	6.40	gas
No. 43	Example	19.57	11.44	0.31	0.068	0.08	0.06	4.02	0.51	0.16	remainder	1.33	0.14	0.45	2.06	gas
No. 44	Comparative Example	18.87	11.24	0.57	0.056	0.00	0.07	3.47	0.22	0.29	remainder	0.00	0.07	0.12	1.25	
No. 45	Comparative Example	19.56	14.15	0.79	0.032	0.15	0.00	3.75	0.09	0.31	remainder	-	0.15	0.19	4.69	
No. 46	Comparative Example	18.78	11.42	0.88	0.012	0.58	0.07	2.58	0.11	0.38	remainder	8.29	0.65	0.74	54.17	
No. 47	Comparative Example	19.65	14.51	0.66	0.053	0.06	0.89	2.36	0.05	0.41	remainder	0.07	0.95	1.44	17.92	
No. 48	Comparative Example	18.87	11.24	0.57	0.056	0.00	0.07	3.47	0.22	0.29	remainder	0.00	0.07	0.12	1.25	HIP treatment

[0201] In Table 2, among the sintered bodies of the respective sample Nos., those corresponding to the invention are indicated by "Example", and those not corresponding to the invention are indicated by "Comparative Example".

[0202] Each sintered body contained very small amounts of impurities, but the description thereof in Table 2 is omitted.

Sample Nos. 49 to 66

[0203] Sintered bodies were obtained in the same manner as the method for producing the sintered body of sample No. 1 except that the composition and the like of the metal powder for powder metallurgy were changed as shown in Table 3, respectively. The sintered body of sample No. 66 was obtained by performing an HIP treatment under the following conditions after firing. Further, the sintered bodies of sample Nos. 59 to 61 were obtained by using the metal powder produced by a gas atomization method, respectively, and indicated by "gas" in the column of Remarks in Table 3.

HIP Treatment Conditions

[0204]

- Heating temperature: 1100°C
- Heating time: 2 hours
- Applied pressure: 100 MPa

Table 3

Sample No.	-	Metal powder for powder metallurgy														
		Alloy composition										E1/E2	E1+E2	(E1+E2) /Si	(E1+E2) /C	Remarks
		Cr	Ni Si		C	E1 (Zr)	E2 (Nb)	Mo	Mn	O	Fe					
		mass%										-	mass%	-	-	-
No. 49	Example	19.21	8.34	0.62	0.038	0.08	0.06	0.00	0.21	0.48	remainder	1.33	0.14	0.23	3.68	
No. 50	Example	19.74	9.56	0.88	0.041	0.05	0.10	0.08	0.04	0.55	remainder	0.50	0.15	0.17	3.66	
No. 51	Example	18.30	10.12	0.44	0.019	0.15	0.09	0.05	0.07	0.68	remainder	1.67	0.24	0.55	12.63	
No. 52	Example	19.35	8.19	1.05	0.069	0.08	0.06	0.00	0.05	0.18	remainder	1.33	0.14	0.13	2.03	
No. 53	Example	19.45	9.65	0.88	0.007	0.05	0.10	0.08	0.00	0.55	remainder	0.50	0.15	0.17	21.43	
No. 54	Example	18.25	10.25	0.44	0.256	0.15	0.09	0.05	0.07	0.68	remainder	1.67	0.24	0.55	0.94	
No. 55	Example	20.58	21.54	1.15	0.074	0.05	0.09	0.00	1.23	0.75	remainder	0.56	0.14	0.12	1.89	
No. 56	Example	20.34	19.25	1.02	0.068	0.05	0.09	0.00	1.23	0.75	remainder	0.56	0.14	0.14	2.06	
No. 57	Example	16.58	7.45	0.56	0.128	0.06	0.08	0.05	0.48	0.25	remainder	0.75	0.14	0.25	1.09	
No. 58	Example	15.72	10.25	0.36	0.058	0.04	0.09	2.54	0.07	0.21	remainder	0.44	0.13	0.36	2.24	
No. 59	Example	19.11	8.43	0.64	0.045	0.07	0.07	0.00	0.23	0.12	remainder	1.00	0.14	0.22	3.11	gas
No. 60	Example	19.72	9.65	0.85	0.048	0.06	0.11	0.09	0.05	0.14	remainder	0.55	0.17	0.20	3.54	gas
No. 61	Example	18.25	10.21	0.46	0.015	0.12	0.12	0.06	0.09	0.18	remainder	1.00	0.24	0.52	16.00	gas
No. 62	Comparative Example	19.11	8.48	0.74	0.064	0.00	0.05	0.00	0.18	0.28	remainder	0.00	0.05	0.07	0.78	
No. 63	Comparative Example	18.78	9.77	0.79	0.023	0.08	0.00	0.02	0.09	0.31	remainder	-	0.08	0.10	3.48	
No. 64	Comparative Example	18.42	8.21	0.39	0.012	0.69	0.07	0.03	0.17	0.38	remainder	9.86	0.76	1.95	62.33	
No. 65	Comparative Example	19.21	8.55	0.42	0.021	0.06	0.61	0.02	0.15	0.32	remainder	0.10	0.67	1.60	31.90	
No. 66	Comparative Example	19.11	8.48	0.74	0.064	0.00	0.05	0.00	0.18	0.28	remainder	0.00	0.05	0.07	0.78	HIP treatment

[0205] In Table 3, among the sintered bodies of the respective sample Nos., those corresponding to the invention are indicated by "Example", and those not corresponding to the invention are indicated by "Comparative Example".
[0206] Each sintered body contained very small amounts of impurities, but the description thereof in Table 3 is omitted.

Sample No. 67

[0207]

(1) First, a metal powder having a composition shown in Table 4 was produced by a water atomization method in the same manner as in the case of sample No. 1.
(2) Subsequently, the metal powder was granulated by a spray drying method. The binder used at this time was polyvinyl alcohol, which was used in an amount of 1 part by mass with respect to 100 parts by mass of the metal powder. Further, a solvent (ion exchanged water) was used in an amount of 50 parts by mass with respect to 1 part by mass of polyvinyl alcohol. In this manner, a granulated powder having an average particle diameter of 50 μm was obtained.
(3) Subsequently, this granulated powder was compact-molded under the following molding conditions. In this molding, a press molding machine was used. The shape of the molded body to be produced was determined to be a cube with a side length of 20 mm.
Molding Conditions

- Material temperature: 90°C
- Molding pressure: 600 MPa (6 t/cm^2)

(4) Subsequently, the obtained molded body was subjected to a heat treatment (degreasing treatment) under the following degreasing conditions, whereby a degreased body was obtained.
Degreasing Conditions

- Degreasing temperature: 450°C
- Degreasing time: 2 hours (retention time at the degreasing temperature)
- Degreasing atmosphere: nitrogen atmosphere

(5) Subsequently, the obtained degreased body was fired under the following firing conditions, whereby a sintered body was obtained.
Firing Conditions

- Firing temperature: 1200°C
- Firing time: 3 hours (retention time at the firing temperature)
- Firing atmosphere: argon atmosphere

Sample Nos. 68 to 85

[0208] Sintered bodies were obtained in the same manner as in the case of sample No. 67 except that the composition and the like of the metal powder for powder metallurgy were changed as shown in Table 4, respectively. The sintered body of sample No. 85 was obtained by performing an HIP treatment under the following conditions after firing.

HIP Treatment Conditions

[0209]

- Heating temperature: 1100°C
- Heating time: 2 hours
- Applied pressure: 100 MPa

Table 4

Sample No.	-	Metal powder for powder metallurgy														
		Alloy composition										E1/E2	E1+E2	(E1+E2) /Si	(E1+E2) /C	Remarks
		Cr	Ni	Si	C	E1 (Zr)	E2 (Nb)	Mo	Mn	O	Fe					
		mass%										-	mass%	-	-	-
No. 67	Example	16.43	12.48	0.73	0.018	0.09	0.07	2.11	0.06	0.28	remainder	1.29	0.16	0.22	8.89	Powder compacting
No. 68	Example	17.12	12.63	0.58	0.023	0.07	0.05	2.43	0.12	0.31	remainder	1.40	0.12	0.21	5.22	Powder compacting
No. 69	Example	17.87	13.24	0.65	0.029	0.05	0.09	2.04	0.07	0.42	remainder	0.56	0.14	0.22	4.83	Powder compacting
No. 70	Example	16.19	14.71	0.84	0.011	0.05	0.05	2.89	0.08	0.25	remainder	1.00	0.10	0.12	9.09	Powder compacting
No. 71	Example	17.55	13.88	0.75	0.026	0.09	0.10	2.61	0.11	0.36	remainder	0.90	0.19	0.25	7.31	Powder compacting
No. 72	Example	16.79	11.58	0.52	0.068	0.12	0.03	2.74	0.12	0.22	remainder	4.00	0.15	0.29	2.21	Powder compacting
No. 73	Example	17.49	13.21	0.69	0.054	0.03	0.12	2.15	0.79	0.41	remainder	0.25	0.15	0.22	2.78	Powder compacting
No. 74	Example	16.88	14.15	0.77	0.024	0.24	0.09	2.23	0.28	0.48	remainder	2.67	0.33	0.43	13.75	Powder compacting
No. 75	Example	17.32	12.65	0.48	0.021	0.08	0.26	2.81	0.17	0.29	remainder	0.31	0.34	0.17	16.19	Powder compacting
No. 76	Example	17.25	12.87	0.35	0.065	0.09	0.05	2.15	0.35	0.62	remainder	1.80	0.14	0.40	2.15	Powder compacting
No. 77	Example	17.66	12.55	0.96	0.017	0.07	0.07	2.24	0.05	0.25	remainder	1.00	0.14	0.15	8.24	Powder compacting
No. 78	Example	16.87	12.91	1.12	0.025	0.15	0.19	2.13	0.05	0.25	remainder	0.79	0.34	0.30	13.60	Powder compacting
No. 79	Example	16.78	12.19	0.54	0.019	0.36	0.42	2.25	0.07	0.58	remainder	0.86	0.78	1.44	41.05	Powder compacting

(continued)

Sample No.	-	Metal powder for powder metallurgy														
		Alloy composition										E1/E2	E1+E2	(E1+E2) /Si	(E1+E2) /C	Remarks
		Cr	Ni	Si	C	E1 (Zr)	E2 (Nb)	Mo	Mn	O	Fe					
		mass%										-	mass%	-	-	-
No. 80	Comparative Example	16.34	12.84	0.75	0.025	0.00	0.07	2.36	0.11	0.29	remainder	0.00	0.07	0.09	2.80	Powder compacting
No. 81	Comparative Example	17.22	13.32	0.79	0.032	0.05	0.00	2.28	0.09	0.31	remainder	-	0.05	0.06	1.56	Powder compacting
No. 82	Comparative Example	16.75	14.23	0.75	0.015	0.00	0.00	2.33	0.12	0.33	remainder	-	0.00	0.00	0.00	Powder compacting
No. 83	Comparative Example	16.43	12.45	0.88	0.021	0.68	0.07	2.58	0.11	0.38	remainder	9.71	0.75	0.85	35.71	Powder compacting
No. 84	Comparative Example	16.35	13.04	0.66	0.035	0.06	0.17	2.36	0.05	0.41	remainder	0.08	0.77	1.17	22.00	Powder compacting
No. 85	Comparative Example	16.34	12.84	0.75	0.025	0.00	0.07	2.36	0.11	0.29	remainder	-	0.07	0.09	2.80	HIP treatment

[0210] In Table 4, among the metal powders for powder metallurgy and the sintered bodies of the respective sample Nos., those corresponding to the invention are indicated by "Example", and those not corresponding to the invention are indicated by "Comparative Example".
[0211] Each sintered body contained very small amounts of impurities, but the description thereof in Table 4 is omitted.

2. Evaluation of Sintered Body (Zr-Nb based)

2.1 Evaluation of Relative Density

[0212] With respect to the sintered bodies of the respective sample Nos. shown in Tables 1 to 4, the sintered density was measured in accordance with the method for measuring the density of sintered metal materials specified in JIS Z 2501 (2000), and also the relative density of each sintered body was calculated with reference to the true density of the metal powder for powder metallurgy used for producing each sintered body.
[0213] The calculation results are shown in Tables 5 to 8.

2.2 Evaluation of Vickers Hardness

[0214] With respect to the sintered bodies of the respective sample Nos. shown in Tables 1 to 4, the Vickers hardness was measured in accordance with the Vickers hardness test method specified in JIS Z 2244 (2009).
[0215] The measurement results are shown in Tables 5 to 8.

2.3 Evaluation of Tensile Strength, 0.2% Proof Stress, and Elongation

[0216] With respect to the sintered bodies of the respective sample Nos. shown in Tables 1 to 4, the tensile strength, 0.2% proof stress, and elongation were measured in accordance with the metal material tensile test method specified in JIS Z 2241 (2011).
[0217] Then, the measured values of these physical properties were evaluated according to the following evaluation criteria.

Evaluation Criteria for Tensile Strength (Tables 5 and 8)

[0218]

A: The tensile strength of the sintered body is 520 MPa or more.
B: The tensile strength of the sintered body is 510 MPa or more and less than 520 MPa.
C: The tensile strength of the sintered body is 500 MPa or more and less than 510 MPa.
D: The tensile strength of the sintered body is 490 MPa or more and less than 500 MPa.
E: The tensile strength of the sintered body is 480 MPa or more and less than 490 MPa.
F: The tensile strength of the sintered body is less than 480 MPa.

Evaluation Criteria for Tensile Strength (Tables 6 and 7)

[0219]

A: The tensile strength of the sintered body is 560 MPa or more.
B: The tensile strength of the sintered body is 550 MPa or more and less than 560 MPa.
C: The tensile strength of the sintered body is 540 MPa or more and less than 550 MPa.
D: The tensile strength of the sintered body is 530 MPa or more and less than 540 MPa.
E: The tensile strength of the sintered body is 520 MPa or more and less than 530 MPa.
F: The tensile strength of the sintered body is less than 520 MPa.

Evaluation Criteria for 0.2% Proof Stress (Tables 5 and 8)

[0220]

A: The 0.2% proof stress of the sintered body is 195 MPa or more.
B: The 0.2% proof stress of the sintered body is 190 MPa or more and less than 195 MPa.
C: The 0.2% proof stress of the sintered body is 185 MPa or more and less than 190 MPa.

D: The 0.2% proof stress of the sintered body is 180 MPa or more and less than 185 MPa.
E: The 0.2% proof stress of the sintered body is 175 MPa or more and less than 180 MPa.
F: The 0.2% proof stress of the sintered body is less than 175 MPa.

Evaluation Criteria for 0.2% Proof Stress (Tables 6 and 7)

[0221]

A: The 0.2% proof stress of the sintered body is 225 MPa or more.

B: The 0.2% proof stress of the sintered body is 220 MPa or more and less than 225 MPa.

C: The 0.2% proof stress of the sintered body is 215 MPa or more and less than 220 MPa.

D: The 0.2% proof stress of the sintered body is 210 MPa or more and less than 215 MPa.

E: The 0.2% proof stress of the sintered body is 205 MPa or more and less than 210 MPa.

F: The 0.2% proof stress of the sintered body is less than 205 MPa.

Evaluation Criteria for Elongation

[0222]

A: The elongation of the sintered body is 48% or more.

B: The elongation of the sintered body is 46% or more and less than 48%.

C: The elongation of the sintered body is 44% or more and less than 46%.

D: The elongation of the sintered body is 42% or more and less than 44%.

E: The elongation of the sintered body is 40% or more and less than 42%.

F: The elongation of the sintered body is less than 40%.

[0223] The above evaluation results are shown in Tables 5 to 8. As described above, the evaluation criteria are different between Tables 5 and 8 and Tables 6 and 7.

2.4 Evaluation of Fatigue Strength

[0224] With respect to the sintered bodies of the respective sample Nos. shown in Tables 1 to 4, the fatigue strength was measured.

[0225] The fatigue strength was measured in accordance with the test method specified in JIS Z 2273 (1978). The waveform of an applied load corresponding to a repeated stress was set to an alternating sine wave, and the minimum/maximum stress ratio (minimum stress/maximum stress) was set to 0.1. Further, the repeated frequency was set to 30 Hz, and the repeat count was set to 1×10^7.

[0226] Then, the measured fatigue strength was evaluated according to the following evaluation criteria.

Evaluation Criteria for Fatigue Strength

[0227]

A: The fatigue strength of the sintered body is 260 MPa or more.
B: The fatigue strength of the sintered body is 240 MPa or more and less than 260 MPa.
C: The fatigue strength of the sintered body is 220 MPa or more and less than 240 MPa.
D: The fatigue strength of the sintered body is 200 MPa or more and less than 220 MPa.
E: The fatigue strength of the sintered body is 180 MPa or more and less than 200 MPa.

F: The fatigue strength of the sintered body is less than 180 MPa.

[0228] The above evaluation results are shown in Tables 5 to 8.

Table 5

		Metal powder	Evaluation results of sintered body					
Sample No.	-	Average particle diameter	Relative density	Vickers hardness	Tensile strength	0.2% proof stress	Elongation	Fatigue
		µm	%	-	-	-	-	-
No. 1	Example	4.05	99.5	165	A	A	A	A
No. 2	Example	3.79	99.6	175	A	A	A	A
No. 3	Example	3.84	99.3	171	A	A	A	A
No. 4	Example	3.92	98.8	153	B	A	A	A
No. 5	Example	4.56	99.7	182	A	A	A	A
No. 6	Example	3.68	98.7	154	B	B	A	B
No. 7	Example	3.77	98.8	156	B	B	A	B
No. 8	Example	3.81	98.3	149	B	B	A	B
No. 9	Example	3.85	98.1	148	B	B	B	B
No. 10	Example	4.23	98.5	152	B	B	A	B
No. 11	Example	3.21	98.1	146	B	B	B	B
No. 12	Example	3.36	97.8	144	B	B	C	B
No. 13	Example	6.18	97.6	142	C	C	C	C
No. 14	Example	10.8	97.5	144	B	C	C	C
No. 15	Example	15.4	97.2	141	C	C	C	C
No. 16	Example	5.23	97.8	141	B	B	B	B
No. 17	Example	4.42	97.3	163	B	B	C	B
No. 18	Example	8.11	99.3	161	A	A	A	A
No. 19	Example	7.65	99.4	171	A	A	A	A
No. 20	Example	7.25	99.1	164	A	A	A	A
No. 21	Comparative Example	3.77	96.4	128	D	D	B	D
No. 22	Comparative Example	3.94	96.8	134	D	D	B	D
No. 23	Comparative Example	3.65	96.2	123	E	E	C	E
No. 24	Comparative Example	4.87	94.7	115	D	D	D	D
No. 25	Comparative Example	4.25	94.6	118	D	D	E	D
No. 26	Comparative Example	3.64	94.5	102	E	E	C	E

(continued)

		Metal powder	Evaluation results of sintered body					
Sample No.	-	Average particle diameter	Relative density	Vickers hardness	Tensile strength	0.2% proof stress	Elongation	Fatigue
		µm	%	-	-	-	-	-
No. 27	Comparative Example	3.55	92.6	135	F	F	E	F
No. 28	Comparative Example	4.87	95.3	118	D	D	B	D
No. 29	Comparative Example	4.66	93.2	138	E	E	F	E
No. 30	Comparative Example	3.77	99.2	175	A	A	B	A

Table 6

		Metal powder	Evaluation results of sintered body					
Sample No.	-	Average particle diameter	Relative density	Vickers hardness	Tensile strength	0.2% proof stress	Elongation	Fatigue strength
		µm	%	-	-	-	-	-
No. 31	Example	5.68	99.3	178	A	A	A	A
No. 32	Example	4.79	99.5	185	A	A	A	A
No. 33	Example	4.05	98.6	167	B	B	A	B
No. 34	Example	3.81	98.8	158	B	B	A	B
No. 35	Example	3.05	98.2	162	B	B	B	B
No. 36	Example	4.25	97.6	154	B	B	C	B
No. 37	Example	9.86	97.8	158	B	B	B	B
No. 38	Example	14.2	97.5	154	B	C	C	C
No. 39	Example	2.56	98.6	171	B	B	A	A
No. 40	Example	14.2	98.3	173	B	B	A	A
No. 41	Example	11.53	99.1	174	A	A	A	A
No. 42	Example	9.64	99.2	180	A	A	A	A
No. 43	Example	8.25	98.3	163	B	B	A	B
No. 44	Comparative Example	5.32	96.4	127	D	D	B	D
No. 45	Comparative Example	5.48	96.7	136	D	D	B	D
No. 46	Comparative Example	4.23	95.2	121	D	D	D	D
No. 47	Comparative Example	4.51	94.8	105	E	E	F	E

(continued)

		Metal powder	Evaluation results of sintered body					
Sample No.	-	Average particle diameter	Relative density	Vickers hardness	Tensile strength	0.2% proof stress	Elongation	Fatigue strength
		μm	%	-	-	-	-	-
No. 48	Comparative Example	5.32	99.2	174	A	A	B	A

Table 7

		Metal powder	Evaluation results of sintered body					
Sample No.	-	Average particle diameter	Relative density	Vickers hardness	Tensile strength	0.2% proof stress	Elongation	Fatigue strength
		μm	%	-	-	-	-	-
No. 49	Example	3.97	99.6	172	A	A	A	A
No. 50	Example	3.25	99.3	167	A	A	B	A
No. 51	Example	6.54	98.4	142	A	A	B	A
No. 52	Example	5.48	98.2	157	B	B	B	B
No. 53	Example	3.92	98.4	161	B	B	B	B
No. 54	Example	3.74	97.3	148	B	B	C	B
No. 55	Example	16.45	97.1	137	C	C	C	C
No. 56	Example	22.1	97.0	135	C	C	C	C
No. 57	Example	10.05	97.5	138	B	B	B	B
No. 58	Example	7.23	98.8	165	B	B	A	B
No. 59	Example	8.12	99.3	165	A	A	A	A
No. 60	Example	7.22	99.0	160	A	A	B	A
No. 61	Example	13.65	98.2	134	A	A	B	A
No. 62	Comparative Example	3.89	96.3	127	D	D	B	D
No. 63	Comparative Example	3.47	96.7	136	D	D	B	D
No. 64	Comparative Example	4.25	94.7	116	D	D	D	D
No. 65	Comparative Example	3.64	95.2	119	D	D	E	D
No. 66	Comparative Example	3.89	99.4	170	A	A	B	A

Table 8

		Metal powder	Evaluation results of sintered body					
Sample No.	-	Average particle diameter	Relative density	Vickers hardness	Tensile strength	0.2% proof stress	Elongation	Fatigue strength
		μm	%	-	-	-	-	-
No. 67	Example	4.05	99.6	168	A	A	A	A
No. 68	Example	3.79	99.6	177	A	A	A	A
No. 69	Example	3.84	99.4	172	A	A	A	A
No. 70	Example	3.92	98.9	155	B	A	A	A
No. 71	Example	4.56	99.7	183	A	A	A	A
No. 72	Example	3.68	98.9	158	B	B	A	B
No. 73	Example	3.77	99.0	162	B	B	A	B
No. 74	Example	3.81	98.5	155	B	B	A	B
No. 75	Example	3.85	98.4	156	B	B	B	B
No. 76	Example	4.23	98.7	157	B	B	A	B
No. 77	Example	3.21	98.4	159	B	B	B	B
No. 78	Example	3.36	98.1	150	B	B	C	B
No. 79	Example	6.18	97.9	146	C	C	C	C
No. 80	Comparative Example	3.77	96.6	129	D	D	B	D
No. 81	Comparative Example	3.94	96.9	136	D	D	B	D
No. 82	Comparative Example	3.65	96.4	128	E	E	C	E
No. 83	Comparative Example	4.87	94.9	119	D	D	D	D
No. 84	Comparative Example	4.25	94.8	125	D	D	E	D
No. 85	Comparative Example	3.77	99.3	180	A	A	B	A

[0229] As apparent from Tables 5 to 8, it was confirmed that the sintered bodies corresponding to Example each have a higher relative density than the sintered bodies corresponding to Comparative Example (excluding the sintered bodies having undergone the HIP treatment). Further, it was also confirmed that there is a significant difference in properties such as tensile strength, 0.2% proof stress, elongation, and fatigue strength between the sintered bodies corresponding to Example and the sintered bodies corresponding to Comparative Example (excluding the sintered bodies having undergone the HIP treatment).

[0230] On the other hand, by comparison of the values of the respective physical properties between the sintered bodies corresponding to Example and the sintered bodies having undergone the HIP treatment, it was confirmed that the values of the physical properties are all comparable to each other.

2.5 Observation of Cross Section of Sintered Body using Scanning Electron Microscope (SEM)

[0231] An observation image was obtained for the cross section of each sintered body corresponding to Example using a scanning electron microscope (JXA-8500F, manufactured by JEOL Ltd.). When the image was taken, the acceleration voltage was set to 15 kV, and the magnification was set to 10000.

[0232] As a result of observation, a region in the form of a particle (first region) which appears dark in color and a region (second region) which is located surrounding the first region and appears light in color were observed in the observation image of the cross section of each sintered body. Therefore, when the average of the circle equivalent diameter of the first region was determined, it was about 2 μm or more and 8 μm or less in all the sintered bodies.

[0233] Subsequently, a qualitative and quantitative analysis of the observation region was performed using an electron beam microanalyzer. As a result, in the first region, the sum of the content of Si and the content of O was 2.5 times to 3.5 times the content of Fe. Further, the content of Si in the first region was 14 times or more the content of Si in the second region. Further, the content of Zr in the first region was 3 times or more the content of Zr in the second region.

[0234] Based on the above results, it was confirmed that in the sintered bodies corresponding to Example, silicon oxide is accumulated by using a Zr carbide or the like as a nucleus.

[0235] The above results revealed that according to the invention, a high density and excellent mechanical properties can be provided to the sintered body in the same manner as in the case of performing an HIP treatment even if an additional treatment of increasing the density such as an HIP treatment is not performed.

[0236] In addition, when a crystal structure analysis was performed for the sintered bodies corresponding to Example by X-ray diffractometry, it was confirmed that all the sintered bodies mainly have an austenite crystal structure.

3. Production of Sintered Body (Hf-Nb based)

Sample Nos. 86 to 113

[0237] Sintered bodies were obtained in the same manner as the method for producing the sintered body of sample No. 1 except that the composition and the like of the metal powder for powder metallurgy were changed as shown in Tables 9 to 11, respectively.

Table 9

		Metal powder for powder metallurgy														
		Alloy composition										E1/E2	E1+E2	(E1+E2) /Si	(E1+E2) /C	Remarks
Sample No.	-	Cr	Ni	Si	C	E1 (Hf)	E2 (Nb)	Mo	Mn	O	Fe					
		mass%										-	mass%	-	-	-
No. 86	Example	16.25	12.56	0.71	0.02	0.09	0.05	2.09	0.05	0.25	remainder	1.80	0.14	0.20	8.24	
No. 87	Example	17.14	12.54	0.57	0.02	0.07	0.05	2.45	0.09	0.32	remainder	1.40	0.12	0.21	5.45	
No. 88	Example	17.78	13.25	0.53	0.03	0.07	0.08	2.06	0.08	0.41	remainder	0.88	0.15	0.28	5.56	
No. 89	Example	16.25	14.68	0.82	0.01	0.06	0.03	2.89	0.08	0.25	remainder	2.00	0.09	0.11	7.50	
No. 90	Example	17.52	13.87	0.74	0.03	0.09	0.10	2.63	0.11	0.34	remainder	0.90	0.19	0.26	7.31	
No. 91	Example	16.82	12.03	0.53	0.07	0.11	0.04	2.76	0.11	0.23	remainder	2.75	0.15	0.28	2.17	
No. 92	Example	17.52	13.25	0.68	0.06	0.07	0.12	2.21	0.78	0.41	remainder	0.58	0.19	0.28	3.45	
No. 93	Comparative Example	16.34	12.84	0.75	0.03	0.00	0.07	2.36	0.11	0.29	remainder	0.00	0.07	0.09	2.80	
No. 94	Comparative Example	17.25	13.35	0.82	0.03	0.08	0.00	2.23	0.09	0.32	remainder	-	0.08	0.10	2.86	
No. 95	Comparative Example	16.75	14.23	0.75	0.02	0.00	0.00	2.33	0.12	0.33	remainder	-	0.00	0.00	0.00	
No. 96	Comparative Example	16.34	12.54	0.87	0.02	0.71	0.05	2.56	0.11	0.36	remainder	14.20	0.76	0.87	36.19	
No. 97	Comparative Example	16.44	13.12	1.65	0.03	0.04	0.68	2.41	0.06	0.42	remainder	0.06	0.72	1.11	21.18	
No. 98	Comparative Example	17.63	13.21	0.14	0.01	0.06	0.07	2.77	0.11	0.27	remainder	0.86	0.13	0.93	10.83	
No. 99	Comparative Example	17.54	13.33	0.91	0.05	0.07	0.05	2.68	0.34	0.48	remainder	1.40	0.12	0.06	2.22	

Table 10

		Metal powder for powder metallurgy														
		Alloy composition										E1/E2	E1+E2	(E1+E2) /Si	(E1+E2) /C	Remarks
Sample No.	-	Cr	Ni	Si	C	E1 (Hf)	E2 (Nb)	Mo	Mn	O	Fe					
		mass%										-	mass%	-	-	-
No. 100	Example	18.96	13.54	0.82	0.041	0.09	0.05	3.55	0.35	0.41	remainder	1.80	0.14	0.17	3.14	
No. 101	Example	18.25	14.86	0.54	0.021	0.06	0.09	3.12	0.87	0.39	remainder	0.67	0.15	0.28	7.14	
No. 102	Example	19.74	11.32	0.34	0.067	0.09	0.09	3.88	0.45	0.55	remainder	1.00	0.18	0.53	2.69	
No. 103	Comparative Example	18.67	11.36	0.78	0.053	0.00	0.07	3.47	0.22	0.29	remainder	0.00	0.07	0.09	1.32	
No. 104	Comparative Example	19.54	14.35	0.89	0.022	0.11	0.00	3.75	0.09	0.31	remainder	-	0.11	0.12	5.00	
No. 105	Comparative Example	18.69	11.87	0.71	0.027	0.54	0.07	3.76	0.12	0.38	remainder	7.71	0.61	0.86	22.59	
No. 106	Comparative Example	19.42	14.58	0.62	0.024	0.06	0.66	3.54	0.07	0.41	remainder	0.09	0.72	1.16	30.00	

Table 11

		Metal powder for powder metallurgy														
		Alloy composition										E1/E2	E1+E2	(E1+E2) /Si	(E1+E2)	Remarks /C
Sample No.		Cr	Ni	Si	C	E1 (Hf)	E2 (Nb)	Mo	Mn	O	Fe					
		mass%										-	mass%	-	-	-
No. 107	Example	19.21	8.25	0.67	0.035	0.08	0.05	0.00	0.18	0.25	remainder	1.60	0.13	0.19	3.71	
No. 108	Example	19.74	9.62	0.89	0.039	0.06	0.09	0.05	0.08	0.29	remainder	0.67	0.15	0.17	3.85	
No. 109	Example	18.30	10.31	0.43	0.017	0.14	0.09	0.03	0.23	0.41	remainder	1.56	0.23	0.53	13.53	
No. 110	Comparative Example	19.11	8.23	0.77	0.055	0.00	0.06	0.00	0.14	0.25	remainder	0.00	0.06	0.08	1.09	
No. 111	Comparative Example	18.78	9.45	0.76	0.024	0.07	0.00	0.02	0.11	0.29	remainder	-	0.07	0.09	2.92	
No. 112	Comparative Example	18.42	8.36	0.38	0.011	0.54	0.08	0.03	0.25	0.28	remainder	6.75	0.62	1.63	56.36	
No. 113	Comparative Example	19.21	8.45	0.45	0.018	0.06	0.58	0.04	0.16	0.32	remainder	1.10	0.64	1.42	35.56	

[0238] In Tables 9 to 11, among the sintered bodies of the respective sample Nos., those corresponding to the invention are indicated by "Example", and those not corresponding to the invention are indicated by "Comparative Example".
[0239] Each sintered body contained very small amounts of impurities, but the description thereof in Tables 9 to 11 is omitted.

4. Evaluation of Sintered Body (Hf-Nb based)

4.1 Evaluation of Relative Density

[0240] With respect to the sintered bodies of the respective sample Nos. shown in Tables 9 to 11, the sintered density was measured in accordance with the method for measuring the density of sintered metal materials specified in JIS Z 2501 (2000), and also the relative density of each sintered body was calculated with reference to the true density of the metal powder for powder metallurgy used for producing each sintered body.
[0241] The calculation results are shown in Tables 12 to 14.

4.2 Evaluation of Vickers Hardness

[0242] With respect to the sintered bodies of the respective sample Nos. shown in Tables 9 to 11, the Vickers hardness was measured in accordance with the Vickers hardness test method specified in JIS Z 2244 (2009).
[0243] The measurement results are shown in Tables 12 to 14.

4.3 Evaluation of Tensile Strength, 0.2% Proof Stress, and Elongation

[0244] With respect to the sintered bodies of the respective sample Nos. shown in Tables 9 to 11, the tensile strength, 0.2% proof stress, and elongation were measured in accordance with the metal material tensile test method specified in JIS Z 2241 (2011).
[0245] Then, the values of the physical properties of the sintered bodies of the respective sample Nos. shown in Table 9 were evaluated according to the above-mentioned evaluation criteria applied to the Tables 5 and 8, and the values of the physical properties of the sintered bodies of the respective sample Nos. shown in Tables 10 and 11 were evaluated according to the above-mentioned evaluation criteria applied to the Tables 6 and 7.
[0246] The evaluation results are shown in Tables 12 to 14.

Table 12

		Metal powder	Evaluation results of sintered body				
Sample No.	-	Average particle diameter	Relative density	Vickers hardness	Tensile strength	0.2% proof stress	Elongation
		μm	%	-	-	-	-
No. 86	Example	4.12	99.5	162	A	A	A
No. 87	Example	4.25	99.3	173	A	A	A
No. 88	Example	4.02	98.7	160	A	A	A
No. 89	Example	3.88	98.5	153	B	A	A
No. 90	Example	4.56	98.9	175	A	A	A
No. 91	Example	3.98	99.2	170	A	A	A
No. 92	Example	3.77	98.2	185	B	B	B
No. 93	Comparative Example	3.86	96.4	185	D	D	B
No. 94	Comparative Example	3.95	96.8	180	D	D	B
No. 95	Comparative Example	4.05	96.2	192	E	E	C

(continued)

		Metal powder	Evaluation results of sintered body				
Sample No.	-	Average particle diameter	Relative density	Vickers hardness	Tensile strength	0.2% proof stress	Elongation
		μm	%	-	-	-	-
No. 96	Comparative Example	4.57	94.7	202	D	D	D
No. 97	Comparative Example	4.52	94.6	211	D	D	E
No. 98	Comparative Example	3.65	94.6	195	E	E	D
No. 99	Comparative Example	3.28	93.4	214	F	F	E

Table 13

		Metal powder	Evaluation results of sintered body				
Sample No.	-	Average particle diameter	Relative density	Vickers hardness	Tensile strength	0.2% proof stress	Elongation
		μm	%	-	-	-	-
No. 100	Example	5.86	99.1	167	A	A	A
No. 101	Example	4.97	98.9	170	A	A	A
No. 102	Example	4.25	98.6	184	B	B	B
No. 103	Comparative Example	5.31	96.3	195	D	D	B
No. 104	Comparative Example	5.83	96.6	189	D	D	B
No. 105	Comparative Example	4.52	95.1	201	D	D	D
No. 106	Comparative Example	4.12	94.9	205	E	E	F

Table 14

		Metal powder	Evaluation results of sintered body				
Sample No.	-	Average particle diameter	Relative density	Vickers hardness	Tensile strength	0.2% proof stress	Elongation
		μm	%	-	-	-	-
No. 107	Example	4.08	99.3	164	A	A	A
No. 108	Example	3.58	99.0	175	A	A	A
No. 109	Example	6.41	98.5	182	A	A	B
No. 110	Comparative Example	3.98	96.3	195	D	D	B

(continued)

		Metal powder	Evaluation results of sintered body				
Sample No.	-	Average particle diameter	Relative density	Vickers hardness	Tensile strength	0.2% proof stress	Elongation
		μm	%	-	-	-	-
No. 111	Comparative Example	3.58	96.7	192	D	D	B
No. 112	Comparative Example	4.35	94.7	205	D	D	E
No. 113	Comparative Example	4.56	95.2	201	D	D	E

[0247] As apparent from Tables 12 to 14, it was confirmed that the sintered bodies corresponding to Example each have a higher relative density than the sintered bodies corresponding to Comparative Example. It was also confirmed that there is a significant difference in properties such as tensile strength, 0.2% proof stress, and elongation between the sintered bodies corresponding to Example and the sintered bodies corresponding to Comparative Example.

5. Production of Sintered Body (Ti-Nb based)

Sample Nos. 114 to 123

[0248] Sintered bodies were obtained in the same manner as the method for producing the sintered body of sample No. 1 except that the composition and the like of the metal powder for powder metallurgy were changed as shown in Table 15, respectively.

Sample No. 124

[0249] A metal powder having an average particle diameter of 4.62 μm, a Ti powder having an average particle diameter of 40 μm, and a Nb powder having an average particle diameter of 25 μm were mixed, whereby a mixed powder was prepared. In the preparation of the mixed powder, each of the mixing amounts of the metal powder, the Ti powder, and the Nb powder was adjusted so that the composition of the mixed powder was as shown in Table 15.

[0250] Then, a sintered body was obtained in the same manner as the method for producing the sintered body of sample No. 1 using this mixed powder.

Table 15

Sample No.	-	Metal powder for powder metallurgy														
		Alloy composition										E1/E2	E1+E2	(E1+E2) /Si	(E1+E2) /C	Remarks
		Cr	Ni	Si	C	E1 (Ti)	E2 (Nb)	Mo	Mn	O	Fe					
		mass%										-	mass%	-	-	-
No. 114	Example	16.52	12.54	0.77	0.015	0.08	0.07	2.13	0.06	0.25	remainder	1.14	0.15	0.19	10.00	
No. 115	Example	16.86	13.15	0.51	0.021	0.08	0.08	2.21	0.51	0.42	remainder	1.00	0.16	0.31	7.62	
No. 116	Example	16.63	11.87	0.81	0.025	0.06	0.10	2.07	0.35	0.24	remainder	0.60	0.16	0.20	6.40	
No. 117	Example	17.12	12.61	0.98	0.065	0.04	0.18	2.23	0.07	0.54	remainder	0.22	0.22	0.22	3.38	
No. 118	Example	16.23	13.54	0.51	0.009	0.04	0.08	2.26	0.02	0.35	remainder	0.50	0.12	0.24	13.33	
No. 119	Example	17.85	12.35	0.42	0.125	0.09	0.08	2.57	0.35	0.25	remainder	1.13	0.17	0.40	1.36	
No. 120	Comparative Example	16.87	11.42	0.56	0.056	0.00	0.08	2.47	0.12	0.25	remainder	0.00	0.08	0.14	1.43	
No. 121	Comparative Example	17.56	14.51	0.78	0.032	0.12	0.00	2.68	0.11	0.33	remainder	-	0.12	0.15	3.75	
No. 122	Comparative Example	16.78	11.24	0.87	0.012	0.54	0.06	2.55	0.15	0.32	remainder	9.00	0.60	0.69	50.00	
No. 123	Comparative Example	17.65	14.15	0.68	0.053	0.08	0.89	2.63	0.06	0.25	remainder	0.09	0.97	1.43	18.30	
No. 124	Comparative Example	16.88	14.10	0.87	0.056	0.45	0.20	2.25	0.08	0.26	remainder	2.25	0.65	0.75	11.61	Mixed powder

[0251] In Table 15, among the sintered bodies of the respective sample Nos., those corresponding to the invention are indicated by "Example", and those not corresponding to the invention are indicated by "Comparative Example".
[0252] Each sintered body contained very small amounts of impurities, but the description thereof in Table 15 is omitted.

6. Evaluation of Sintered Body (Ti-Nb based)

6.1 Evaluation of Relative Density

[0253] With respect to the sintered bodies of the respective sample Nos. shown in Table 15, the sintered density was measured in accordance with the method for measuring the density of sintered metal materials specified in JIS Z 2501 (2000), and also the relative density of each sintered body was calculated with reference to the true density of the metal powder for powder metallurgy used for producing each sintered body.
[0254] The calculation results are shown in Table 16.

6.2 Evaluation of Vickers Hardness

[0255] With respect to the sintered bodies of the respective sample Nos. shown in Table 15, the Vickers hardness was measured in accordance with the Vickers hardness test method specified in JIS Z 2244 (2009).
[0256] The measurement results are shown in Table 16.

6.3 Evaluation of Tensile Strength, 0.2% Proof Stress, and Elongation

[0257] With respect to the sintered bodies of the respective sample Nos. shown in Table 15, the tensile strength, 0.2% proof stress, and elongation were measured in accordance with the metal material tensile test method specified in JIS Z 2241 (2011).
[0258] Then, the measured values of the physical properties were evaluated according to the above-mentioned evaluation criteria applied to the Tables 5 and 8.
[0259] The evaluation results are shown in Table 16.

Table 16

		Metal powder	Evaluation results of sintered body				
Sample No.	-	Average particle diameter	Relative density	Vickers hardness	Tensile strength	0.2% proof stress	Elongation
		μm	%	-	-	-	-
No. 114	Example	4.34	98.9	179	A	A	A
No. 115	Example	4.79	99.3	178	A	A	A
No. 116	Example	4.05	99.4	175	A	A	A
No. 117	Example	3.89	98.7	180	B	B	A
No. 118	Example	4.12	98.5	185	B	B	B
No. 119	Example	4.26	98.2	189	B	B	C
No. 120	Comparative Example	4.31	96.5	191	D	D	B
No. 121	Comparative Example	4.48	96.6	189	D	D	B
No. 122	Comparative Example	4.25	95.3	205	D	D	D
No. 123	Comparative Example	4.36	94.7	215	E	E	F
No. 124	Comparative Example	4.62	95.9	214	E	E	F

[0260] As apparent from Table 16, it was confirmed that the sintered bodies corresponding to Example each have a higher relative density than the sintered bodies corresponding to Comparative Example. It was also confirmed that there is a significant difference in properties such as tensile strength, 0.2% proof stress, and elongation between the sintered bodies corresponding to Example and the sintered bodies corresponding to Comparative Example.

7. Production of Sintered Body (Nb-Ta based)

Sample Nos. 125 to 134

[0261] Sintered bodies were obtained in the same manner as the method for producing the sintered body of sample No. 1 except that the composition and the like of the metal powder for powder metallurgy were changed as shown in Table 17, respectively.

Table 17

Sample No.	-	Metal powder for powder metallurgy														
		Alloy composition										E1/E2	E1+E2	(E1+E2)/Si	(E1+E2)/C	Remarks
		Cr	Ni	Si	C	E1 (Nb)	E2 (Ta)	Mo	Mn	O	Fe					
		mass%										-	mass%	-	-	-
No. 125	Example	16.21	12.15	0.63	0.035	0.07	0.12	2.21	0.06	0.38	remainder	0.58	0.19	0.30	5.43	
No. 126	Example	16.74	11.36	0.87	0.042	0.05	0.10	2.26	0.05	0.45	remainder	0.50	0.15	0.17	3.57	
No. 127	Example	16.30	10.25	0.45	0.018	0.12	0.09	2.68	0.07	0.58	remainder	1.33	0.21	0.47	11.67	
No. 128	Example	16.35	13.68	1.03	0.067	0.05	0.08	2.77	0.06	0.22	remainder	0.63	0.13	0.13	1.94	
No. 129	Example	16.45	14.18	0.86	0.009	0.03	0.04	2.45	0.00	0.45	remainder	0.75	0.07	0.08	7.78	
No. 130	Example	16.25	12.35	0.47	0.123	0.15	0.09	2.12	0.08	0.48	remainder	1.67	0.24	0.51	1.95	
No. 131	Comparative Example	17.11	12.29	0.74	0.064	0.00	0.08	2.18	0.15	0.29	remainder	0.00	0.05	0.07	0.78	
No. 132	Comparative Example	16.78	12.48	0.79	0.023	0.08	0.00	2.06	0.12	0.33	remainder	-	0.08	0.10	3.48	
No. 133	Comparative Example	16.42	13.65	0.39	0.012	0.69	0.07	2.89	0.08	0.37	remainder	9.86	0.76	1.95	63.33	
No. 134	Comparative Example	17.21	10.88	0.42	0.021	0.06	0.61	2.98	0.13	0.35	remainder	0.10	0.67	1.60	31.90	

[0262] In Table 17, among the sintered bodies of the respective sample Nos., those corresponding to the invention are indicated by "Example", and those not corresponding to the invention are indicated by "Comparative Example".
[0263] Each sintered body contained very small amounts of impurities, but the description thereof in Table 17 is omitted.

8. Evaluation of Sintered Body (Nb-Ta based)

8.1 Evaluation of Relative Density

[0264] With respect to the sintered bodies of the respective sample Nos. shown in Table 17, the sintered density was measured in accordance with the method for measuring the density of sintered metal materials specified in JIS Z 2501 (2000), and also the relative density of each sintered body was calculated with reference to the true density of the metal powder for powder metallurgy used for producing each sintered body.
[0265] The calculation results are shown in Table 18.

8.2 Evaluation of Vickers Hardness

[0266] With respect to the sintered bodies of the respective sample Nos. shown in Table 17, the Vickers hardness was measured in accordance with the Vickers hardness test method specified in JIS Z 2244 (2009).
[0267] The measurement results are shown in Table 18.

8. 3 Evaluation of Tensile Strength, 0.2% Proof Stress, and Elongation

[0268] With respect to the sintered bodies of the respective sample Nos. shown in Table 17, the tensile strength, 0.2% proof stress, and elongation were measured in accordance with the metal material tensile test method specified in JIS Z 2241 (2011).
[0269] Then, the measured values of the physical properties were evaluated according to the above-mentioned evaluation criteria applied to Tables 5 and 8.
[0270] The evaluation results are shown in Table 18.

Table 18

		Metal powder	Evaluation results of sintered body				
Sample No.	-	Average particle diameter	Relative density	Vickers hardness	Tensile strength	0.2% proof stress	Elongation
		μm	%	-	-	-	-
No. 125	Example	3.87	99.0	166	A	A	A
No. 126	Example	4.12	99.1	167	A	A	B
No. 127	Example	6.45	98.5	173	A	A	B
No. 128	Example	5.82	98.3	178	B	B	B
No. 129	Example	3.45	98.2	175	B	B	B
No. 130	Example	3.25	97.4	181	B	B	C
No. 131	Comparative Example	3.98	96.3	187	D	D	B
No. 132	Comparative Example	3.74	96.0	198	D	D	B
No. 133	Comparative Example	4.21	93.8	236	D	D	D
No. 134	Comparative Example	3.87	94.2	225	D	D	E

[0271] As apparent from Table 18, it was confirmed that the sintered bodies corresponding to Example each have a

higher relative density than the sintered bodies corresponding to Comparative Example. It was also confirmed that there is a significant difference in properties such as tensile strength, 0.2% proof stress, and elongation between the sintered bodies corresponding to Example and the sintered bodies corresponding to Comparative Example.

9. Production of Sintered Body (Y-Nb based)

Sample Nos. 135 to 145

[0272] Sintered bodies were obtained in the same manner as the method for producing the sintered body of sample No. 1 except that the composition and the like of the metal powder for powder metallurgy were changed as shown in Table 19, respectively.

Table 19

Sample No.	-	Metal powder for powder metallurgy														
		Alloy composition										E1/E2	E1+E2	(E1+E2) /Si	(E1+E2) /C	Remarks
		Cr	Ni	Si	C	E1 (Y)	E2 (Nb)	Mo	Mn	O	Fe					
		mass%										-	mass%	-	-	-
No. 135	Example	16.55	12.58	0.85	0.025	0.08	0.09	2.13	0.07	0.26	remainder	0.89	0.11	0.20	6.80	
No. 136	Example	17.32	12.87	0.68	0.023	0.05	0.08	2.21	0.11	0.33	remainder	0.63	0.13	0.19	5.65	
No. 137	Example	16.35	12.32	0.74	0.029	0.09	0.05	2.04	0.08	0.41	remainder	1.80	0.14	0.19	4.83	
No. 138	Example	16.31	14.52	0.53	0.011	0.03	0.08	2.68	0.07	0.26	remainder	0.38	0.11	0.21	10.00	
No. 139	Example	17.12	13.88	0.57	0.024	0.09	0.10	2.51	0.12	0.34	remainder	0.90	0.19	0.33	7.92	
No. 140	Example	16.66	11.58	1.02	0.057	0.11	0.04	2.74	0.12	0.22	remainder	2.75	0.51	0.15	2.63	
No. 141	Example	16.21	13.21	0.32	0.044	0.08	0.12	2.15	0.79	0.41	remainder	0.67	0.20	0.63	4.55	
No. 142	Comparative Example	16.55	12.74	0.84	0.026	0.00	0.06	2.24	0.13	0.32	remainder	0.00	0.06	0.07	2.31	
No. 143	Comparative Example	17.25	12.79	0.74	0.023	0.07	0.00	2.21	0.06	0.27	remainder	-	0.07	0.09	3.04	
No. 144	Comparative Example	16.87	12.36	0.86	0.029	0.64	0.12	2.64	0.21	0.41	remainder	5.33	0.76	0.88	26.21	
No. 145	Comparative Example	16.39	13.11	0.71	0.033	0.08	0.72	2.35	0.06	0.39	remainder	0.11	0.80	1.13	24.24	

[0273] In Table 19, among the sintered bodies of the respective sample Nos., those corresponding to the invention are indicated by "Example", and those not corresponding to the invention are indicated by "Comparative Example".

[0274] Each sintered body contained very small amounts of impurities, but the description thereof in Table 19 is omitted.

10. Evaluation of Sintered Body (Y-Nb based)

10.1 Evaluation of Relative Density

[0275] With respect to the sintered bodies of the respective sample Nos. shown in Table 19, the sintered density was measured in accordance with the method for measuring the density of sintered metal materials specified in JIS Z 2501 (2000), and also the relative density of each sintered body was calculated with reference to the true density of the metal powder for powder metallurgy used for producing each sintered body.

[0276] The calculation results are shown in Table 20.

10.2 Evaluation of Vickers Hardness

[0277] With respect to the sintered bodies of the respective sample Nos. shown in Table 19, the Vickers hardness was measured in accordance with the Vickers hardness test method specified in JIS Z 2244 (2009).

[0278] The measurement results are shown in Table 20.

10.3 Evaluation of Tensile Strength, 0.2% Proof Stress, and Elongation

[0279] With respect to the sintered bodies of the respective sample Nos. shown in Table 19, the tensile strength, 0.2% proof stress, and elongation were measured in accordance with the metal material tensile test method specified in JIS Z 2241 (2011).

[0280] Then, the measured values of the physical properties were evaluated according to the above-mentioned evaluation criteria applied to Tables 5 and 8.

[0281] The evaluation results are shown in Table 20.

Table 20

		Metal powder	Evaluation results of sintered body				
Sample No.	-	Average particle diameter	Relative density	Vickers hardness	Tensile strength	0.2% proof stress	Elongation
		μm	%	-	-	-	-
No. 135	Example	4.11	99.2	169	A	A	A
No. 136	Example	3.89	99.1	170	A	A	A
No. 137	Example	3.94	99.0	172	A	A	A
No. 138	Example	4.23	98.7	177	B	A	A
No. 139	Example	4.12	99.2	174	A	A	A
No. 140	Example	3.87	98.5	180	B	B	B
No. 141	Example	3.69	98.4	181	B	B	B
No. 142	Comparative Example	3.77	96.1	192	D	D	B
No. 143	Comparative Example	3.94	95.9	196	D	D	B
No. 144	Comparative Example	4.78	94.8	201	D	E	E
No. 145	Comparative Example	4.56	94.6	204	D	E	E

[0282] As apparent from Table 20, it was confirmed that the sintered bodies corresponding to Example each have a higher relative density than the sintered bodies corresponding to Comparative Example. It was also confirmed that there is a significant difference in properties such as tensile strength, 0.2% proof stress, and elongation between the sintered bodies corresponding to Example and the sintered bodies corresponding to Comparative Example.

11. Production of Sintered Body (V-Nb based)

Sample Nos. 146 to 155

[0283] Sintered bodies were obtained in the same manner as the method for producing the sintered body of sample No. 1 except that the composition and the like of the metal powder for powder metallurgy were changed as shown in Table 21, respectively.

Table 21

		Metal powder for powder metallurgy														
		Alloy composition										E1/E2	E1+E2	(E1+E2) /Si	(E1+E2) /C	Remarks
Sample No.	-	Cr	Ni	Si	C	E1 (V)	E2 (Nb)	Mo	Mn	O	Fe					
		mass%										-	mass%	-	-	-
No. 146	Example	16.56	12.65	0.79	0.025	0.08	0.15	2.35	0.06	0.26	remainder	0.53	0.23	0.29	9.20	
No. 147	Example	16.42	12.36	0.11	0.016	0.05	0.10	2.28	0.09	0.31	remainder	0.50	0.15	0.21	9.38	
No. 148	Example	17.23	12.15	0.89	0.022	0.15	0.21	2.23	0.07	0.68	remainder	1.25	0.27	0.30	12.27	
No. 149	Example	17.89	11.75	0.97	0.047	0.09	0.09	2.59	0.05	0.18	remainder	1.00	0.18	0.19	3.83	
No. 150	Example	18.23	13.21	0.88	0.011	0.05	0.10	2.87	0.07	0.31	remainder	0.50	0.15	0.17	13.64	
No. 151	Example	18.25	10.25	0.44	0.187	0.12	0.12	2.47	0.07	0.47	remainder	1.00	0.24	0.55	1.28	
No. 152	Comparative Example	16.54	12.74	0.58	0.056	0.00	0.06	2.68	0.12	0.28	remainder	0.00	0.06	0.10	1.07	
No. 153	Comparative Example	16.39	12.47	0.75	0.032	0.09	0.00	2.13	0.11	0.32	remainder	-	0.09	0.12	2.81	
No. 154	Comparative Example	17.87	12.48	0.36	0.014	0.68	0.09	2.54	0.18	0.44	remainder	7.56	0.77	2.14	55.00	
No. 155	Comparative Example	17.65	12.77	0.47	0.023	0.07	0.63	2.77	0.16	0.39	remainder	0.11	0.70	1.49	30.43	

[0284] In Table 21, among the sintered bodies of the respective sample Nos., those corresponding to the invention are indicated by "Example", and those not corresponding to the invention are indicated by "Comparative Example".
[0285] Each sintered body contained very small amounts of impurities, but the description thereof in Table 21 is omitted.

12. Evaluation of Sintered Body (V-Nb based)

12.1 Evaluation of Relative Density

[0286] With respect to the sintered bodies of the respective sample Nos. shown in Table 21, the sintered density was measured in accordance with the method for measuring the density of sintered metal materials specified in JIS Z 2501 (2000), and also the relative density of each sintered body was calculated with reference to the true density of the metal powder for powder metallurgy used for producing each sintered body.
[0287] The calculation results are shown in Table 22.

12.2 Evaluation of Vickers Hardness

[0288] With respect to the sintered bodies of the respective sample Nos. shown in Table 21, the Vickers hardness was measured in accordance with the Vickers hardness test method specified in JIS Z 2244 (2009).
[0289] The measurement results are shown in Table 22.

12.3 Evaluation of Tensile Strength, 0.2% Proof Stress, and Elongation

[0290] With respect to the sintered bodies of the respective sample Nos. shown in Table 21, the tensile strength, 0.2% proof stress, and elongation were measured in accordance with the metal material tensile test method specified in JIS Z 2241 (2011).
[0291] Then, the measured values of the physical properties were evaluated according to the above-mentioned evaluation criteria applied to Tables 5 and 8.
[0292] The evaluation results are shown in Table 22.

Table 22

		Metal powder	Evaluation results of sintered body				
Sample No.	-	Average particle diameter	Relative density	Vickers hardness	Tensile strength	0.2% proof stress	Elongation
		μm	%	-	-	-	-
No. 146	Example	4.12	98.2	172	A	A	B
No. 147	Example	4.25	99.0	167	A	A	A
No. 148	Example	6.89	98.5	175	A	A	B
No. 149	Example	5.74	98.3	181	B	B	B
No. 150	Example	3.25	98.7	161	B	B	A
No. 151	Example	4.11	97.4	194	B	B	C
No. 152	Comparative Example	3.98	96.2	202	D	D	C
No. 153	Comparative Example	3.74	96.0	211	D	D	C
No. 154	Comparative Example	4.52	94.5	215	D	D	D
No. 155	Comparative Example	3.45	94.3	223	D	D	E

[0293] As apparent from Table 22, it was confirmed that the sintered bodies corresponding to Example each have a

higher relative density than the sintered bodies corresponding to Comparative Example. It was also confirmed that there is a significant difference in properties such as tensile strength, 0.2% proof stress, and elongation between the sintered bodies corresponding to Example and the sintered bodies corresponding to Comparative Example.

13. Production of Sintered Body (Ti-Zr based)

Sample Nos. 156 to 165

[0294] Sintered bodies were obtained in the same manner as the method for producing the sintered body of sample No. 1 except that the composition and the like of the metal powder for powder metallurgy were changed as shown in Table 23, respectively.

Table 23

Sample No.	-	Metal powder for powder metallurgy														
		Alloy composition										E1/E2	E1+E2	(E1+E2) /Si	(E1+E2) /C	Remarks
		Cr	Ni	Si	C	E1 (Ti)	E2 (Zr)	Mo	Mn	O	Fe					
		mass%										-	mass%	-	-	-
No. 156	Example	16.85	12.74	0.86	0.023	0.06	0.12	2.54	0.07	0.31	remainder	0.50	0.18	0.21	7.83	
No. 157	Example	17.24	12.14	0.74	0.039	0.05	0.10	2.36	0.04	0.49	remainder	0.50	0.15	0.20	3.85	
No. 158	Example	16.21	12.46	0.62	0.019	0.12	0.09	2.78	0.07	0.54	remainder	1.33	0.21	0.34	11.05	
No. 159	Example	16.57	12.98	0.97	0.059	0.08	0.06	2.23	0.05	0.21	remainder	1.33	0.14	0.14	2.37	
No. 160	Example	17.85	12.41	0.88	0.009	0.05	0.10	2.74	0.07	0.35	remainder	0.50	0.15	0.17	16.67	
No. 161	Example	17.65	13.21	0.44	0.175	0.09	0.09	2.68	0.07	0.44	remainder	1.00	0.18	0.41	1.03	
No. 162	Comparative Example	17.44	12.47	0.72	0.055	0.00	0.06	2.75	0.18	0.26	remainder	0.00	0.06	0.08	1.09	
No. 163	Comparative Example	16.54	12.87	0.78	0.032	0.09	0.00	2.69	0.08	0.35	remainder	-	0.09	0.12	2.81	
No. 164	Comparative Example	16.32	13.58	0.38	0.021	0.64	0.08	2.41	0.07	0.28	remainder	8.00	0.72	1.89	34.29	
No. 165	Comparative Example	16.25	13.75	0.43	0.018	0.07	0.59	2.21	0.06	0.22	remainder	0.12	0.66	1.53	36.67	

[0295] In Table 23, among the sintered bodies of the respective sample Nos., those corresponding to the invention are indicated by "Example", and those not corresponding to the invention are indicated by "Comparative Example".
[0296] Each sintered body contained very small amounts of impurities, but the description thereof in Table 23 is omitted.

14. Evaluation of Sintered Body (Ti-Zr based)

14.1 Evaluation of Relative Density

[0297] With respect to the sintered bodies of the respective sample Nos. shown in Table 23, the sintered density was measured in accordance with the method for measuring the density of sintered metal materials specified in JIS Z 2501 (2000), and also the relative density of each sintered body was calculated with reference to the true density of the metal powder for powder metallurgy used for producing each sintered body.
[0298] The calculation results are shown in Table 24.

14.2 Evaluation of Vickers Hardness

[0299] With respect to the sintered bodies of the respective sample Nos. shown in Table 23, the Vickers hardness was measured in accordance with the Vickers hardness test method specified in JIS Z 2244 (2009).
[0300] The measurement results are shown in Table 24.

14.3 Evaluation of Tensile Strength, 0.2% Proof Stress, and Elongation

[0301] With respect to the sintered bodies of the respective sample Nos. shown in Table 23, the tensile strength, 0.2%proof stress, and elongation were measured in accordance with the metal material tensile test method specified in JIS Z 2241 (2011).
[0302] Then, the measured values of the physical properties were evaluated according to the above-mentioned evaluation criteria applied to Tables 5 and 8.
[0303] The evaluation results are shown in Table 24.

Table 24

		Metal powder	Evaluation results of sintered body				
Sample No.	-	Average particle diameter	Relative density	Vickers hardness	Tensile strength	0.2% proof stress	Elongation
		μm	%	-	-	-	-
No. 156	Example	4.12	98.8	172	A	A	B
No. 157	Example	4.25	99.0	167	A	A	A
No. 158	Example	5.87	98.6	184	A	A	B
No. 159	Example	5.12	98.5	191	B	B	B
No. 160	Example	3.89	98.2	195	B	B	B
No. 161	Example	4.47	97.4	199	B	B	C
No. 162	Comparative Example	4.11	96.3	205	D	D	C
No. 163	Comparative Example	3.78	96.7	211	D	D	C
No. 164	Comparative Example	4.52	94.7	235	D	D	E
No. 165	Comparative Example	3.88	95.2	221	D	D	E

[0304] As apparent from Table 24, it was confirmed that the sintered bodies corresponding to Example each have a

higher relative density than the sintered bodies corresponding to Comparative Example. It was also confirmed that there is a significant difference in properties such as tensile strength, 0.2% proof stress, and elongation between the sintered bodies corresponding to Example and the sintered bodies corresponding to Comparative Example.

15. Production of Sintered Body (Zr-Ta based)

Sample Nos. 166 to 175

[0305] Sintered bodies were obtained in the same manner as the method for producing the sintered body of sample No. 1 except that the composition and the like of the metal powder for powder metallurgy were changed as shown in Table 25, respectively.

Table 25

Sample No.	-	Metal powder for powder metallurgy														
		Alloy composition										E1/E2	E1+E2	(E1+E2) /Si	(E1+E2) /C	Remarks
		Cr	Ni	Si	C	E1 (Zr)	E2 (Ta)	Mo	Mn	O	Fe					
		mass%										-	mass%	-	-	-
No. 166	Example	16.61	12.45	0.68	0.023	0.06	0.09	2.55	0.11	0.38	remainder	0.67	0.15	0.22	6.52	
No. 167	Example	16.94	12.21	0.72	0.039	0.05	0.10	2.47	0.06	0.24	remainder	0.50	0.15	0.21	3.85	
No. 168	Example	17.43	12.89	0.85	0.019	0.12	0.09	2.05	0.54	0.49	remainder	1.33	0.21	0.25	11.05	
No. 169	Example	17.21	13.42	0.97	0.058	0.08	0.06	2.78	0.07	0.31	remainder	1.33	0.14	0.14	2.41	
No. 170	Example	16.31	12.87	0.88	0.011	0.05	0.10	2.74	0.12	0.55	remainder	0.50	0.15	0.17	13.64	
No. 171	Example	16.54	12.25	0.44	0.146	0.09	0.09	2.32	0.07	0.68	remainder	1.00	0.18	0.41	1.23	
No. 172	Comparative Example	17.24	12.14	0.72	0.018	0.00	0.06	2.56	0.08	0.27	remainder	0.00	0.06	0.08	3.33	
No. 173	Comparative Example	16.87	12.56	0.82	0.026	0.09	0.00	2.24	0.09	0.32	remainder	-	0.09	0.11	3.46	
No. 174	Comparative Example	16.54	12.32	0.35	0.025	0.78	0.05	2.89	0.11	0.35	remainder	15.60	0.83	2.37	33.20	
No. 175	Comparative Example	16.35	12.47	0.45	0.022	0.04	0.58	2.77	0.16	0.33	remainder	0.07	0.62	1.38	28.18	

[0306] In Table 25, among the sintered bodies of the respective sample Nos., those corresponding to the invention are indicated by "Example", and those not corresponding to the invention are indicated by "Comparative Example".
[0307] Each sintered body contained very small amounts of impurities, but the description thereof in Table 25 is omitted.

16. Evaluation of Sintered Body (Zr-Ta based)

16.1 Evaluation of Relative Density

[0308] With respect to the sintered bodies of the respective sample Nos. shown in Table 25, the sintered density was measured in accordance with the method for measuring the density of sintered metal materials specified in JIS Z 2501 (2000), and also the relative density of each sintered body was calculated with reference to the true density of the metal powder for powder metallurgy used for producing each sintered body.
[0309] The calculation results are shown in Table 26.

16.2 Evaluation of Vickers Hardness

[0310] With respect to the sintered bodies of the respective sample Nos. shown in Table 25, the Vickers hardness was measured in accordance with the Vickers hardness test method specified in JIS Z 2244 (2009).
[0311] The measurement results are shown in Table 26.

16.3 Evaluation of Tensile Strength, 0.2% Proof Stress, and Elongation

[0312] With respect to the sintered bodies of the respective sample Nos. shown in Table 25, the tensile strength, 0.2% proof stress, and elongation were measured in accordance with the metal material tensile test method specified in JIS Z 2241 (2011).
[0313] Then, the measured values of the physical properties were evaluated according to the above-mentioned evaluation criteria applied to Tables 5 and 8.
[0314] The evaluation results are shown in Table 26.

Table 26

		Metal powder	Evaluation results of sintered body				
Sample No.	-	Average particle diameter	Relative density	Vickers hardness	Tensile strength	0.2% proof stress	Elongation
		μm	%	-	-	-	-
No. 166	Example	4.12	99.2	172	A	A	A
No. 167	Example	4.32	99.3	167	A	A	A
No. 168	Example	5.74	98.7	181	A	A	B
No. 169	Example	5.21	98.5	185	B	B	B
No. 170	Example	4.32	98.2	189	B	B	B
No. 171	Example	4.23	97.5	197	B	B	C
No. 172	Comparative Example	3.88	96.2	199	D	D	C
No. 173	Comparative Example	4.22	96.2	199	D	D	C
No. 174	Comparative Example	4.11	94.8	211	D	D	E
No. 175	Comparative Example	3.89	95.1	205	D	D	E

[0315] As apparent from Table 26, it was confirmed that the sintered bodies corresponding to Example each have a

higher relative density than the sintered bodies corresponding to Comparative Example. It was also confirmed that there is a significant difference in properties such as tensile strength, 0.2% proof stress, and elongation between the sintered bodies corresponding to Example and the sintered bodies corresponding to Comparative Example.

17. Production of Sintered Body (Zr-V based)

Sample Nos. 176 to 185

[0316] Sintered bodies were obtained in the same manner as the method for producing the sintered body of sample No. 1 except that the composition and the like of the metal powder for powder metallurgy were changed as shown in Table 27, respectively.

Table 27

		Metal powder for powder metallurgy														
		Alloy composition										E1/E2	E1+E2	(E1+E2) /Si	(E1+E2) /C	Remarks
Sample No.		Cr	Ni	Si	C	E1	E2	Mo	Mn	O	Fe					
		mass%										-	mass%	-	-	-
No. 176	Example	16.58	12.47	0.75	0.022	0.09	0.06	2.36	0.08	0.31	remainder	1.50	0.15	0.20	6.82	
No. 177	Example	16.32	12.24	0.89	0.051	0.05	0.08	2.64	0.06	0.25	remainder	0.63	0.13	0.15	8.67	
No. 178	Example	16.87	12.55	0.98	0.025	0.09	0.09	2.88	0.07	0.39	remainder	1.00	0.18	0.18	7.20	
No. 179	Example	17.28	12.36	0.54	0.069	0.12	0.06	2.12	0.05	0.23	remainder	2.00	0.18	0.33	2.61	
No. 180	Example	17.59	12.98	0.88	0.012	0.08	0.08	2.58	0.02	0.45	remainder	1.00	0.16	0.18	13.33	
No. 181	Example	17.25	12.78	0.44	0.118	0.09	0.09	2.68	0.07	0.61	remainder	1.00	0.18	0.41	1.53	
No. 182	Comparative Example	16.34	12.63	0.77	0.054	0.00	0.06	2.84	0.08	0.36	remainder	0.00	0.06	0.08	1.11	
No. 183	Comparative Example	16.78	12.24	0.78	0.032	0.09	0.00	2.64	0.11	0.27	remainder	-	0.09	0.12	2.81	
No. 184	Comparative Example	16.24	12.36	0.38	0.021	0.61	0.08	2.31	0.09	0.18	remainder	7.63	0.69	1.82	32.86	
No. 185	Comparative Example	17.12	12.89	0.45	0.025	0.08	0.59	2.15	0.05	0.24	remainder	0.14	0.67	1.49	26.80	

[0317] In Table 27, among the sintered bodies of the respective sample Nos., those corresponding to the invention are indicated by "Example", and those not corresponding to the invention are indicated by "Comparative Example".
[0318] Each sintered body contained very small amounts of impurities, but the description thereof in Table 27 is omitted.

18. Evaluation of Sintered Body (Zr-V based)

18.1 Evaluation of Relative Density

[0319] With respect to the sintered bodies of the respective sample Nos. shown in Table 27, the sintered density was measured in accordance with the method for measuring the density of sintered metal materials specified in JIS Z 2501 (2000), and also the relative density of each sintered body was calculated with reference to the true density of the metal powder for powder metallurgy used for producing each sintered body.
[0320] The calculation results are shown in Table 28.

18.2 Evaluation of Vickers Hardness

[0321] With respect to the sintered bodies of the respective sample Nos. shown in Table 27, the Vickers hardness was measured in accordance with the Vickers hardness test method specified in JIS Z 2244 (2009).
[0322] The measurement results are shown in Table 28.

18.3 Evaluation of Tensile Strength, 0.2% Proof Stress, and Elongation

[0323] With respect to the sintered bodies of the respective sample Nos. shown in Table 27, the tensile strength, 0.2% proof stress, and elongation were measured in accordance with the metal material tensile test method specified in JIS Z 2241 (2011).
[0324] Then, the measured values of the physical properties were evaluated according to the above-mentioned evaluation criteria applied to Tables 5 and 8.
[0325] The evaluation results are shown in Table 28.

Table 28

		Metal powder	Evaluation results of sintered body				
Sample No.	-	Average particle diameter	Relative density	Vickers hardness	Tensile strength	0.2% proof stress	Elongation
		μm	%	-	-	-	-
No. 176	Example	4.15	99.3	172	A	A	A
No. 177	Example	4.26	98.9	167	A	A	B
No. 178	Example	5.74	99.0	180	A	A	B
No. 179	Example	5.12	99.1	178	B	B	B
No. 180	Example	3.86	98.3	197	B	B	B
No. 181	Example	3.65	97.5	202	B	B	C
No. 182	Comparative Example	4.05	96.2	209	D	D	C
No. 183	Comparative Example	4.13	96.5	208	D	D	C
No. 184	Comparative Example	4.05	94.7	225	D	D	E
No. 185	Comparative Example	3.88	95.2	212	D	D	E

[0326] As apparent from Table 28, it was confirmed that the sintered bodies corresponding to Example each have a

higher relative density than the sintered bodies corresponding to Comparative Example. It was also confirmed that there is a significant difference in properties such as tensile strength, 0.2% proof stress, and elongation between the sintered bodies corresponding to Example and the sintered bodies corresponding to Comparative Example.

19. Evaluation of Specularity of Sintered Body

19.1 Evaluation of Porosity near Surface and Inside

[0327] First, each of the sintered bodies of the respective sample Nos. shown in Table 29 was cut and the cross section was polished.

[0328] Then, a porosity A1 near the surface of the sintered body and a porosity A2 inside the sintered body were calculated and also A2-A1 was calculated.

[0329] The calculation results are shown in Table 29.

19.2 Evaluation of Specular Gloss

[0330] First, each of the sintered bodies of the respective sample Nos. shown in Table 29 was subjected to a barrel polishing treatment.

[0331] Then, the specular gloss of the sintered body was measured in accordance with the method for measuring the specular gloss specified in JIS Z 8741 (1997). The incident angle of light with respect to the surface of the sintered body was set to 60°, and as a reference plane for calculating the specular gloss, a glass having a specular gloss of 90 and a refractive index of 1.500 was used. Then, the measured specular gloss was evaluated according to the following evaluation criteria.

Evaluation Criteria for Specular Gloss

[0332]

A: The specularity of the surface is very high (the specular gloss is 200 or more).
B: The specularity of the surface is high (the specular gloss is 150 or more and less than 200).
C: The specularity of the surface is slightly high (the specular gloss is 100 or more and less than 150).
D: The specularity of the surface is slightly low (the specular gloss is 60 or more and less than 100).
E: The specularity of the surface is low (the specular gloss is 30 or more and less than 60).
F: The specularity of the surface is very low (the specular gloss is less than 30).

[0333] The evaluation results are shown in Table 29.

Table 29

		Alloy composition		Evaluation results	
Sample No.	Example/ Comparative Example	E1	E2	A2-A1 [%]	specular gloss
2	Example	Zr	Nb	1.0	A
23	Comparative Example			0.2	E
86	Example	Hf	Nb	0.9	A
95	Comparative Example			0.2	E
116	Example	Ti	Nb	1.2	A
120	Comparative Example			0.1	E
126	Example	Nb	Ta	0.6	C
131	Comparative Example			0.1	E
135	Example	Y	Nb	1.2	A
142	Comparative Example			0.2	E

(continued)

		Alloy composition		Evaluation results	
Sample No.	Example/ Comparative Example	E1	E2	A2-A1 [%]	specular gloss
147	Example	V	Nb	0.6	C
152	Comparative Example			0.1	E
157	Example	Ti	Zr	0.7	C
162	Comparative Example			0.1	E
167	Example	Zr	Ta	0.6	B
172	Comparative Example			0.2	E
176	Example	Zr	V	0.5	B
182	Comparative Example			0.2	E

[0334] As apparent from Table 29, it was confirmed that the sintered bodies corresponding to Example each have a higher specular gloss than the sintered bodies corresponding to Comparative Example. This is considered to be because the porosity near the surface of the sintered body is small, and therefore, light scattering is suppressed, however, the ratio of regular reflection is increased.

Claims

1. A metal powder for powder metallurgy, comprising:

   Fe as a principal component;
   Cr in a proportion of 15% by mass or more and 26% by mass or less;
   Ni in a proportion of 7% by mass or more and 22% by mass or less;
   Si in a proportion of 0.3% by mass or more and 1.2% by mass or less; and
   C in a proportion of 0.005% by mass or more and 0.3% by mass or less, wherein
   when one element selected from the group consisting of Ti, V, Y, Zr, Nb, Hf, and Ta is defined as a first element, and one element selected from the group consisting of Ti, V, Y, Zr, Nb, Hf, and Ta, and having a larger group number in the periodic table than that of the first element or having the same group number in the periodic table as that of the first element and a larger period number in the periodic table than that of the first element is defined as a second element,
   the first element is contained in a proportion of 0.01% by mass or more and 0.5% by mass or less, and
   the second element is contained in a proportion of 0.01% by mass or more and 0.5% by mass or less.

2. The metal powder for powder metallurgy according to claim 1, wherein the metal powder has an austenite crystal structure.

3. The metal powder for powder metallurgy according to claim 1 or 2, wherein the ratio (X1/X2) of a value (X1) obtained by dividing the content (E1) of the first element by the mass number of the first element to a value (X2) obtained by dividing the content (E2) of the second element by the mass number of the second element is 0.3 or more and 3 or less.

4. The metal powder for powder metallurgy according to any one of claims 1 to 3, wherein the sum of the content of the first element and the content of the second element is 0.05% by mass or more and 0.6% by mass or less.

5. The metal powder for powder metallurgy according to any one of claims 1 to 4, further comprising Mo in a proportion of 1% by mass or more and 5% by mass or less.

6. The metal powder for powder metallurgy according to any one of claims 1 to 5, wherein the metal powder has an average particle diameter of 0.5 μm or more and 30 μm or less.

7. A compound, comprising the metal powder for powder metallurgy according to any one of claims 1 to 6 and a binder

which binds the particles of the metal powder for powder metallurgy to one another.

8. A granulated powder, wherein the granulated powder is obtained by granulating the metal powder for powder metallurgy according to any one of claims 1 to 6.

9. A Method for producing a sintered body, comprising the steps of:

preparing a material composition comprising the metal powder for powder metallurgy according to any one of claims 1 to 6 and a binder or the granulated powder according to claim 8;
molding the material composition into a molded body;
degreasing the obtained molded body to remove the binder; and
firing the degreased body to obtain the sintered body.

10. The method for producing a sintered body according to claim 9, further comprising at least one of the steps of:

subjecting the sintered body to a hot isostatic pressing treatment to increase its density, and
polishing the surface of the sintered body.

11. A sintered body obtainable by the method according to claim 9 or 10.

12. The sintered body according to claim 11, wherein the sintered body includes a first region which is in the form of a particle and has a relatively high silicon oxide content and a second region which has a relatively lower silicon oxide content than the first region.

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2012087416 A **[0003]**
- JP 6279913 A **[0004]**
- JP 2007177675 A **[0005]**